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Towards A Food-Secure Future In An Era Of Uncertainty: Cultivating Resilience In Vulnerable Smallholder Food Systems

Maya Moore
University of Vermont

TOWARDS A FOOD-SECURE FUTURE IN AN ERA OF UNCERTAINTY: CULTIVATING RESILIENCE IN VULNERABLE SMALLHOLDER FOOD SYSTEMS

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Maya Moore

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Dissertation Examination Committee:

Meredith T. Niles, Ph.D., Advisor
Taylor Ricketts, Ph.D., Chairperson
Amy B. Trubek, Ph.D.
V. Ernesto Méndez, Ph.D.
Cynthia J. Forehand, Ph.D., Dean of the Graduate College

ABSTRACT

Smallholder food systems in sub-Saharan Africa and other tropical regions are at the crux of the “triple threat” of the Anthropocene: climate change, biodiversity loss and food insecurity. At the same time, they are considered pivotal to the global food system transformation needed to address these challenges. However, while there have been many proposed pathways to achieve desired outcomes, smallholders are often constrained in their ability to adapt and transform. Therefore, in this three-article dissertation, I use mixed methods to study traditional food security coping strategies and apply socio-psychological behavioral intention theories to understand the cognitive factors behind farmers’ decisions within a context of extreme vulnerability and uncertainty.

Each chapter highlights a dimension of resilience in rain-fed small-scale subsistence farming systems in relation to the proposed food system adaptation and transformation pathways of agricultural diversification (Chapter 1), climate-resilient agriculture (Chapter 2) and sustainable intensification (Chapter 3). Specifically, chapter 1 examines household food security among park-adjacent communities, explores detrimental coping strategies as a result of persistent stressors, and problematizes the theory of diversified farming systems in the context of small and scattered agricultural plots. Chapters 2 and 3 take a behavioral approach to understanding farmer decision-making as it relates to climate-resilient agricultural practices and adoption of sustainable intensification techniques, respectively. Chapter 2 applies Protection Motivation Theory to understand farmer intention to adapt practices in response to observed changes in temperature and rainfall. Chapter 3 uses a blended Theory of Planned Behavior – Technology Acceptance Model Framework to examine farmer adoption of an agroecological rice-growing practice and philosophy developed in Madagascar. As gender equality is central to food systems transformation, we also examine the role that gender plays in smallholder farmer decision-making across chapters.

In the concluding chapter, I first summarize the lessons learned vis-à-vis smallholder food system change. I then use the 7 C’s resilience framework to highlight the elements of resilience within smallholder food systems which emerged in Chapters 1 – 3; notably 1) coping, 2) connection, and 3) confidence/control. Lastly, I consider vulnerabilities embedded within smallholder farming systems which impact resilience and adaptive capacity.

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DEDICATION

To Madagascar's human and non-human communities, may this work contribute in some small way to a healthier and more resilient future;

And for my mom, who sparked my interest in wild plant foods and desire to understand other languages and cultures.

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I am incredibly grateful to the Manombo area farmers, who generously shared their personal struggles of food insecurity with us, and their hopes for a better future. I am also indebted to the Madagascar team headed by Kimmerling Razafindrina, our partners at Health in Harmony, and Dr. Tim Treuer who conceptualized and wrote the grants that provided funding to support this work. Without their collaboration and efforts, this research would not have been possible. Also, *misaotra indrindra* to Dr. Patricia Wright for believing in my ability to pursue a PhD and introducing me to Health in Harmony, Mariah Donohue for inviting me to visit Manombo all those years ago, and Drs. Lynne Gaffikin and Christof den Biggelaar for unofficially taking me under their wings.

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Lastly, I wish to thank my family for moving across the world so that I could pursue this opportunity, and for being so understanding when I was up working all of those late nights. Thank you for cooking the rice, changing the diapers and doing the laundry.

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PREFACE

There is a well-known Malagasy proverb: “They who drink the water from the Manangareza river always come back to Madagascar.” While I generally try to avoid drinking river water, this draw to Madagascar certainly applies to me. Ever since I stepped foot on the island in 2004 as a 23-year old Peace Corps Volunteer fresh out of college, I have felt a strong connection to place, at home with the island’s biodiversity and natural beauty, the Malagasy people, their language, (agri-)culture and food!

I would spend much of the next decade living and working in various parts of Madagascar, mainly on the east coast. But it was not until August of 2017, one year before starting the PhD program in Food Systems at the University of Vermont, that I had the opportunity to travel to the *Atsimo Atsinanana* region and visit the communities surrounding Manombo Special Reserve. At the time, I was employed by Stony Brook University, running its research campus in Ranomafana, Madagascar. I was on a quick mission to check up on an American researcher studying lemurs, as there had been reports of insecurity in the area and I wanted to ensure her safety. I could never have predicted at the time that, six years later, I would still be thinking and writing about Manombo.

From 2017-2019, I had the opportunity to return to Manombo several more times and participate in over a dozen “Radical Listening” sessions with communities on behalf of the NGO, Health in Harmony (HIH). Then in February of 2020, while six months pregnant with my son, I was hired by HIH to travel to Manombo and assist in the contract process in which community members agreed to protect the forest in exchange for reduced cost of health care. It would be the last time that I would physically be able to travel to Manombo for several years…

COVID-19 upended many aspects of our lives, including the ability to carry out on-the-ground international research. Because I love talking to farmers, visiting their fields, sharing cups of coffee, I had envisioned my research being much more participatory and in-person. COVID changed all of that. But through the modern "miracle" of technology, I was able to assemble a Malagasy research team, communicating with them mainly via Facebook Messenger and email, and carrying out trainings over Zoom. There are many shortcomings with this long-distance research approach, and I sometimes wonder, if COVID had not hit one and a half years into my PhD journey, how things might have gone.

Nonetheless, equipped with a fairly good understanding of life in Manombo, I was able to add a nuanced analysis to the two quantitative-focused surveys that provide the bulk of the data for this dissertation. And in August of 2022, I was finally able to travel to Madagascar again, share preliminary findings from our surveys with Manombo area community members, talk with them about their struggles during and in the aftermath of COVID and successive cyclones, and drink coffee together.

INTRODUCTION

Tahaka ny zava-maniry eny amin'ny rivotra ny olona: miondrika izy ka mitsangana indray.
(People are like plants in the wind: they bow down and rise up again)
- Malagasy proverb

The planet is mired in three global, interconnected crises of unprecedented scale: climate change, biodiversity loss and food insecurity. As complex socio-ecological systems (SES), in which humans and non-human nature intersect, food systems are at the heart of this "triple threat" of the Anthropocene (Petersen-Rockney et al., 2021). Furthermore, due to the level of producing their own food and often heavy reliance on rainfed agriculture and natural ecosystems, semi-/subsistence (farming) food systems (henceforth, smallholder food systems[1]) in sub-Saharan Africa (SSA) and other tropical regions are especially situated at the crux of this polycrisis (Figure 1).

[1]Following definitions by Ellis (1993) and Cornish (1998), a smallholder farm system is one which derives its livelihood mainly from agriculture and which relies primarily on family labor (household members are both producers and consumers) but may also be entwined in market systems to a limited extent. Here, we also use the FAO's definition that a smallholder farm may be up to 10 hectares of agricultural land, as opposed to two hectares which is commonly used but somewhat arbitrary, as many farmers have multiple small parcels of land. Thus, definitions linked to scale can be limiting (Morton, 2007).

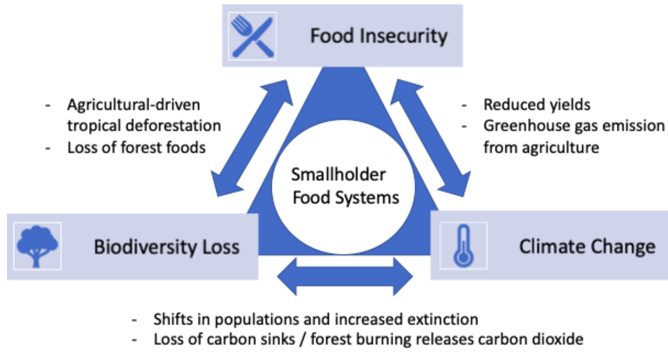

Figure 1. Conceptual framework of smallholder vulnerability within the triple threat framework

At the same time, because they make up so much of the world's population,[2] play a central role in provisioning it, and yet continue to comprise the hungriest in the world (Fanzo et al., 2021), experts at the 2021 United Nations Food Systems Summit call for smallholders to be central to the urgent transformation needed to address the triple threat (Opoku Gakpo, 2021). However, the onus for shifting to more productive, sustainable and climate-resilient agricultural practices should not be placed on smallholders alone, who are often resource-limited and constrained in their capacity to adapt. Rather, to bring about meaningful change, governments and policymakers must prioritize the needs and interests of smallholders in order to create conditions that enable adoption of sustainable and resilient agricultural practices (White, 2020). Therefore, understanding the specific realities of smallholders, their preferences and goals, and the psychosocial drivers behind their agriculture decision-making becomes crucial.

[2] While estimates vary, it is currently thought that there are 2 billion people involved in small-scale agriculture, from the nearly 500 million households that are farming on 2 hectares or less (World Bank, 2016), making up an estimated 85% (HLPE, 2013) of the world's 570 million farms (Lowder et al, 2021). Woodhill et al. (2020) estimate that there are currently 410 million farms under 1 hectare.

1.1 Unique vulnerabilities of smallholder food systems

1.1.1 Food insecurity

It is estimated that smallholder farms provide roughly one-third[3] of the world's food supply (Cohn et al., 2017; Herrero et al., 2017; Ricciardi et al., 2018), but up to 80% of the food consumed in Asia and SSA (HLPE, 2013). Despite their enormous contributions to the food supply,[4] many smallholder farm families are among the poorest and most vulnerable in the world (Fanzo et al., 2021), receive little to no extension support services, and suffer from chronic and seasonal food insecurity[5] (Mazoyer & Roudart, 2006). Furthermore, there is evidence that anthropogenic activities, largely from climate change and agricultural-driven deforestation, are contributing to reduced food security and nutrition outcomes in these regions. For example, in a study across 15 countries in SSA, researchers found deforestation to be associated with reduced dietary diversity among children (Galway et al., 2018).

1.1.2 Climate change

Many smallholders, particularly in SSA, rely solely on rainfed agriculture (Muluneh, 2021, Wani et al., 2009), making them highly vulnerable to altered precipitation

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[3] This is still hotly contested, with many claiming that the estimate is closer to 70% of the world's food supply.

[4] In addition to producing food, smallholders are, as Vandana Shiva (2016) writes, "custodians of seed and soil, conservators of water and land, and protectors and rejuvenators of biological and cultural diversity" (p.63).

[5] Food security, as defined by the United Nations' Committee on World Food Security, is a state in which all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (IFPRI, n.d.).

patterns as a result of climate change (Satori et al., 2022; Thornton et al. 2011). Changes in global temperature and frequency of extreme events such as droughts and cyclones are also affecting agricultural growing conditions. These changes are deepening food insecurity and increasing undernutrition (Lloyd et al., 2011) due to lower yields (Ringler, 2010) brought on by changes in growing season length (Thornton et al., 2011), loss of soil moisture and nutrients (Bedeke, 2023), increased damage from crop pests and disease (Morton, 2007), etc. Climate change-induced water scarcity is also leading to losses in livestock (FAO, 2008).

The effects of climate change on rice production are of particular concern, as rice is the staple food for more than half of the world's population (Fukagawa & Ziska, 2019). As Nguyen (2005) reports, rice is predominantly grown in tropical regions, with an estimated 40% of rice grown under rainfed conditions (lowland or upland). It is expected that global rice production will decline by at least 10% due to climate change (Ringler, 2010).

Climate change is also accelerating biodiversity loss (Kremen & Merenlender, 2018), causing shifts in populations of plants and animals, and increased extinction (Muluneh, 2021). This loss is expected to lead to increased conflict, particularly in SSA where temperatures are warming more than the global average (Niang et al., 2014). Conflict, especially in biodiversity hotspots, has historically led to reductions in biodiversity as well (Chapman et al., 2022). Loss of biodiversity, in turn, negatively impacts food security among local communities who depend upon wild plants and animals for their food and other basic needs (Sunderland et al., 2013). However, there is evidence that some edible "weeds" and crop wild relatives may be more climate-resilient than their domesticated counterparts (Satori et al., 2022; Ziska, 2021; Ziska et al., 2019).

1.1.3 Biodiversity loss

While industrial agriculture and monocropping has led to loss of agrobiodiversity through a process of landscape simplification, smallholder agriculture is also a contributor to biodiversity loss. Research has found smaller farm sizes and more smallholder-dense regions of SSA to be associated with higher rates of deforestation per hectare of agricultural land (Cohn et al., 2017); with the conversion of natural ecosystems into new cultivated areas predicted to increase as current agricultural land becomes less suitable under climate change (Thornton et al., 2011). This expansion is among the leading drivers of global forest loss (Curtis et al., 2018), especially in the tropics where much of the world's biodiversity lies (Foley et al., 2011). At the same time, food insecurity in SSA has been framed as a Malthusian crisis in which population growth is outpacing that of agricultural production increases.[6] Indeed, Laurance et al. (2014) predict a tropical "agricultural bomb," especially in SSA where the population is expected to quadruple by the end of the century (Chapman et al., 2022).

[6] There is a long history, tracing back to the 18th century British economist Thomas Malthus, of projecting into the future and saying that population growth will devastate societies. Even today, echoes of Malthusian thinking resound in the numerous calls for doubling food production by 2050, primarily by closing the "yield gap" in the Global South through sustainable agricultural intensification (e.g., Tilman et al., 2011; Foley et al., 2011). But this hegemonic notion of population growth and famine is far too simplistic given that the world already produces enough food now to feed 10 billion (Chappell, 2018), though transporting food around the world is another matter, as well as a major contributor of greenhouse gas emissions. Nonetheless, as Amartya Sen explained in his seminal 1981 work, while lack of food availability can lead to lack of food access, hunger is less a production issue and more about poverty and power.

Whereas efforts like the Amsterdam Declarations target commercial agriculture, which is the primary driver of forest loss in Brazil and Indonesia, smallholder agriculture is equally responsible for deforestation in Africa and other parts of Asia, accounting for about one-third of tropical forest clearance (Hosonuma et al., 2012). In addition, both agricultural-driven tropical deforestation and agricultural food production, itself, are major contributors to climate change (West et al., 2014). For example, greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) are emitted from agricultural activities such as slash-and-burn shifting cultivation and the flooding of lowland rice paddies, respectively (ibid.).

1.2 Focus on Madagascar as a biodiversity and hunger hotspot with extreme vulnerability to climate change

In this dissertation, I focus on semi-/subsistence[7] smallholder food systems at the forest frontier in Madagascar, a country recognized as one of the most vulnerable countries to climate change (Harvey et al., 2014). With its already high rate of cyclone landfalls (Rakotobe et al., 2016), which are expected to further increase as a result of climate change (Tadross et al., 2008; Weiskopf et al., 2021), and limited capacity to cope with these changes (Ericksen et al., 2011), Madagascar stands out as a "hotspot" for climate change impacts (de Sherbinin, 2014). It is also a "hunger hotspot" (WFP and FAO, 2023), with the fourth highest rate of chronic malnutrition (47.3%; IFAD, n.d.), and predictions indicating

[7] As defined by Wood et al. (2020), semi-/subsistence farm systems consist of "farmers who sell none or only a small proportion of surplus (usually to local markets) and who tend to have low productivity. [They are] poor to very poor with many below poverty line, depend on production for own food, and may have diverse livelihood strategies" (p. 12).

a future loss of at least 5% of its length of growing period (LGP) due to climate change (Ericksen et al., 2011).

Adding to these challenges, Madagascar holds global conservation significance as one of the world's "hottest" biodiversity hotspots (Ganzhorn et al., 2001), with severe threats to the endemic flora and fauna only found on this "diverse mini-continent" (Jones et al., 2021). Traditional swidden agricultural practices have been primarily blamed for this ecological damage (Corson, 2016; Jarosz, 1993). Consequently, Madagascar is also known as a hotspot for conflict between biodiversity conservation and food security (Molotoks et al., 2017), with Malagasy smallholder farmers firmly centered at the intersection of these critical challenges.

1.2.1 Madagascar's food and agricultural landscape (pre- and post-colonization)

Though population density in Madagascar is still relatively low (Richard, 2022), it is one of the world's fastest growing countries, nearly doubling in size since 2000 (Jones et al., 2021), with a current population growth rate of 2.41% (World Bank, 2021). Approximately 85% of its 30 million people are smallholders who heavily rely on low-input[8] farming systems (IFAD, n.d.). The agricultural landscape is characterized by a matrix of small farm parcels. Rice cultivation is ubiquitous, taking place in paddies and on hillsides (while some terracing can be found in the highlands, it is not prevalent on the

[8] Sandhu (2021) describes low-input farming systems (LIFS) as "traditional farming methods with low levels of input and output. The inputs are mainly seed, animal power for cultivation, simple machinery such as ploughs, and human labor. It has sustained populations in many countries for centuries by utilizing the principles of minimal inputs. It comprises a restorative phase of pasture or legumes between phases of crop cultivations. Such systems are unable to meet the growing demand for more food" (p. 11).

coast). Additionally, diverse mixed crop agroforestry systems are commonplace, featuring fruit trees such as jackfruit, litchi, banana, breadfruit and avocado, alongside cash crops such as vanilla and coffee, often grown in the understory.

However, Malagasy farmers, similar to their sub-Saharan Africa (SSA) counterparts, face significant challenges that hinder agricultural development across the island. Limited access to extension agents and lack of irrigation infrastructure are notable obstacles (Bedeke, 2023). Furthermore, the areas where the most sophisticated irrigation and rice production exists is not coincidentally home to the island's *de facto* ruling ethnic group, the Merina[9] (Richard, 2022).

Rice serves as the main staple food in Madagascar, with the country classified as "very highly dependent" (> 800 kcal/person/day) on rice (Nguyen, 2005). However, despite being among the top three rice producers in SSA, Madagascar's average rice production falls significantly short at less than 0.7 tons/ha, well below the global average of 3 tons/ha (Maminirivo & Kyo, 2020). While the Green Revolution's emphasis on chemical fertilizers and high-yielding varieties greatly increased yields in other rice economies, Madagascar, along with most of SSA, was largely overlooked (Blaustein, 2008). Today, there is a high dependence on imported rice in Madagascar, a pattern observed throughout SSA with other cereals (van Ittersum et al., 2016). Figure 2 illustrates the relatively lower change to production of annual cereal yields in SSA compared to other regions in the world since the 1960s.

[9] Though part of their rise is undoubtedly a result of the huge slave force they amounted from other ethnic groups (Campbell, 1981).

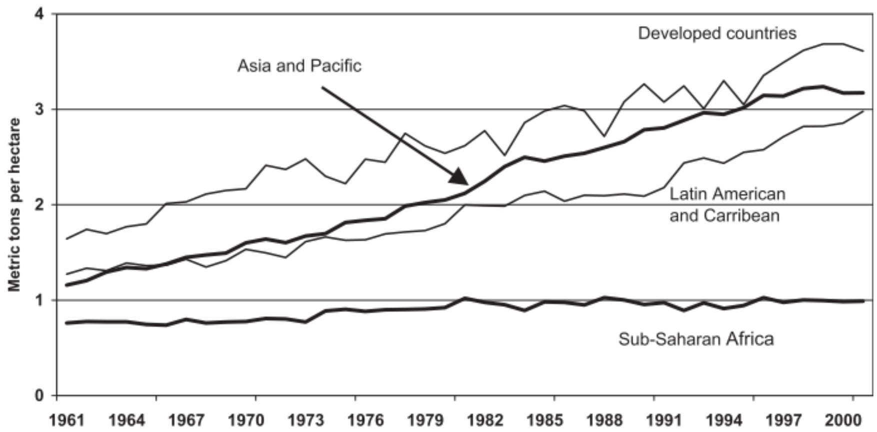

Figure 2. Annual cereal yields by regions, 1961-2000 (source: Jayne et al., 2010)

While the global food security conversation has expanded beyond its initial focus on availability in the early 1970s to encompass other critical dimensions (access, utilization, stability, agency and sustainability; Clapp et al., 2022), availability remains a pressing issue in many rural villages throughout Madagascar and the country as a whole. Thus, from a Malthusian perspective of food availability decline (FAD), insufficient rice production, coupled with predictions of declining harvests as a result of climate change (Nematchoua et al., 2018), poses a significant challenge to meeting the needs of a rapidly growing population. Furthermore, making food available by shipping commodities from other parts of the world, or supplying food aid (still critical in emergencies), is neither a sustainable solution nor does it ensure agency.

However, food insecurity, while worsening, is not a recent phenomenon in Madagascar. Instead, it is a culmination of centuries of intervention by external actors, from early traders to colonial settlers, and currently exacerbated by present-day anthropogenic climate change, largely driven by the Global North. These factors have severely disrupted and transformed traditional food systems in Madagascar to the point that they no longer adequately sustain the population.

Rural Malagasy remain predominantly reliant on agrarian and foraging practices. Their first ancestors to arrive approximately 10,000 years ago were foragers (Richard, 2022). Farmers and crafters settled later, and while much of the archaeological evidence is either lost or has yet to be unearthed, it is thought that rice cultivation[10] and animal husbandry was firmly established on the island by the 14th century (Richard, 2022). What is interesting is that, as the ethnic makeup of the average Malagasy person is roughly 40% Indonesian and 60% African Bantu, linguistic similarities indicate that Indonesian ancestors brought agriculture while domesticated animals were brought from Africa, though the island's zebu cattle are genetic descendants from India (Richard, 2022).

As Bjornlund et al. (2020) argue, prior to the arrival of European traders on the shores of SSA, the region had complex agricultural systems that were well adapted to its climatic conditions and capable of meeting food security needs. However, with the advent of interference by European powers, farming systems began to shift to fewer (and more non-indigenous) crops, often destined for overseas consumption. Madagascar's historical provisioning of fresh food (e.g., fruit, rice and zebu beef) to Europeans can be traced back to at least the 16th c. and the arrival of Portuguese sailors. Hooper (2017) describes how, in 1643, an Englishman published a pamphlet proclaiming Madagascar as the "richest and most fruitful island in the world," implying discovery of the long sought after earthly

[10] Mariel et al. (2023) report that rainfed rice on hillsides cleared by fire (*tavy*) was the first form of agriculture on Madagascar. However, Le Bourdiec (1978; cited in Mariel et al., 2023) reports that *tavy* did not create self-sufficiency and farmers still supplemented their diets with foods gathered from the forest.

paradise, or Garden of Eden, which has been so pervasive in western culture (Richard, 2022). A half century later, the Dutch would arrive and begin provisioning their settler colonies, such as Mauritius, with both Malagasy rice and slaves (Hooper, 2017).

By the time the French colonized Madagascar at the end of the 19th century, communities across SSA had already been devastated by the transatlantic slave trade[11] (Hooper writes of Malagasy rulers trading both rice and slaves for guns). In their pursuit of establishing plantation economies as part of the "colonial dream," there is evidence suggesting that the French deliberately destroyed indigenous food systems, leading to the displacement of community members and contributing to recurring food shortages. For example, in 1924, the French waged biological warfare on cactus food systems in the south by introducing a prickly pear-eating cochineal insect and triggering mass starvation (Rice, 2020).[12]

Then, in addition to timber export and the utilization of indentured labor for new plantations, the French established an export-oriented food system which prioritized the cultivation of cash crops (Jones et al., 2021; Mariel et al., 2023), particularly of spices like vanilla, cloves, cacao and coffee, as well as sisal and cotton for fiber. As a consequence, fertile land was expropriated and concessions were given to "colonial allies" (Randrup, 2010). This shift towards export crops not only led to displacement of traditional

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[11] Starting in the mid-17th century, Madagascar was a "major hub" in the slavery network in East Africa (Richard, 2022), and between the 17th and 19th centuries, thousands of Malagasy were forcibly brought to the Americas (Wilson-Fall, 2015). They were also sent to neighboring Indian ocean islands to work on sugar plantations (Campbell, 1981).

[12] The botanist that suggested releasing the cochineal, Henri Perrier de la Bâthie, is also the one credited with spreading the now somewhat debunked narrative that Madagascar's vast grasslands were not original but a result of Malagasy use of fire to clear forested land, leading to the oft quoted '90% forest loss' tale (Richard, 2022).

subsistence food production but also diverted attention and resources away from it, further contributing to persistent issues of undernutrition.

While the impact of cash cropping on household food security is still a subject of ongoing debate (Kirimi et al., 2013), numerous examples across SSA and Madagascar indicate that, rather than increased well-being, subsistence substitution can have a negative effect on both food security and sovereignty. One such example comes from Malawi in the 1990s when tobacco became highly profitable for farmers, leading them to stop growing their staple crop, maize (Wiggins et al., 2015). Similarly, Langat et al. (2011) observed that among smallholder tea farmers in Kenya, household food insecurity rose when much of the arable land was converted from maize to cash crops.

In Madagascar, Sodikoff (2012) writes of local Malagasy in the Mananara region abandoning rice paddy production to engage in clove harvesting, which then necessitated purchasing rice with their clove-picking earnings. Today, in the SAVA region of northeastern Madagascar, Andriamparany et al. (2021) report that households that have contracts with vanilla buyers/exporters are significantly more food insecure than households that have not entered into such arrangements. Additionally, in exploring the effect of large-scale agribusinesses in Madagascar, which entails more than 30,000 (0.2%) farmers across the island (Burnod et al., 2015), Fitawek et al. (2020) found that households with at least one employed member had higher food security and were more resilient, but that contract households were worse off.

Since gaining independence in 1960, the colonial food regime in Madagascar has been perpetuated as government, private and civil society actors continue to promote export-oriented cash crop cultivation,[12] despite attempts in the 1970s under Ratsiraka's socialist government to increase food self-sufficiency by setting low rice prices (Laney & Turner, 2015) and by promoting the clearing of forests for more rice production (Jones et al., 2021). Notwithstanding the high rates of food insecurity across the island, tens of thousands of Malagasy farmers in the highlands continue to export vegetables (not to mention spices) to markets in Europe (Minten et al., 2009), as well as to the nearby French island territory of La Reunion. While perhaps less of an in issue in Madagascar compared to other parts of Africa, the colonial legacy has also left land inequalities between smallholder and large-scale estates[13] (Jayne et al., 2010), as our 2019 research team witnessed with wild pepper. Furthermore, the government's focus on agricultural production for export in the 1980s and 90s, as well as emphasis on large-scale agricultural investment (Burnod et al., 2015) and linking smallholders to markets (Woodhill, 2016), has translated into little support for the most vulnerable smallholders.

In addition to the 'long shadow of colonialism,' SSA's "food security conundrum" (Giller, 2020) can also be attributed to the fact that farm sizes (average 1 Hectare; Chauvin et al., 2012) have become increasingly fragmented as the population increases (Alobo Loison, 2015), leading to shorter fallow periods and loss of soil fertility. Moreover, as a result of forest loss and subsequent efforts to protect remaining forests, often through "fortress-style" conservation efforts, communities in Madagascar and across SSA have

[12] Most fascinating, perhaps, is the suggestion that Malagasy themselves do not perceive these cash crops to be connected with colonialism as some Westerners (such as myself) do, as is evidenced by Sarah Ousterhoudt's work among vanilla farmers in northeastern Madagascar who were in disbelief and resisted the notion that vanilla was brought by the French (via La Reunion).

[13] Plantation crops in Madagascar include sisal, sugarcane, tobacco, bananas, and cotton.

experienced increasingly diminished access to wild food resources (Randrup, 2010). For this reason, among others, this dissertation focuses on smallholder farmer living at the forest frontier, specifically park-adjacent communities in the Manombo area in southeastern Madagascar.

The Manombo area contains one of the last remaining lowland forest fragments, designated as the Manombo Special Reserve in 1962. It is also home to at least 31 smallholder farming and fishing communities. Unfortunately, the local food system faces recurrent shocks (e.g., cyclones) and stressors (e.g., drought), and there are high rates of both chronic and seasonal food insecurity. For example, in February 2022, the region was hit by back-to-back cyclones, Batsirai and Emnati, and continues to grapple with a multi-year drought.

Multiple international and national conservation organizations and grant-makers, such as Health in Harmony, GERP, Conservation International, the Darwin Initiative, the International Union for Conservation of Nature support, sustainable agricultural development interventions in the area. In addition to conservation programs, numerous bilateral and multilateral organizations, such as InterAid, Welthungerhilfe, and World Food Program are actively involved in food insecurity alleviation and providing emergency food aid in the region. However, in order to move away from an emergency relief model towards a more resilient food system, it is imperative to conduct research on the lived reality underpinning farmers' decision-making as it relates to making changes in their farming practices. Such studies are crucial for comprehending, not only their interest but also their capacity to actively participate in systemic transformation, ultimately improving community well-being in the face of climate uncertainty while also contributing to the desired ‘win-win’ outcomes related to food security and environmental protection that the conservation and development community is after.

1.3 Food system resilience

The concept of resilience, derived from the Latin verb “resilire” meaning “to jump back” or “recoil,” was first used by physicists to describe the characteristics of a spring,[14] and was later extended to ecology by Holling (1973) in order to describe how ecosystems recover after disturbances. Over time, its use has expanded to various social sciences, including psychology, public health, and economics, and is today recognized as a valuable (if not ubiquitous) concept for addressing the entwined social and ecological challenges of the Anthropocene. However, the adoption of this social–ecological resilience (Berkes & Folke, 2000), as it has come to be known, has only more recently gained traction in the context of food systems (Fanzo et al., 2021), with slow uptake among food system policy-makers (Hodbod & Eakin, 2015).

As resilience is a multidisciplinary concept, it is not surprising that multiple definitions exist, which has led to some confusion and lack of clarity (de Steenhuijsen Piters et al. 2021; van Wassenaer et al., 2021), if not contention (Faulkner et al., 2020). In general, the concept refers to the bounce-back-ability of a system to return to its original state (“return-to-normal”) after experiencing shocks/stressors. The FAO (n.d.) defines

[14] According to Norris et al. (2008), the term resilience was originally used to describe the “capacity of a material or system to return to equilibrium after a displacement” (p. 128).

resilience as "the ability to prevent disasters and crises as well as to anticipate, absorb, accommodate or recover from them in a timely, efficient and sustainable manner.”

However, there now seems to be consensus on the importance of not just returning to how things were before (a state which might not be desirable for everyone; Santiago-Vera et al., 2021), but viewing system disruptions as opportunities to re-structure and move forward on a more resilient pathway (“bounce back better”), or what Davoudi et al. (2012) call “bouncing forth.” In their 3D resilience framework, Béné, et al. (2012) present the concept of resilience as a continuum of reorganization possibilities, from being able to absorb losses due to disturbances (cope), make incremental adjustments (adapt), or transform through radical changes, depending on the type of capacity that exists (coping, adaptive or transformative).

1.3.1 Definitions of food system resilience

Since Ericksen (2008) first proposed resilience as a useful approach to understanding the vulnerabilities of food systems to global environmental change, this framing has proliferated. Indeed, Queiroz et al. (2021) recently called social-ecological resilience a “precondition for a sustainable and just food system transformation” (p.546). However, as there are multiple dimensions of food system resilience (e.g., political, economic, social, infrastructural, agricultural) which also differ across the system and by actor (e.g., consumers, producers, processors and food distributors, and retailers; Toth et al., 2016), it is important to consider what is meant by the concept.

As listed in

Table 1, most definitions found in the literature tend to be quite general and emphasize food security as the desired state or outcome. Santiago-Vera et al. (2021) argue for the need to expand current definitions of food system resilience beyond Western individualistic worldviews to more fully encompass the multitude of "peasant worlds," including the notion of "peasant resistance" to loss of autonomy (aka food sovereignty) as a form of resilience.

Table 1. Selected definitions of food system resilience

Source	**Definition**
Bullock et al. (2017)	Maintaining production of sufficient and nutritious food in the face of chronic and acute environmental perturbations
de Steenhuijsen Piters et al. (2021)	The capacity of food systems to deliver desired outcomes in the face of shocks and stressors
Ericksen (2008)	A resilient socio-ecological [food] system (SES) has plenty of buffering capacity and can absorb disturbances. Usually, slowly changing variables are responsible for this, especially over the long term. Diversity is a key factor for buffering capacity. A resilient system can also take action, including restructuring or reorganizing, to respond to feedbacks, which in an SES depends on how well social managers understand these feedbacks. Finally, a resilient system can learn, which means that past mistakes are incorporated into new responses and better management…
Fanzo et al. (2021)	The ability of different individual and institutional food system actors to maintain, protect, or quickly recover the key functions of that system despite the impacts of disturbances
Farm First webpage	Resilience is about our inner strength and our human capacity to bounce back after bad events

Tendall et al. (2015)	The capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate, and accessible food to all, in the face of various and even unforeseen disturbances
Toth et al. (2016)	Food resilience ensures…ability to secure adequate food can be sustained in the face of shocks, such as economic hardship or break-downs in social relations

In this dissertation, smallholder food system resilience is viewed as a continuum from surviving to thriving, and defined as the ability of actors in the system (producers/consumers) to maintain their access to nutritious, culturally appropriate food- whether cultivated, wild, purchased or bartered - to meet the dietary needs of their family regardless of external shocks and stressors. Ideally these actors have the agency to adapt and transform these systems as they desire, all within a supportive structural framework.

For the majority of households in the Manombo area households, as well as smallholder households across Madagascar facing persistent stressors, food system resilience can be a matter of survival. It hinges on their ability to self-procure food through a mixture of means, such as cultivating crops, hunting, fishing, gathering, or selling crops, fish, etc. in local markets and then using earnings to buy other foods. However, this ability is highly precarious - if the weather is bad and the ocean is too rough for fishing, there is no fish to eat or sell that day. Similarly, when there is no money to take a *taxi brousse* to Farafangana to sell a chicken or basket, there is no money to buy basic necessities like cooking oil and soap.

1.3.2 Objectives and measures of resilient food systems

As mentioned above, most of the definitions for resilient food systems refer to a desired state which relates to food security outcomes. Indeed, as food is a non-negotiable biological requirement, food security is considered the normative goal of a resilient food system at all scales, differentiating it from resilience in broader social-ecological systems (Hodbod & Eakin, 2015). However, Béné et al. (2019) point out that "more than a simple 'more-food' approach" is needed to achieve food system resilience (p. 117). In a move to ''shift the focus from feeding people to nourishing them" (Haddad & Hawkes, 2016, p.30), the main desired outcome of food systems can be understood as not only providing food security, but also nutrition security (Béné et al., 2019). Thus, a resilient food system is one that can "bounce back" (survive) and ideally "bounce back better" (thrive) from reduced food security and nutrition (FSN).

In addition to FSN goals, other objectives of resilient food systems include positive environmental[15] and socioeconomic outcomes (Hertel et al., 2023). As Fanzo et al. (2021) write, the objective is "to transform food systems so that they support healthy diets in sustainable, resilient, just, and equitable ways" (p. 2). Lastly, as we are in an era of global environmental change, this must be central to the food system resilience debate (van Wassenaer et al., 2021).

However, food system resilience is inherently difficult to measure (Béné, 2020; Zurek et al., 2022). As FSN outcomes are the normative goal, it is often measured using commonly used food security indicators (Ansah et al., 2019), which are rarely able to

[15] Interestingly, when Ericksen (2008) first proposes the use of resilience theory to food systems, she suggests that it may be more useful for "certain natural resource-based livelihood strategies."

sufficiently represent real-world situations (Payne et al., 2021). For example, in our study area, to cope with food shortages, households regularly consume a wild plant food called *via* and therefore might be considered food secure based on affirmative responses to common food insecurity measurements such as “Did you eat anything in the last 24-hours?,” etc. Another example is when communities receive emergency food aid, thus making them temporarily “food secure,” and yet the food might not be something that they are familiar with cooking or eating (as Malagasy women shared with me when receiving dried peas during a food-for-work disaster response program). Thus, to measure the true extent of resilience, one would need to have a deep understanding of local food preferences (‘good food’ versus ‘bad food’) and what is considered to be acceptable (to survive) and better yet, desirable (to thrive).

1.3.3 Resilience frameworks

Numerous resilience frameworks have been developed across disciplines to evaluate how different levels, from the micro- to macro-, are able to absorb, adapt and transform. Some still view vulnerability and resilience as diametrically opposed, and thus focus on a ‘from vulnerability to resilience’ approach, such as Practical Action’s Vulnerability to Resilience (V2R) Framework (Pasteur, 2011). Some focus on individual characteristics of resilience, such as the 7C’s of resilience framework proposed by Dr. Kenneth Ginsburg, while others may be applied across scales or even whole systems. A few frameworks specific to food system resilience have been developed as well, such as the ABCDs of food system resilience building (de Steenhuijsen Piters et al., 2021; Fonteijn et al., n.d.) and the Food system resilience framework (Karoliina et al., 2023). Presented in Table 2 are a selection of these frameworks, each emphasizing various elements of resilience, but with commonalities across many of them including the importance of diversity across scales, (social) connectivity/networks, and self-efficacy (agency, adaptive capacity, confidence and control).

Table 2. Building blocks of resilience presented within various frameworks

Framework	**Components of resilience**	**Level**
3D Resilient Framework	Absorptive coping capacity, Adaptive capacity, Transformative capacity	Across levels
7 C's	Competence, Confidence, Connection, Character, Contribution, Coping, Control	Micro-level (individual)
Vulnerability to Resilience Framework	Ability to adapt to change, Ability to cope and recover from shocks, Ability to secure sufficient food, Ability to move out of poverty	Across levels
Frameworks specific to food systems		
ABCDs of food systems resilience building	**A**gency: the means and capacities of people to mitigate risks and to respond to shocks. **B**uffering: resources to fall back on in the face of shocks and stressors. **C**onnectivity: the interconnection of and communication between actors and market segments. **D**iversity: diversity at different scales and in different places, from production to consumption and from farm level to regional diversity.	Across levels

Food system resilience framework	Four key elements for resilient food systems (in Finland): system thinking, redundancy of activities and networks, diversity of production and partners, and buffering strategies.	Macro-level (institutions, systems)

1.4 Pathways to Food Systems Resilience at the Farm Production Level

As (agri)food systems are a major contributor to the triple threat outlined in Section 1, they must necessarily be central to solutions. While most of the focus on smallholder agriculture over the last decade has been on connecting them to markets (Woodhill, 2016), there are now calls for radical food system transformation at multiple scales, a "new agriculture" (Steiner, 2011), with a focus on those most vulnerable (Queiroz et al., 2021). To this end, recommendations have been made on how to adapt and transform smallholder food systems at the production level. Sustainable agricultural pathways commonly suggested for achieving food insecurity in a manner that transitions away from emergency relief and food aid (as well as achieving SDG 2's FSN outcomes) and improve environmental outcomes include 1) agroecological diversification, 2) climate-resilient agriculture, and 3) sustainable intensification.

It is important to note that each of these proposed solutions carries varying implications for biodiversity, food security and climate change, as well as for the farmers themselves. For example, certain practices may support more biodiverse ecosystems and reduce greenhouse gas emissions while improving food security and nutrition outcomes, but they might also increase the 'drudgery of labor' for farmers or have unintended socio-cultural impacts. Hence, any redesign processes of production systems must involve the ultimate users—the farmers—or risk perpetuating a neo-colonial approach. Thus, across chapters, it is important to evaluate what stage each of the solutions already sit and from which direction they are coming (internal versus external) – whether it already existing within communities (Chapter 1), whether practices are autonomously adapted or planned (Chapter 2), or if a solution is co-produced by researchers and farmers but 'pushed' by NGOs (Chapter 3). Additionally, in both Chapters 2 and 3, we measure the perceptions of farmers vis-à-vis the underlying cognitive drivers of these actions or perceptions of them (in terms of their usefulness, ease of use, and how 'important others' perceive them, etc.).

1.4.1 Diversification

While there are mixed results as to the impact of diversified livelihoods on smallholders in SSA (Alobo Loison, 2015), diversification at multiple scales is widely touted as a pathway towards cultivating food systems resilience (e.g., Gill, 2020; Hertel et al., 2023; Kremen et al., 2012; Waha et al., 2018). At the agricultural production level, diversified farming systems (DFS) are defined by Kremen et al. (2012) as "farming practices and landscapes that intentionally include functional biodiversity at multiple spatial and/or temporal scales in order to maintain ecosystem services that provide critical inputs to agriculture, such as soil fertility, pest and disease control, water use efficiency, and pollination." Examples include mixed varieties/crops/livestock (addressed in Chapter 1), crop rotation, fallowing, and the inclusion of hedgerows alongside natural areas. In addition to the environmental health benefits that DFS provides, it can also be a critical component of resilient food landscapes/seascapes among vulnerable farmers (Queiroz et al., 2021; Sabin et al., 2022), and considered by agroecologists as an important strategy for improving FSN in Africa (Waha et al., 2018). For instance, a recent study in Malawi found that increased crop diversity was positively associated with food security among smallholder farmers through both direct consumption and food purchases (Madsen et al., 2021).

However, it is important to acknowledge that most smallholder food systems are already characterized by diversified agriculture (e.g., Mariel et al., 2023; Sampson, 2018). For example, farmers in the Manombo area cultivate, on average, at least eight different crops, in addition to foraging for wild plants and maintaining diverse agroforestry systems. This emphasizes the notion that there is no 'one size fits all' approach to food system change. Thus, recommended pathways must take into account the pre-existing diversity and various starting points among different types of farmers and their respective farming systems. Furthermore, missing from conversations on diversification is the importance of striking a balance between cultivating a wide range of crops with mediocre results versus focusing attention on a smaller number of crops.

1.4.2 Climate-resilient agriculture (CRA)

CRA involves adapting agricultural practices in light of current and predicted changes in climatic growing conditions, increases in pest and diseases, more frequent storms, etc., resulting from global environmental change (addressed in Chapter 2), and is increasingly promoted as a response to the predicted Malthusian crisis (Taylor, 2018). Described as the sustainable use of natural resources to "achieve long-term higher productivity and farm incomes under climate variabilities" (Srinivasarao, 2021), CRA is designed to mitigate against climate change's harmful impacts to food security and livelihoods. This adaptation may be autonomous, initiated by farmers themselves, or planned by governments and other institutions (Mersha & van Laerhoven, 2018). However, adapting agricultural systems for an uncertain future is challenging, as it is entirely possible that environments will look very different from what has been imagined (Darnhofer, 2021).

1.4.3 Sustainable intensification (SI)

SI (as opposed to *extensification*), is one of the most commonly recommended action points to increase food production and curb agricultural land expansion in the tropics (e.g., Sandhu, 2021; Queiroz et al. 2021). However, the situation is not as straightforward as the Boserupian theory of agricultural intensification, which suggests that population growth and the subsequent increased pressure on natural resources will lead to adoption of more intensive farming methods. In Chapter 3, we specifically examine the challenges underlying adoption decisions of a sustainable agroecological intensification practice, which differs from mainstream SI by emphasizing agroecological principles rather than the use of external inputs to increase yields (Mockshell & Kamanda, 2018). The System of Rice Intensification (SRI) is a 'best management practice' posited to achieve food security while reducing human pressure on nearby forests.

Moreover, a production-oriented theory of change embraced by conservationists to halt agricultural expansion appears to be overly simplistic and flawed. Freudenberger and Freudenberger (2009) question whether agricultural intensification interventions in Madagascar, particularly around rice production, might actually be contributing to greater deforestation. This is because farmers' decisions to abandon traditional shifting cultivation are influenced by a multitude of factors, including socioeconomic, sociocultural, and political trade-offs. Furthermore, considering the interdependence between food security and biodiversity conservation (Chappell & LaValle, 2011), this tension between the two, especially among forest-frontier communities, is a "false dichotomy" (Wittman et al., 2017). Rather, agriculturalists and conservationists must be in lockstep to find synergistic approaches that address both objectives (Steiner, 2011).

1.5 Farmer decision-making

Agricultural diversification (especially introducing shade-grown cash crops) and intensification (mainly for rice) pathways described, a major focus of conservation and development interventions in Madagascar (e.g., Jones et al., 2021), have met with resistance from farmers who are either unable or not willing to implement these new practices (Esquivel et al., 2021). In order to better understand the lack of success in 'converting' farmers, Sanchez (1995; cited in Pattanayak et al., 2003) highlighted the "need to develop a predictive understanding of how farm households make decisions regarding land use" (p.137). Despite the plethora of research that followed, the results remain mixed and lack consensus[16] on the factors that ultimately influence farmer adoption of practices (Foguesatto et al., 2020; Knowler & Bradshaw, 2007). Thus, a deeper understanding of farmer behavior and decision-making at the individual and group level is still needed, as

[16] Though it is important to note that much of the research has measured adoption as a dichotomous variable (Alexander et al., 2020), despite decision-making being an iterative process (Singh et al., 2016), which can be misleading.

well as of the structural elements that enable agri-food systems to change (Darnhofer, 2021). Therefore, this research sets out to understand the underlying factors belying farmer decision-making using a case study of a particularly vulnerable population of smallholders in coastal Madagascar.

Historically, farmer decision-making was viewed through a singular economic lens. Farmers were assumed to be rational (business) actors ('homo economicus') seeking to maximize their well-being, technically termed as utility, and often measured in the form of profits or yields (Edwards-Jones, 2006). However, following Chayanov (1986), the *rational man* assumption of neoclassical profit maximization theory is insufficient in explaining farmer decision-making in smallholder systems where farms are both families and small enterprises with household food consumption and income needs. For example, in line with Chayanovian thinking, Umar (2014) finds that, though economic calculations were still involved, smallholders in Zambia were not motivated to maximize their profits until household food security requirements were met.

Recognizing the importance of moving beyond purely economic models to using integrated frameworks that bring together multiple disciplines, a "melding of different insights" (Feola & Binder, 2010, p.2324), this research attempts to more fully consider both the extrinsic and intrinsic factors affecting farmer decision-making. For example, while still relatively rare in the farmer adoption studies literature (Foguesatto et al., 2020), this work blends multiple behavior intention theories to examine how sociopsychological constructs impact both farmer intention and actual behavior,[17] while also grounding the work in lived experience and voices of farmers to understand who is coping and how.

While some argue that the inability of models using sociopsychological determinants to explain farmer decision-making is a result of poor selection of constructs, and that greater inclusion of constructs such as efficacy, trust, awareness, and knowledge is needed (Rosário et al. (2022), this dissertation provides additional evidence of the necessity to move beyond considering only singular adopter (individual and household) level factors that influence farmer decision-making to more fully consider the role of structural factors, such as access to resources (including disaster aid), land tenure, government policies and institutional support, and infrastructure. For example, recent work by Rodríguez-Cruz and Niles (2021) found that agricultural adaptation decisions among farmers in Puerto Rico were influenced by lack of institutional support, rather than by cognitive factors such as perceived capacity and vulnerability.

This dissertation research further illustrates that smallholder farmer decisions are shaped, not only by intrinsic psychological traits and household characteristics, but also by intricate socio-cultural pressures and historical processes. For example, one should not underestimate the importance of *fihavanana*, the Malagasy term referring to the importance of maintaining a conciliatory, non-confrontational relationship with both living and spirit kin, and the impact that it has on individual decision-making and behavior. Furthermore, while individual farmers have the autonomy to make decisions to change, their adaptive

[17] Admittedly, this sociopsychological approach is very Western, being applied to a very non-Western society.

capacity is often inhibited by overarching structural factors such as inadequate access to infrastructure, supplies, trainings and other forms of information.

1.6 Overview of dissertation

In this three-article dissertation, smallholder food system resilience is explored at the micro-level (individual and farm/household level unit of analysis), contextualized by meso- and macro-level factors. Using both quantitative and qualitative methods, I investigate both the internal drivers and external barriers to coping, adapting and transforming among one of the most vulnerable farming populations on earth.

To accomplish this, I first examine traditional food security coping strategies to establish the key elements within the local foodshed, the geographical area in which food is obtained, enabling farmers to survive. I then apply socio-psychological theories increasingly used in the smallholder farmer adoption literature, such as Protection Motivation Theory (PMT), the Theory of Planned Behavior (TPB) and the Technology Acceptance Model (TAM), to examine the cognitive and social factors behind farmers' decisions to either maintain *status quo* (survive) or possibly thrive. Qualitative data from focus groups then provides a broader understanding of the contextual factors underpinning farmer intentions and behavior.

Each chapter highlights a unique aspect of resilience in rain-fed small-scale subsistence farming systems in relation to the proposed food system adaptation and transformation pathways of agricultural diversification (Chapter 1), climate-resilient agriculture (Chapter 2) and sustainable intensification (Chapter 3). Furthermore, while

Chapters 1 and 2 delve into traditional adaptive strategies, such as coping during the ‘hunger season’ or autonomous adaptation to climate change, Chapter 3 focuses on what has been referred to as “imposed innovation” (Dawson et al., 2016) or a “strong institutionalized push” (Taylor & Bhasme, 2019).

Chapter 1 specifically examines household food security among park-adjacent communities under extreme circumstances (i.e., farmer-forager coping strategies during the hunger season), explores detrimental coping strategies as a result of persistent stressors, and problematizes the theory of diversified farming systems in the context of endemic food shortages when cultivated landholdings are small and scattered. Chapters 2 and 3 take a behavioral approach to understanding farmer decision-making as it relates to climate-resilient agricultural practices and adoption of sustainable intensification techniques, respectively. Chapter 2 employs Protection Motivation Theory to explore farmers’ intention to adapt practices in response to observed changes in temperature and rainfall, while Chapter 3 uses a blended Theory of Planned Behavior – Technology Acceptance Model Framework to examine farmer adoption of an agroecological rice-growing practice and philosophy developed in Madagascar. Recognizing the importance of gender in food systems transformation, and calls for more research applying a “stronger gender lens” (Visser & Wangu, 2021), we also examine the role of gender in smallholder farmer decision-making making across chapters.

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CHAPTER 1: FINDING FOOD IN THE HUNGER SEASON: A MIXED METHODS APPROACH TO UNDERSTANDING FOOD SECURITY AND DIETARY DIVERSITY IN SOUTHEASTERN MADAGASCAR

Na kely aza ny sakafo ananantsika dia zarainay izany na dia valala iray monja aza.
(However little food we have, we'll share it, even if it's only one locust)
- Malagasy proverb

1.1 Introduction

Smallholder farmers, generally cultivating multiple small plots totaling ten hectares or less, provide an estimated one-third of the world's food supply (Herrero et al., 2017; Lowder et al., 2021; Ricciardi et al., 2018), and up to 90% of the food in some parts of sub-Saharan Africa (SSA; Kaur, 2021). However, in what has been termed the "hungry farmer paradox" (Bacon et al., 2014), many smallholder farmers, despite growing crops for both subsistence and sale, remain impoverished, undernourished (Wiggins & Keats, 2013), and experience seasonal and/or chronic food insecurity (Alpízar et al. 2020; Mazoyer & Roudart, 2006). Food (in)security has been defined as not having "physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit, 1996).

During periods of food shortage ("hunger season"), when stores of staple crops have run low or are entirely depleted, traditional coping strategies among rural farming populations have included, in addition to eating seed stocks intended for future plantings (Minnis, 2021), increased collection and consumption of seasonally available wild, or uncultivated, foods (Erskine et al., 2015; Paumgarten et al., 2018). Specifically, when sufficient quantities of preferred staple foods become (temporarily) unavailable, farmers may turn to certain wild plant foods (henceforth WPFs) not regularly consumed, known as “famine foods” or “emergency foods” (Minnis, 2021). Indeed, wild foods are important for the diets of more than a billion people across the globe (Burlingame, 2000), including farmers. For example, consumption of WPFs has been extensively documented in agricultural environments (e.g. fields, fallows, pastures, etc.) throughout South and Southeast Asia (Cruz-Garcia & Price, 2011; Ogle, 2001; Price, 1997; 2006; Ray & Ray, 2022; White, 2014), as well as across Africa (Bharucha & Pretty, 2010). Powell et al. (2013) found that farmers in Tanzania gathered more wild foods from their farmland than from the forest. Thus, despite some dominant ideas on how food insecurity is addressed among farming communities, supplementing agricultural production with foraging as a short-term solution to hunger remains an important function of many rural societies and should not be overlooked (Hickey et al., 2016). Furthermore, an ability to obtain foodstuffs outside of subsistence production and markets contributes to indigenous food sovereignty, and also ensures a level of agency to manage food security challenges without solely relying on external assistance (e.g. food aid).

Despite the potential importance of WPFs in the food security and nutrition (FSN) of smallholder farmers, there is limited understanding of their role. This is largely due to agricultural and household nutritional surveys which have historically failed to collect information on wild food consumption (Erskine et al., 2015). Even the 2019 report on sustainable diets from the EAT-Lancet Commission on Healthy Diets from Sustainable

Food Systems omitted wild foods (Sax, 2019), highlighting how western assumptions on what constitutes everyday diets have colored the research and analysis on food acquisition and consumption. Furthermore, notwithstanding the continued existence of mixed foraging-farming subsistence modes, the major assumption has been that food security is achieved through cultivated food production (Tucker et al., 2010). And while there has been an uptick in studies on the contribution of wild foods to human diets in recent years (Minnis, 2021; Pieroni, 2021), research on rural populations, food security and dietary diversity has predominantly focused on agricultural systems (Bharucha & Pretty, 2010; Sunderland et al., 2013). Relatively little food insecurity work has looked at the "overlapping, interdependent, coequal and complementary" (Sponsel, 1989; cited in Bharucha & Pretty, 2010) roles of both farming and foraging on FSN in agricultural communities.

In addition, research has shown that living near forests and protected areas (PAs) is associated with greater dietary diversity and improved nutritional status (e.g. Blaney et al., 2009; Fungo et al., 2016; Rasolofoson et al., 2018). However, though buffer zones and "zones of utilization" within and around PAs have become increasingly common, many fortress-style PAs still forbid the collection of wild plants from within their boundaries. Despite evidence that reduced access to wild foods can negatively affect FSN, specifically micronutrient consumption (Galway et al., 2018; Johnson et al., 2013; Powell et al., 2015; Rasolofoson et al., 2018), the impact of PAs on food security, and human well-being in general, remains underexamined in the literature (Jouzi et al., 2020; Pullin et al., 2013). Of the studies focusing on wild food access in these spaces, most has focused on wildlife (e.g.

Golden et al., 2011; Mavah et al., 2018). Thus, more research is needed to understand the role that access to WPFs plays in the FSN of communities living in and along the boundary of PAs.

Using a case study based on survey data and focus group interviews collected from smallholder farmers in rural Madagascar, we contribute to filling these gaps by documenting the two main WPFs important for populations living within proximity of a PA, as well drivers of their consumption and barriers to accessing them, during food insecure periods.

1.1.1 Forager-Farmers of Madagascar

Madagascar, one of the most biodiverse countries on earth and a top global conservation priority (Mittermeier et al., 2011), is also one of the most impoverished and food insecure, with 30,000 people in near-famine conditions (World Bank, 2020). It has the fourth highest rate of chronic malnutrition in the world (IFAD, n.d.) and 42% of children under age five suffer from stunting (INSTAT & UNICEF, 2019). Most of the population (80%) are considered to be farmers (World Bank, 2020) – the vast majority of which are smallholders (Rakotobe et al., 2016), who are among the world's most vulnerable to climate change (Harvey et al., 2014). However, despite the prevalence of agriculture across the island, wild foods remain a prominent approach for coping with food insecurity (Golden et al., 2016; Randrianarison et al., 2020). Indeed, even before farming and herding came to the island, foraging was an important food procurement strategy for the Malagasy (Dewar et al., 2013). Thus, we argue that most of today's population actually falls along a forager-farmer continuum.

While the primary focus of this study is on WPFs consumed as famine foods, it is important to highlight that wild plants and animals are also important components of everyday Malagasy diets. For example, in the southwest, 77% of interviewed households had collected wild yam (Andriamparany et al., 2014), and across three eastern rainforest sites, Styger et al. (1999) documented 150 different wild fruit species being consumed both regularly as well as during periods of food shortage. Furthermore, it is still common to see a family walking home from a long day in their fields carrying wild greens along with small fish and crustaceans gleaned from the rice paddies, a practice which has also been documented among other rice cultures (e.g. Cruz-Garcia & Price, 2011; Ray & Chakraborty, 2021). Therefore, as we assess consumption of WPFs in Madagascar as an indication of food insecurity, we also recognize the role of WPFs in providing important micronutrients (Cantwell-Jones et al., 2022; Ray & Chakraborty, 2021), as well as its ties to ancestral food pathways (Campbell et al., 2021), and cultural food identity (Ghosh-Jerath et al., 2021; Tucker et al., 2010).

Of the substantial body of research on wild food consumption in Madagascar, the majority has been on aquatic animal-source foods (AASFs; Golden et al., 2019a; Le Manach et al., 2012; Taylor et al., 2019) and wild terrestrial animals, or bushmeat (Golden et al., 2011; 2016), such as lemurs (Borgerson et al., 2017; 2018; 2022; Golden, 2009), tenrecs (Golden et al., 2014b; Stiles, 1991), small carnivores (Z. J. Farris et al., 2015), bats (Jenkins & Racey, 2008; Golden et al., 2014a), and frogs (Jenkins et al., 2009). And while rural communities in Madagascar still depend heavily on wild plants, not only for the provisioning of food, but also for fuel and fiber (Brown et al., 2011; Ingram & Dawson, 2006), most of the ethnobotanical research has been limited to their use in traditional medicine (e.g. Golden et al., 2012; Novy, 1997; Rabearivony et al., 2015; Rasoanaivo, 1990; Razafindraibe et al., 2013; Riondato et al., 2019; Tida et al, 2020). Furthermore, as researchers have observed a distinct loss in traditional ecological knowledge (TEK) of WPFs from older to younger generations of Malagasy (Styger et al., 1999), there is an increasing need to document TEK on "neglected" plant species important for FSN (Baldermann et al., 2016), including their identification and preparation (Mbhenyane, 2017; Minnis, 2021; Pawera et al., 2020).

In our study area, the two main wild plants that are typically consumed during the hungry season are the giant aquatic arrowhead or water banana, locally known as *via* (*Typhonodorum lindleyanum*, also called *T. madagascariense;* family *Araceae*) (Figure 1-1A), and the Polynesian arrowroot, locally known as *tavolo* (*Tacca leontopetaloides;* family *Taccaceae*) (Figure 1-1B). Little is understood of their nutritional value, though all parts of the *via* plant are known to contain calcium oxalate crystals, making it toxic if not cooked or fully dried, and particularly concerning for people suffering from conditions related to the buildup of uric acid, such as rheumatoid arthritis and gout (Bown, 1995). *Tavolo*, which has been naturalized in Madagascar, is typically found in tropical forest openings and grasslands (Missouri Botanical Gardens, n.d.). *Via*, a wild aroid native to Madagascar and South Africa (Croat & Ortiz, 2020), grows in marshy areas. Both are used as medicinal plants: *tavolo* to treat malnutrition, and *via* to aid in placental evacuation, alleviate hip problems (Razafindraibe et al., 2013), treat burns and wounds (Rabearivony et al., 2015), and as a remedy against venomous bites (USDA Bureau of Plant Industry, 1919). There is also evidence of *via* being consumed as a famine food in both Zanzibar (Freedman, 2019; Walsh, 2009) and Zimbabwe (Manduna & Vibrans, 2018). Additionally, *via* leaves are used in woven handicrafts across eastern Madagascar.

Figure 1-1. *Tavolo* flower with seeds, (B) *Via* plant

In this paper, a mixed methods approach is taken to examine the relationship of *tavolo* and *via* to food security and dietary diversity (a proxy for nutritional status) among farming and fishing communities situated around Manombo Special Reserve in southeastern Madagascar, as well as predictors of their consumption. The research was guided by the following questions: (1) What is the relationship of WPF (*tavolo* and *via*) consumption to food security and nutrition (FSN) outcomes?; (2) To what extent are WPFs consumed as a food insecurity coping strategy, and what factors predict the consumption of *tavolo* and *via* as a coping strategy?; and (3) How are these WPFs perceived by farmers, and what are their implications for health and biodiversity conservation?

Based on previous research findings (e.g. Niles & Salerno, 2018), we hypothesized that larger, poorer households would be more likely to consume WPFs as a food insecurity coping strategy. We also predicted that household food insecurity and consumption of wild plant famine foods will be associated with low dietary diversity/inadequate nutrition, while greater farm crop diversity and household wealth will be associated with higher dietary diversity levels/adequate nutrition (Faber et al., 2009).

1.2 Materials and Methods

1.2.1 Study site

Our study population consisted of rural smallholder farmers (growing on 10 Ha of land or less) and fisherfolk, who self-identified as being primarily of the Antaifasy (People of the Sand) ethnolinguistic group and sub-groups (e.g. Antevatobe, Rabakara, Zaravalala, Zaramanampy), living within 2 km of Manombo Special Reserve (5320 Ha) in southeastern Madagascar (Figure 1-2), which is among the most food insecure regions of the island (Randrianarison et al., 2020). Manombo, established in 1962, is an International Union for Conservation of Nature (IUCN) category IV protected area (PA). Managed by Madagascar National Parks (MNP), human entry into Manombo is regulated and extraction (hunting, tree cutting, etc.) is strictly prohibited. There is no buffer zone or "zone of utilization" associated with this PA. Communities are highly reliant on local food production and fisheries, as both market access and agricultural extension services are extremely limited, and farmers employ traditional methods to grow rice and other crops, such as cassava, jackfruit, banana, breadfruit, etc. They also engage in cash crop production of coffee and cloves to a lesser extent.

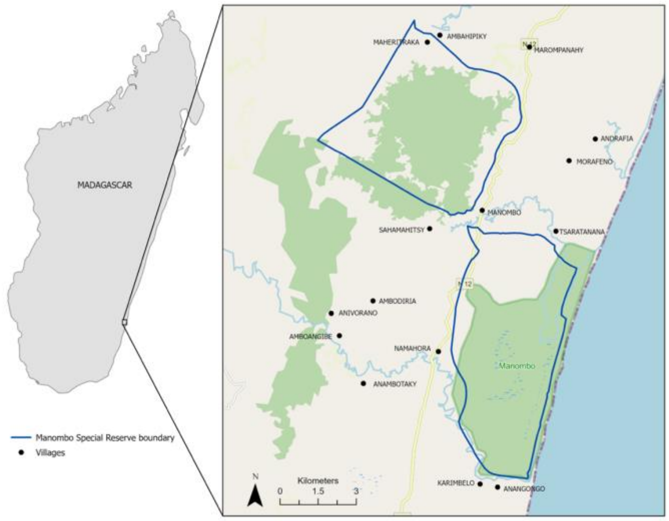

Figure 1-2. Map of study area with 15 survey villages, southeastern Madagascar

Note: Black dots are villages with village names. Blue outline denotes Manombo PA boundaries. Green shaded area is remaining forest. Yellow line is RN12.

1.2.2 Data collection

1.2.2.1 Survey data collection

Data was used from a cross-sectional survey of male and female adult rice farmers (n=328), each representing a separate and distinct household, living in 15 villages and sub-villages surrounding Manombo Special Reserve. Each village was assigned to one of three groups indicating increasing distance (Km) from coast (see Table 1-1). As our initial sample (n=204) consisted of participants in a 2020-2021 rice-growing training, we wanted to ensure that we also sampled farmers that had not self-selected to participate in the training. Therefore, probability proportional to size (PPS) sampling (Skinner, 2014) was used to estimate the target number of remaining households within a given village of which to randomly select additional respondents – one per household (n=124). To randomly select households and within-household respondents *i*) a number was assigned to each remaining eligible household and a random number table was used to select households

(WHO, 2000), and *ii*) to select the respondent when more than one adult (over age 18) in the household was present at the time of the interview, a "lottery method" of drawing a name from a hat was employed (Yadav et al., 2019).

Table 1-1. Variables included in the models

Variable type	Variable name	Variable description
Geographic	Village category	Categorical, 15 villages categorized into three groups (coastal/littoral forest, along road, near lowland rainforest) by increasing distance from coast
Socioeconomic	Household (HH) size	Continuous, number of persons living in the household (adults and children)
	HH type	Binary, 1= female-headed, 0= male-headed
	Assets	
	- HH assets	Continuous, 0-30
	- Zebu ownership	Continuous, number of zebu owned (0-40)
	- Land ownership	Binary, 1= own land, 0 = does not own land
Agricultural	Farm production diversity	Continuous, number of food crops grown (1-12)
Diet and food insecurity	Individual dietary diversity score (IDDS)	Continuous, 0-13
	Food insecurity level	Categorical: food secure, moderately food insecure, very food insecure
	Adequate nutrition	Binary, 1= IDDS of 4 and above, 0 = Below 4
	Wild plant food (WPF) consumption	Binary, 1= consumption of WPFs over 12-month period, 0 = no consumption of WPFs

Note. Bolded variables are outcome variables in the logistic regression models.

Fieldwork took place over three weeks in February 2021, during the start of the region's main "hungry season" (*sakave*), as collecting data during this period is recommended to capture acute food insecurity (Coates et al., 2007). Exemption for this study was received from the University of Vermont's Institutional Review Board (IRB; study #00001290). Verbal informed consent was received from all participants and documented as per the IRB protocol. A trained team of five Malagasy enumerators conducted face-to-face interviews in Malagasy and recorded data on standardized paper surveys. The questionnaire consisted predominantly of closed-ended questions, took 60 - 90 minutes to complete, and collected household and farm characteristic information, as well as data on agricultural practices, household food insecurity and dietary diversity from a 24-hour open-ended dietary recall (see Supplementary materials Table 1 for a subset of questions from the questionnaire). A team of Malagasy and American research assistants entered the responses from paper surveys into a digital format and conducted translations of qualitative data from the survey.

1.2.2.2 Focus group interviews

To better assess famine food consumption patterns and document traditional ecological knowledge (TEK) in the Manombo area, communities in which participants had reported consumption of *tavolo* and/or *via*, the only two wild plant species specifically mentioned in the dietary recall, were identified, and four focus group (FG) interviews were conducted in October 2021. In particular, we were interested to learn if *tavolo* and *via,* as well as other WPFs, were harvested from within the reserve or elsewhere, local opinions on consumption of these plants, which parts of the plants were edible, if there were any local taboos or stigmas surrounding their consumption, how they make people feel physically, and any other issues or concerns related to accessing WPFs. Each FG lasted 45-60 minutes and consisted of eight participants (four men and four women) selected by *ampanjaka* (village elders). Interviews were voice recorded, transcribed verbatim into Malagasy, and then translated into English by a native Malagasy speaker. Two of the FGs also included narrative walks to view plant habitats; short demonstrations of processing techniques were also filmed.

1.2.3 Variables

1.2.3.1 Outcome variables

Adequate nutrition based on individual dietary diversity scores

Data on food consumption was gathered using an open-ended dietary intake over 24-hours, following standard dietary diversity questionnaire procedures (FAO, 2010; Swindale & Bilinsky, 2006). Enumerators asked respondents to list the food items that they had eaten for breakfast, lunch and dinner, as well as any snacks eaten between meals, during the previous day. Food consumption information from those that responded positively to a question as to whether the previous day was a feast day, celebration or holiday was omitted from the analysis (n=5). Responses were recorded in Malagasy and then translated into English. Translated data was then coded and used to generate food variety scores (FVS) from the number of unique food items consumed, and individual dietary diversity scores (IDDS) from the number of food groups in which consumed foods were classified under (Ruel, 2003), using IBM SPSS Statistics for Macintosh, Version 28.0. Both FVS and DDS are useful, simple indicators of micronutrient adequacy (Steyn et al., 2006).

Foods were classified into 13 out of 16 possible food groups suggested by FANTA (Swindale & Bilinsky, 2006; see Table 2 in Supplementary Materials for a list of food groups). Based on the findings of Moursi et al. (2008), we omitted group 14 (fats and oils). We also omitted groups 15 and 16 (sweets, spices, condiments, and beverages) as they are typically consumed in quantities too small to be nutritionally important (Faber et al., 2009), although when available, likely contribute greatly to palatability and food enjoyment. A score of 1 was entered if the respondent ate one or more foods within a food group, and a score of 0 was used to indicate an absence of any foods consumed within that group. We then calculated an individual dietary diversity score (IDDS) for each respondent from 0-13 (out of the 13 food categories), as well as generated a binary variable to represent dietary diversity scores of four and above or lower than four (1= 4 and above, 0= below 4), as consuming from four different food groups per day is generally accepted as the critical value for adequate nutrition (Steyn et al., 2006).

WPF consumption as a food insecurity coping strategy

Respondents were surveyed on various food insecurity coping strategies, including famine food consumption (see Supplementary material Table 1). Specifically, respondents were asked if they had eaten any plant foods (such as *tavolo* or *via*) as a food insecurity coping strategy in the last 12 months. Given the custom of liquidating assets, such as large livestock, as a food insecurity coping strategy (e.g. Dercon, 2002), and the high socio-cultural and economic value of zebu cattle (*Bos indicus*) in Malagasy society (Fauroux et al., 1990), we also examined the interaction between the number of zebu owned and household food insecurity as it relates to WPF consumption.

1.2.3.2 Predictors of adequate nutrition and WPF consumption

Farm and household characteristics. To gauge the complexity of the local agri-food system, survey respondents were asked about their farming practices, including the types of crops grown, and type and number of livestock owned. Farm production diversity was calculated by counting the number of food crops that respondents reported growing on their farm, out of a list of 12 possible crops (see Supplementary material Table 1). Data was also collected on distance (measured in minutes walking) of nearest and farthest rice fields, cash crop (vanilla, coffee and cloves) engagement, as well as household size and type (female-headed or not).

Assets. Following methods developed by Demographic and Health Surveys (DHS; Rutstein & Johnson, 2004) to assess household wealth, an asset index was created by asking questions regarding ownership of durable assets such as radio, cellphone, bicycle, dugout canoe, etc. as well as ownership of specific agricultural tools such as machete, spade, and ox cart (see Supplementary material Table 1 for a complete list). The presence of each of these assets was aggregated as a count variable from 0-30. In addition to the asset index, the number of large livestock owned – in this case, zebu – as a continuous variable, and land ownership as a binary variable, were also included.

Food insecurity. To measure household food insecurity, respondents were asked five yes-no questions about their experience with food insecurity in the last 30 days (see Supplementary material Table 1). Affirmative responses were used to generate a food (in)security score expressed in numerical values ranging from 0-5. The first question, "In the past 30 days, have household members ever had to eat meals without rice?" was included because of the cultural significance of eating rice, Madagascar's staple food.[1] The second question, "In the past 30 days, have you ever feared that your food supply would run out?" comes from FAO's Food Insecurity Experience Scale (FIES) and is used to measure concern or anxiety over having sufficient food. The last three questions comprise the three-question Household Hunger Scale (HHS), a subset of USAID's Household Food Insecurity Access Scale (HFIAS) which has been validated across seven countries (Deitchler et al., 2011). A recall period of 30 days is a standard way to capture food security and has been validated for HFIAS (Coates et al., 2007). As is standard in many food security assessments (e.g. USDA six-item food security module; Bickel et al., 2000), we then categorized households into three food (in)security categories based on the number of affirmative responses to our questions: food secure (answering 'yes' to zero or one of the five insecurity questions), moderately food insecure (answering 'yes' to two or three questions), and very food insecure (answering 'yes' to four or five questions).

1.2.4 Data analysis

1.2.4.1 Statistical models

[1] In cultures where one food dominates the diet, hunger is often associated with decreased availability of that staple (Minnis, 2021). Indeed, one of the Malagasy words for "to eat" (*mihinim-bary)* translates as "to eat rice," and in a form of culinary discontent, many Malagasy do not consider having eaten if they have not had rice, even if they have eaten less preferred staples known collectively as *haninkotrana* (e.g. cassava, sweet potato, taro, etc.). Furthermore, there is a Malagasy belief that if you go to bed without eating rice (*mandry fotsy*; Richardson, 1885), then you will not sleep well (Conti et al., 2021b). These expressions are important in terms of the politics of (food) adequacy, which considers the social and emotional "dimensions of food consumption…beyond the caloric content" (Garth, 2020, p. 158).

Using a generalized linear mixed (GLM) model function in IBM SPSS Statistics for Macintosh, Version 28.0, we fitted two multilevel mixed effects logistic regression models to analyze the relationship between food security, dietary diversity and WPF consumption where all households are clustered at the village level. Correlation analysis using Spearman's *rho* was used to determine relationships between variables to be included in the models. Lowest Akaike Information Criteria (AIC) score and highest percent correct were used to select the most parsimonious, best fitting models.

Table 1-1 lists both the outcome and predictor variables included in the two models. The first model used adequate nutrition based on independent dietary diversity scores (IDDS; IDDS of 4 and above) as a binary dependent variable to analyze the relationship of consuming WPFs and food security on the odds of having adequate nutrition. The second model was fitted with WPF consumption as a binary dependent variable. Both models included four variable types to document geographic, socioeconomic, agricultural and diet/food insecurity variables following what has commonly appeared in the food security literature. WPF consumption was also included as a predictor variable in the first model; IDDS and the interaction term between zebu ownership and food insecurity were included as predictor variables in the second model. Engaging in cash crop production and selling crops were significantly correlated with farm production diversity and therefore, not included in the models. All continuous variables were standardized before analysis (z-score transformation). To account for variation across villages, we treated them as a random effect.

Both logit models take the same basic form:

$$logit(p) = \beta_0 + \beta_1 V + \beta_2 HH + eV + e(HH)$$

where p is the probability of the outcome variable being equal to 1, or p = P{Y = 1}, β_0 is the overall intercept, and β_1 and β_2 are the coefficients for the fixed predictor effects, V is village predictor, HH is household predictor, eV is the random variation from village to village, and e(HH) is household, or residual, variability that cannot be explained by any other factor. The model assumption is that deviation from overall mean is the same for all households on average. We can make this assumption because we have already accounted for the fact that some combinations of household measurements are more similar by including the extra village error term.

1.2.4.2 Analysis of qualitative data from focus group interviews

Transcript-based analysis was used to analyze the word-for-word written record from the audio recordings of the focus group (FG) interviews. Using classic analysis strategy for analyzing FG results (SAGE, 2015), responses were organized according to themes, and compiled into a written descriptive summary including English translations of direct quotes from FG participants.

1.3 Results

1.3.1 Descriptive statistics

Individual and farm household characteristics. Our sample was 64.5% (n=211) female and 35.5% (n=116) male, with ages ranging from 18 to 71 years (mean age of 35.7 years). Table 1-2. provides details on household type and size. Households were primarily male-headed (81%, n= 262), and size ranged from one to 20 individuals (adults and children), with an average of 6.2 individuals per household. Three-quarters of all respondents (75.6%, n=248) identified farming/agriculture as their primary occupation. Weaving mats was a primary occupation for 13.7% (n=45), while only 4% (n=13) of respondents identified fishing as their primary occupation.

Table 1-2. Summary of descriptive results

Variable	Mean	Standard deviation	Minimum	Maximum
Household (HH) size	6.17	2.64	1	20
HH type (female-headed)	0.19	0.39	0	1
HH assets	4.83	2.86	1	23
Land ownership	0.88	0.32	0	1
Farm production diversity	8.13	2.64	1	12
Zebu ownership	1.19	3.38	0	40
Food variety score (FVS)	3.68	1.27	1	9
Individual dietary diversity score (IDDS)	3.22	0.99	1	6
Adequate nutrition (IDDS of 4 and above)	0.33	0.47	0	1
Food insecurity coping strategies	3.43	2.00	1	9
Wild plant food consumption	0.55	0.50	0	1

Durable assets. Manombo area households exhibited low household wealth, as evidenced by the low number of assets owned (see Table 1-2). The most commonly owned household items were a bed, radio and cellphone. The most commonly owned agricultural tools were a spade ("his spade is a matter of pride to every [Malagasy] farmer," Linton, 1927, p. 655), machete, and axe.

Land. Most respondents (88.3%; n=287) reported owning multiple small parcels of land (10 Ha or less) under traditional tenure (see Table 1-2), as opposed to growing on rented cropland. However, of those with land, just over half (53.3%; n=153) had a title deed for the land. Distance to rice fields averaged between 30-60 minutes walking time to nearest and furthest fields, respectively.

Farm production. Farmers grew 8.13 (s.d. 2.64) different food crops on average (see Table 1-2). All respondents grew rice, with 95.7% (n=314) practicing rice paddy cultivation and 43.9% (n=144) practicing upland rice production. After rice, cassava was the most commonly grown food crop, followed by jackfruit, bananas, breadfruit, pineapple, avocado and litchi. Many respondents also engaged in cash crop production (71.3%; n= 234), with most growing coffee (63.7%; n=209), cloves (52.4%; n=172), and vanilla (29.3%; n=97) to a lesser extent. While growing predominantly for subsistence, 53.9% (n=174) of respondents reported selling crops locally; only 0.6% (n=2) reporting selling crops at the national level or for international export.

There are two rice growing seasons in this area. Half of all respondents (50.6%, n=166) only grow rice during *vary vatomandry,* the primary rice-growing season (see **Error! Reference source not found.**); 46% (n=150) grow in both *vary vatomandry* and *varihosy*.[2] Very few respondents (1.8%, n=6) grew rice during *varihosy* season alone. On average, respondents reported harvesting 24.9 and 11.2 *daba*[3] of rice during *vary vatomandry* and *varihosy*, respectively.

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[2] There are two rice-growing seasons locally known as *vary vatomandry* and *varihosy* or *vary kitra* (off-season rice), which correspond to a warmer season (Vatomandry) from December - May, and a drier season (Hosy) from June - November. Vary vatomandry is the main harvest in May/June and the start of a roughly four-month "period of abundance." Varihosy is harvested in December and supplies last about one month (Randrianarison et al., 2020).
[3] *Daba* is a local unit of measurement made from 18-20 liter metal coconut oil containers used to measure rice seed (with hull still intact), which equates to roughly 15-20 kilograms).

In general, area rice production falls short of meeting farmers' needs. Figure 1-3 shows the percentage of farmers buying and selling rice per month. Nearly three-quarters of respondents (73.8%; n=239) indicated that they had not sold any of their rice harvest in the previous year, and almost all reported needing to buy rice at some point during the year (98.5%, n=322). Furthermore, as is common practice across Madagascar, farmers reported selling rice at a lower price (471 Ariary/*kapoaka* on average)[4] during harvest season and then buying it back later at a higher price (544 Ariary/*kapoaka* on average).

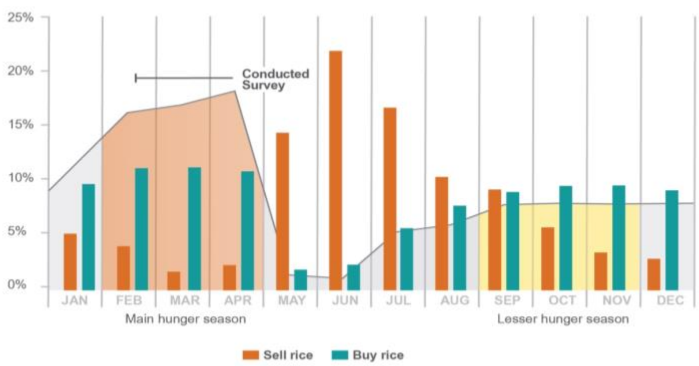

Figure 1-3. Percentage of farmers buying and selling rice per month; Percentage of households reporting food insecurity by month

Note: Black line indicates 3-week time period in which survey was conducted, which is the beginning of the "hunger season" in which rice stores run low or are completely depleted.

Poultry was the most commonly owned livestock type (74.7% of households; n=242), followed by pigs (35.8%; n=116) and zebu (25.9%; n=84). The number of zebu owned varied by household, from zero to 40, with an average of 1.19 zebu per household (s.d. 3.38; see Table 1-2).[5] Livestock was more important for income generation than home

[4] *Kapoaka* is a local unit of measurement using an empty condensed milk can to measure hulled rice.
[5] Locally, zebu numbers may have reduced in recent years due to frequent attacks by *dahalo* ("zebu thieves"; Randrianarison et al., 2020).

consumption, with 82.3% (n=219) of respondents reporting selling livestock compared to 64.7% (n=172) of respondents reporting livestock used for feeding the family .

Results from 24-hour dietary recall. A total of 31 distinct foods were listed as being consumed over a single 24-hour period during the month of February (See Supplementary material Table 4),[6] with a mean food variety score (FVS) of 3.68 (s.d. 1.27; see Table 1-2). Typical of the Malagasy diet and in line with what Randrianarison et al. (2020) previously reported in two Manombo area villages, respondents consumed a monotonous diet predominantly consisting of starchy staples (rice, breadfruit, and cassava), and low in animal and plant protein and non-starchy vegetables (see Supplementary material Table 2). As surveys were conducted during breadfruit season, breadfruit was a common substitute for rice.[7] Cassava (tuber) was also consumed frequently but to a lesser extent. As February is the beginning of the approximately three-month hungry season, only 9.6% (n=31) reported eating no rice in the 24-hour period, indicating that rice stocks had not been depleted at the time of the survey.

The main source of protein was from aquatic animal-source foods (AASFs) or blue foods (19.3%; n=62). Just 2.8% (n=9) of respondents reporting consumption of domesticated animal protein (zebu, pork, chicken, and eggs). There were no reports of bushmeat consumption, despite recent alerts raised by American researchers of increased

[6] This contrasts to the 250 distinct foods consumed by households in the more verdant northeastern area of Madagascar over a nine-month period as reported by Golden et al. (2019b), demonstrating that a 24-hour dietary recall only provides a snapshot of the full range of foods available to a community throughout the year.
[7] Breadfruit is typically boiled for *kadaky* (cut into small pieces then boiled and mixed with salt to get a savory porridge) or *sambaiky* (whole breadfruit is cut into four pieces and boiled).

lemur hunting within the reserve (M. Donohue, *personal communication, Feb. 2020*), and previous documented cases of subsistence hunting of lemurs and tenrecs (Johnson & Overdorff, 1999). Though entomophagy (insect consumption) is also part of Malagasy culinary tradition (Borgerson et al., 2021; Conti et al., 2021b), our data does not reflect this.

Foods collected from the wild comprised five of the 31 (16.1%) distinct food items listed in the 24-hour recall – three (9.7%) were blue foods and two (6.5%) were wild plants (*tavolo* and *via*). However, while consumption of one or both of these plants was reported by only 2.5% (n=8) of respondents over the 24-hour period (see Table 2 in Supplementary Materials), 55.3% (n=177) of households reported consuming *tavolo* and/or *via* as a food insecurity coping strategy during the last 12 months (see Figure 1-4). In February, at the start of the main hunger season, many households still have access to breadfruit (see Figure 1 in Supplemental materials) and *tavolo* tubers may not yet be mature. Therefore, reliance on *via* and *tavolo* likely increases later in the season, as rice stocks become depleted.

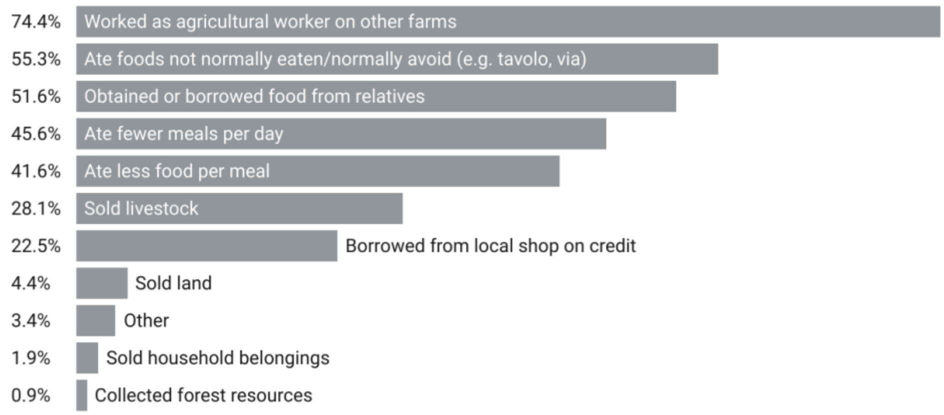

Figure 1-4. Percentage of respondents employing types of food insecurity coping strategies

Dietary diversity. Overall, dietary diversity of individual respondents was nutritionally inadequate, with an average individual dietary diversity score (IDDS) of 3.22 (s.d. 0.99; see Table 1-2); 65.9% of respondents (n=216) had an IDDS below four (see Table 1-2). Figure 1-5 shows the percentage of respondents consuming foods from each of the 13 food groups. The majority of respondents consumed foods from three food groups (cereals, white roots & tubers, dark green leafy vegetables). Consumption of foods from several food groups were not reported by any respondents (dairy, organ meats) or were reported by a single respondent (eggs, vitamin A-rich vegetables).

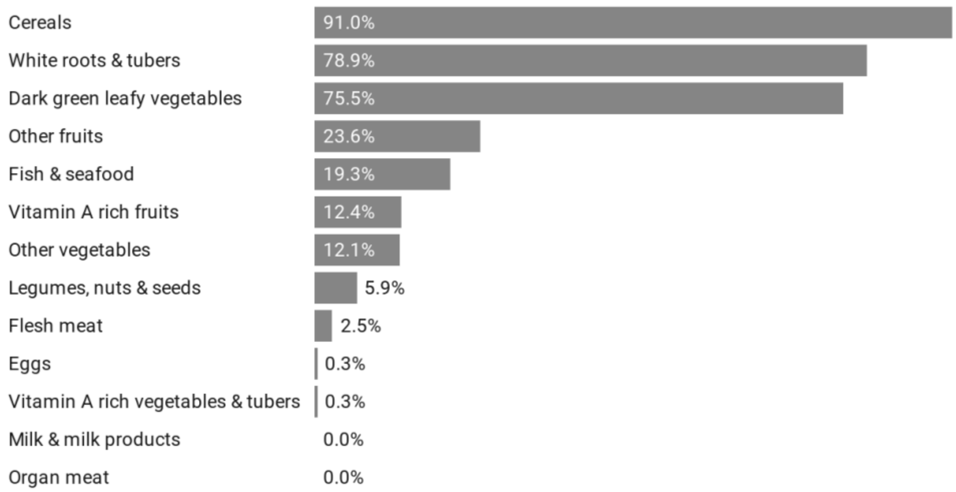

Figure 1-5. Percentage of respondents consuming foods from each food group

Food insecurity. Results from the five-item food insecurity experience questionnaire indicated a high level of food insecurity among Manombo area households in the 30 days preceding the survey (see

Table 1-3), with 91.1% (n=296) of respondents fearing running out of food, 82.2% (n=267) having gone without eating rice, and 66.7% (n=217) having gone to bed hungry in the previous month. As shown in Table 1-4, nearly half of households were categorized as being very food insecure (47.3%, n=155) in the previous month, with 36.9% as moderately food insecure (n=121), and just 14.9% (n=49) as food secure. Mean IDDS also decreased with increasing levels of household food insecurity, and on average, moderately and very food insecure households owned less zebu than more food secure households (see Table 1-4).

Table 1-3. Response rates to food insecurity questions making up the five-item food insecurity scale.

In the past 30 days,	Yes	N	Total N
Have household members ever had to eat meals without rice?	82.15%	267	325
Have you ever feared that your food supply would run out?	91.08%	296	325
Have you ever lived without food in the household?	48.46%	157	324
Have household members ever gone to bed hungry at night?	66.77%	217	325
Did household members spend a full day and night without eating?	37.85%	123	325

Table 1-4. Key results disaggregated by food (in)security category

	% of respondents	Mean number of food crops grown	Mean number of zebu owned	Mean dietary diversity score	No. of households consuming WPFs in last 12 months
Food secure (n=49)	14.9%	8.55 (S.D. 2.54)	3.10 (S.D. 4.60)	3.64 (S.D. 0.99)	21
Moderately food insecure (n=121)	36.9%	8.45 (S.D. 2.50)	0.64 (S.D. 1.54)	3.53 (S.D. 0.96)	67
Very food insecure (n=155)	47.3%	7.78 (S.D. 2.74)	1.02 (S.D. 3.80)	2.85 (S.D. 0.88)	88

Figure 3 shows the percentage of respondents experiencing food insecurity by month, with the period from February - April having the highest prevalence of food insecurity.[8] There was also a marked decrease in food insecurity reported in May and June which coincides with the May/June *vatomandry* rice harvest. Higher rates of food insecurity are also evidenced by the percentage of farmers reporting needing to buy rice, versus the periods of time when rice is plentiful enough to sell (see Figure 3).

Food insecurity coping strategies. Out of a list of 10 pre-coded responses selected based on past experience and literature (see Table 1 in Supplementary Materials), respondents reported employing a mean of 3.43 (s.d. 2.0) coping strategies in the previous 12 months (see Table 1-2). As shown in Figure 1-4, the most commonly reported strategy was working as an agricultural day laborer, followed by eating foods not normally eaten, such as *tavolo* and *via*. Of those that consumed WPFs, 38.1% (n=67) and 50.0% (n=88) were moderately and very food insecure respectively, whereas only 11.9% (n=21) of food secure households reported having consumed them (see Table 1-4), indicating that the consumption of *tavolo* and *via* are important coping strategies for households dealing with greater food insecurity. Other commonly cited strategies included obtaining food from relatives, reducing the number of meals per day and eating less food per meal. Weaving baskets and mats, using natural materials such as *mahampy* (*Lepironia micronata*) to generate additional income, was another common strategy cited as an open-ended response by female respondents.

[8] Though Madagascar is highly cyclone-prone and cyclones routinely exacerbate food insecurity by destroying crops, no major cyclones made direct landfall with the southeast coast during the 2019-2020 and 2020-2021 cyclone seasons (December – March/April).

1.3.2 Predictors of adequate nutrition and WPF consumption

In the first model, we analyzed the relationship between consuming WPFs and household food (in)security on the probability of having adequate nutrition (consuming foods from four food groups or more in a 24-hour period). Overall, households reporting greater food insecurity (as compared to the baseline of more food secure households) and those that had consumed WPFs in the last 12 months as a food security coping strategy were both significant predictors of inadequate nutrition ($p<0.05$; Figure 1-6). Specifically, the odds of having adequate nutrition were lower for both individuals from very food insecure households (OR=0.338; CI [.154,.739]; Table 1-5), and for individuals in households consuming WPFs (OR=.526; CI [.299,.923]).

We also found that household wealth (measured using the household asset index) was a significant predictor of adequate nutrition ($p<0.10$; Figure 1-6). Wealthier households had greater odds of having adequate nutrition than households with fewer assets (OR=1.349; CI [.995,1.828]; Table 1-5). While not significant, farm production diversity was also associated with greater odds of adequate nutrition (OR=1.145; CI [.847,1.547]). Lastly, as we would expect, we did not find any significant interaction effects between zebu ownership and household food insecurity on diet diversity outcomes (e.g. consuming foods from additional food groups) because zebus are not typically slaughtered for home consumption, even during periods of food insecurity.

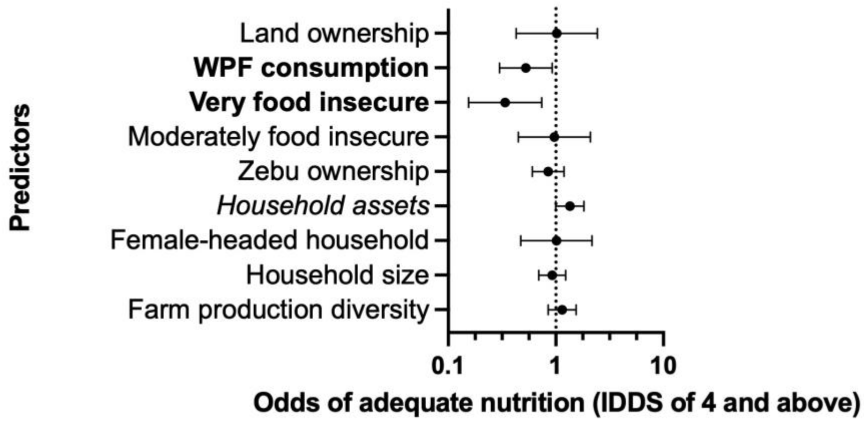

Figure 1-6. Standardized effects of predictor variables on adequate nutrition based on individual dietary diversity scores (IDDS) of four and above.

Note. Points represent the odds ratio estimates with upper and lower 95% confidence intervals. Bolded predictors indicate significance at the p<0.05 level. Italicized predictors indicate significance at the p<0.10 level. The value of 1 on the x-axis (dashed line) is equivalent to no effect. Results based on a multilevel random effects model of data from 302 respondents.

Table 1-5. Main effects from multilevel mixed effects Model 1.

Effect	OR	*SE*	95% CI		*p*
			LL	*UL*	
Main effects					
Intercept	1.372	.5189	.493	3.817	.543
Farm Production Diversity	1.145	.1532	.847	1.547	.379
Household (HH) size	.925	.1470	.692	1.235	.595
Female-headed HH	1.012	.3865	.473	2.166	.975
HH assets	1.349	.1545	.995	1.828	.054
Zebu ownership	.851	.1729	.605	1.195	.350
Land ownership	1.020	.4412	.428	2.431	.964
Food Secure	.	.	.	.	.
Moderately food insecure	.970	.3912	.449	2.095	.938
Very food insecure	.338	.3983	.154	.739	.007
Wild plant food consumption	.526	.2859	.299	.923	.025

Note. Odds ratio (OR) above 1 indicates greater odds of adequate dietary diversity, while OR below 1 indicates greater odds of inadequate dietary diversity. Total $N = 302$. CI = confidence interval; *LL* = lower limit; *UL* = upper limit. Bolded predictors indicate significance at the $p<0.05$ level. Italicized predictors indicate significance at the $p<0.10$ level.

In the second model, we examined predictors of consuming WPFs during periods of food shortage as a binary dependent variable, and found that larger households, female-headed households and households growing more types of crops were more likely to consume WPFs (Figure 1-7). Specifically, the model estimates that wealthier households are significantly less likely to consume WPFs (OR= 0.608, CI [.432, .854]; Table 1-6), while farms with more diversified production (OR=1.434, CI[1.056,1.947]) and larger households are significantly more likely to (OR=1.353; CI[1.001,1.829]). Female-headed households were also associated with greater odds of WPF consumption than male-headed households (OR=1.885; CI[.879, 4.004]), while greater individual dietary diversity scores (IDDS) were negatively associated with WPF consumption (OR=.929; CI[.695, 1.242]). Though not significant, both moderately food insecure (OR=2.051; CI [.828,5.083]) and very food insecure households (OR=1.302; CI [.564,3.009]) were more likely to consume WPFs than food secure households.

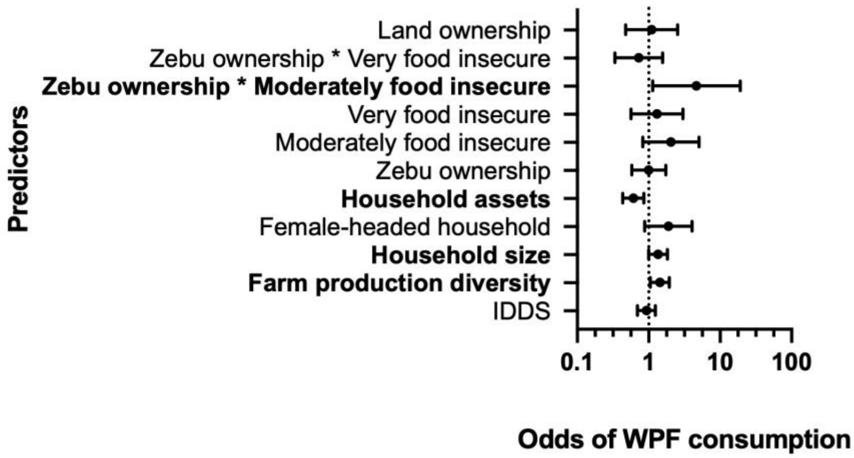

Figure 1-7. Standardized effects of predictor variables on consumption of wild plant foods (WPFs).

Note. Points represent the odds ratio estimates with upper and lower 95% confidence intervals. Bolded predictors indicate significance at the p<0.05 level. The value of 1 on the x-axis (dashed line) is equivalent to no effect. Results based on a random effects model of data from 302 respondents.

In addition to the main effect estimates, there was a significant positive interaction effect between moderately food insecurity households that also owned zebu on WPF consumption, compared to food secure, zebu-owning households (OR=4.661; CI [1.139, 19.083]; Table 1-6). This suggests non-linear effects, where zebu ownership itself is not a predictor of WPF consumption, but instead moderates the effect of household food (in)security in predicting the odds of WPF consumption (Figure 1-8).

Table 1-6. Main effects and interaction effect from random effects Model 2.

Effect	OR	*SE*	95% CI		*p*
			LL	*UL*	
Main effects					
Intercept	.471	.6948	.114	1.947	.287
Farm Production Diversity	1.434	.1555	1.056	1.947	.021
Household (HH) size	1.353	.1532	1.001	1.829	.049

Female-headed HH	1.885	.3877	.879	4.044	.103
HH assets	.608	.1729	.432	.854	.004
Zebu ownership	1.002	.2791	.579	1.736	.993
Land ownership	1.100	.4255	.476	2.541	.823
Individual Dietary Diversity Score (IDDS)	.929	.1477	.695	1.242	.619
Interaction effects					
Zebu*Food Secure HHs	.	.	.	.	.
Zebu*Moderately Food Insecure HHs	4.661	.7161	1.139	19.083	.032
Zebu*Very Food Insecure HHs	.725	.3914	.335	1.565	.411

Note. Odds ratio (OR) above 1 indicates greater odds of consuming wild plant foods (WPFs), while OR below 1 indicates lower odds of consuming WPFs. Total N = 302. CI = confidence interval; LL = lower limit; UL = upper limit. Bolded predictors indicate significance at the p<0.05 level.

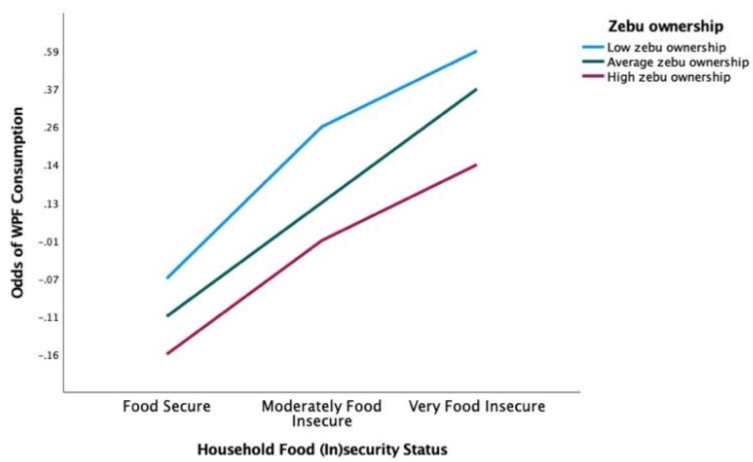

Figure 1-8. Interaction of number of zebus owned and food (in)security level on odds of WPF consumption

Note: This plot of simple slopes displays the odds of WPF consumption among the three food (in)security categories on the x-axis, and a separate line for each level of zebu owned (mean, 1 SD above, 1 SD below).

1.3.3 Farmer perceptions of and access to WPFs: implications for health and biodiversity conservation

As indicated by the results of the surveys, focus group participants articulated their struggles with food security and the niche that WPFs, specifically *tavolo* and *via*, fill when preferred staple foods (i.e. rice) are not available. Therefore, while these WPFs are part of the overall diet, they do not function as dietary or culinary staples. Ultimately, the complexity of harvesting and processing, the implications for health, the hierarchy of famine foods, and changing access to certain lands emerged as crucial.

Collection, beliefs and regulations

There are customary practices governing the timing of WPF collection. Specifically, as Randrianarison et al. (2020) also found, local regulations dictate when *via* harvest may occur. It is *fady* (taboo) to collect *via* during the May-June rice harvest period because, we were told, doing so will cause the rice crop to be destroyed by hail. Similar restrictions on harvesting *tavolo* were not uncovered. Collection of *via* may start as early as November, but *tavolo* is typically harvested starting in late February/early March.[9]

As *via* grows in marshy area, its collection can be demanding, often necessitating crossing waist- or even chest-deep water, and that collecting it makes the body itchy. Therefore, men are primarily responsible for digging it up. *Tavolo* is less challenging to collect, growing in *joliky* (coffee plantations around village) and *roanga* (grassy area or

[9] A survey conducted during this period would likely uncover higher consumption levels of *tavolo* than was found in February.

bush). However, respondents shared that by May/June, *tavolo* plants are already dried out, making it difficult to spot the plant and know where to dig for the tuber.

Access and availability of WPFs

In the interviews, a tension surfaced between the existence of WPFs that are important for community food security, and yet, because of local conservation efforts, made inaccessible to them. One respondent evoked the collective memory of the long-standing prohibition of extracting WPFs, like *oviala* (generic vernacular for wild yam spp.), from the PA, as well as the frustration that much needed WPFs are "off limits" within its boundaries:

> Before [the creation of the PA], people were able to enter the forest. Now it is not allowed anymore. Before there were a lot of *oviala*, enough for food. Now in this lean season, we should collect *oviala* but [Madagascar National Parks (MNP)] owns it now, forbidden. It's banned to enter the forest.

Similarly, while FG participants were aware of *tavolo* growing within Manombo Reserve, they also knew that they were not allowed to collect it, and expressed fear of retribution:

> I work there in the reserve, but we don't collect it from there…We will get into trouble if [MNP] learns that we said there is no *tavolo* in the reserve. There is [a] cleared area in the reserve, and there are *tavolo* in that area.

At the same time, community members indicated a growing struggle to find sufficient amounts of WPFs outside of the reserve. In what Hardin (1968) famously termed the "Tragedy of the Commons," *tavolo* and *via* are becoming increasingly scarce as greater numbers of people collect them. To cope, respondents reported initiating some limited management of these resources, e.g. transplanting the *sauvageons* (wild seedlings) of *tavolo* into their cassava fields and *joliky*. *Via* is also occasionally planted – for food as well as to prevent soil erosion around earthen irrigation dams – in marshy areas not under rice cultivation. Thus, while blurring the line between "wild" and "semi-domesticated" plants (see Bharucha & Pretty, 2010), these practices also speak to human resilience and ability to innovate when overharvesting of a common resource poses a problem.

Preparation

Some WPFs have toxic, anti-nutritive factors that cause adverse effects on human health and thus require significant processing to make palatable (Minnis, 2021; Ocho et al., 2012). This is the case with *via* tuber, which must first be peeled and cut into pieces, then crushed, dried in the sun, and pounded into a powder. The powder is then made into *bonoky* (mixture wrapped in leaves of banana, *ravinala* or *longoza – Aframomum augustifolium* – and boiled in a pot of water). To eat the seeds of the *via* fruit, the fruit bunch (Figure 9A) is peeled and the grains are removed ("your hand becomes itchy because of the liquid from it"). The first layer of the seeds is removed using wood ash; then the "eye" of the seed is removed (See Video 1 in Supplementary materials). The remaining "core" is then washed and boiled in water until all of the water evaporates. It is then either dried and stored for several days, or more water is added, and the process is repeated two to three times until the bitterness is removed. The resulting seed mush is then eaten immediately.

After digging up the tuber (Figure 9B), *tavolo* is washed and then crushed using a rock or *fandra* (local crushing tool). It is then mixed with water and placed in a piece of cloth to strain out the water (see Figure 9C; see Video 2 in Supplementary materials). The solid residue is discarded, and the remaining solution is placed in either a plastic bucket, or a local "bucket" made from *ravinala* (*Ravenala madagascariensis*). Once the water separates from the solid, the water is poured out again and replaced with clean water. This process is repeated several times, depending on how mature the tuber is, to remove the bitterness. The resulting paste is then pressed thin onto the inner side of a pot lid and placed over the fire (See Video 3 in Supplementary materials). The *tavolo* "pancake" (Figure 9D) is often eaten immediately but can last up to one week by drying it in the sun. One respondent said, "It's good if we eat them for three days or sell…then collect again." Men are mainly responsible for crushing the tubers, while women do the "twisting" to wring out the water.

Figure 9. (*clockwise*) (A) Peeled *via* flower with seeds (B) Immature *tavolo* tuber, (C) *Tavolo* tuber being processed, (D) *Tavolo* "pancake", (E) *Tavolo* powder sold in market

Not all plants (and plant parts) are created equal

While we did not find any social stigmas related to local consumption of either of these two WPFs, we were told that there is shame associated with preparing *via* for guests, especially foreigners (both Malagasy and non-Malagasy from other parts of the island). One FG participant told us, "I am shy [to serve you *via*] because I should give you rice with chicken, but between us [community members], there is no shame to share it." This corresponds with a marked preference for *tavolo* over *via*, as well as a preference for *via* seeds over *via* tuber ("we don't hope to eat it").

Furthermore, while both WPFs may be found in the market, *tavolo* is more commonly bought and sold. As one farmer explained: "People rarely sell *via* … people are shy… people don't sell *via* around here, because no one will buy it here." Respondents reported selling *tavolo* powder (Figure 9E) for 200-300 Ariary per *kapoaka* in order to buy basic necessities such as rice, salt and sugar. Another FG participant told us, "We sell them because our kids are hungry - kids get hungry even eating *tavolo* - so you have to sell it to get rice."

Respondents shared that, unlike *tavolo* which they feel makes them "stronger" because of its "vitamins" ("even a baby can eat it, the baby gains weight even if they don't breastfeed"), they only eat *via* tuber when they are "afraid to die," "it's real starvation," and when they "don't have [any other] choice." Reported side effects of collecting and consuming *via* include contact dermatitis (from collecting and preparing) and itchy throat (from consuming).

Not only do nutritional and anti-nutritional qualities vary between plant species, but they can also differ among parts of the same plant (Read, 1945; cited in Minnis, 2021), such that certain parts of a plant are more preferable than others and involve different techniques to remove toxins. Thus, respondents told us that they preferred *via* seeds to *via* tuber. Consumption of *via* tuber extreme weakness and trembling, facial swelling, stomachache and diarrhea. One respondent described the horrible outcomes of consuming *via*: "You can't even ride a bicycle…because it sucks your blood. It's not a real food…it has no vitamins, so sad!" Another respondent explained the potential consequences of consuming via:

> Only hard-working people can eat *via* [tuber]. If you eat too much *via* but you [are] just sitting, not working, your stomach is heavy. It's ok if you go to the field and plant cassava for example. If you just sit, you will have digestion problems.

Nevertheless, despite its deleterious effects on human health, *via* serves as an important stopgap measure to save communities from hunger and starvation when desirable foods are unavailable.

1.4 Discussion

Manombo area households have low dietary diversity and are heavily reliant on wild plants

Forest fringe communities living around Manombo Protected Area had very low food variety (FVS) and dietary diversity scores (DDS) during the main hungry season, indicating micronutrient inadequacy in the diet (Steyn et al., 2006). Individuals had lower average FVS and DDS than has been reported elsewhere in sub-Saharan Africa (SSA; Table 3 in Supplementary Materials), with the exception of children from rural Burundi and Rwanda (Custodio et al., 2019). As many of these studies have focused on children's diets, comparisons are difficult. Nonetheless, our results (mean DDS of 3.22) match the average DDS reported by Niles et al. (2021) for children five and under in 19 low- and middle-income countries. Our findings are also in line with the Global Food Security Index (GFSI) which, based on consumption of non-starchy foods, classifies Madagascar as having "very weak" dietary diversity (GFSI, 2021).[10]

The causes of low dietary diversity are complex. As A. R. Farris et al. (2019) found among primary caregivers in the Betampona area of eastern Madagascar, dietary diversity was not a major driver for food selection (either purchasing or preparing), underlining how different cultural beliefs surrounding what constitutes "nutritious" and

[10] The 2021 GFSI scores Madagascar's dietary diversity as 1.5 (out of 100) and lists it as 100th out of 113 countries in terms of its food security score.

“healthy” foods affect dietary diversity and nutrition outcomes. In Tanzania, Keding et al. (2012) found that dietary diversity was more dependent on the purchase of foods than from on-farm production diversity. Thus, the underlying causes of the low dietary diversity scores recorded in Manombo may be a combination of low farm productivity, seasonality, limited market access and financial capital to purchase a variety of foods, as well as cultural views on adequate meal composition.

In addition to having very low FVS and DDS, Manombo area communities are heavily reliant on natural resources for their food security needs, mixing foraging with farming in order to cope with hunger. In between harvests, when rice stocks have run low or are completely depleted, WPFs clearly fill a gap in the local food environment, evidenced by over half of surveyed households eating WPFs in the last 12 months as a food insecurity coping strategy. Similarly, among subsistence farming communities in Timor-Leste, Erskine et al. (2015) document that 50% of households foraged for WPFs during periods of food insecurity. Moreover, our finding that weaving baskets and mats made of reeds growing in marshy areas in and around the reserve, to sell during periods of food shortage, further highlights the importance of access to natural resources in coping with depleted stores of staple foods. However, based on the qualitative data from our focus group interviews, we find evidence that some wild plants are becoming increasingly scarce, which may compound food insecurity severity.

Assets, dietary diversity and food security

The early twentieth-century American anthropologist, Ralph Linton, recorded that “poor [Malagasy] people eat boiled greens with their rice while the rich have meat or fish”

(Linton, 1927, p.658). A century later, we find that Linton's observation of WPFs being "poor man's food" (Andriamparany et al., 2014) persists. In our study population, wealthier households were significantly less likely to consume WPFs. Consistent with extensive findings in the literature (e.g. Faber et al., 2009), wealthier households were also significantly more likely to have adequate nutrition, indicating that poorer households are consuming a more limited variety of foods. Indeed, we found that Manombo households had very monotonous diets high in starchy carbohydrates, owned very few durable assets, and had extremely high levels of food insecurity.

Furthermore, while many researchers argue that ownership of large assets, such as land and large livestock (e.g. Anderzén et al., 2020; Niles & Salerno, 2018) lowers food insecurity among smallholder farmers, we did not find these variables alone to significantly explain consumption of WPFs as a food insecurity coping strategy. Despite nearly 90% of respondents reporting owning their land in the customary sense (with over half having a title deed for the land), land ownership was not a significant predictor of adequate nutrition or WPF consumption; nor did we find owning large livestock (zebu cattle) to have a significant main effect on these two outcomes. Similarly, in a study among smallholder farmers in Central America, Alpízar et al. (2020) found no significant effect of land ownership on food security, and that selling livestock as a food insecurity coping strategy was used only infrequently. In addition, Bogale and Shimelis (2009) report that the number of oxen owned did not have a statistically significant effect on household food security in Ethiopia. Thus, as other studies have shown, zebu ownership alone is not protective against food insecurity and famine food consumption.

However, while zebu ownership alone has no significant main effect on the odds of WPF consumption, we found a more nuanced relationship in which food insecure households that own a larger zebu herd are less likely to eat WPFs than households that own less zebu (Figure 8). Indeed, in Madagascar, zebus are typically only slaughtered for ritual celebrations, or to pay for large expenses (e.g. school fees, purchasing land). They are not for home consumption. Thus, households with more zebu (wealthier, more food secure) are more likely to sell or slaughter a zebu during periods of food shortage than those with just one or two. This supports the buffer stock hypothesis, in which large livestock, such as zebu, are kept in reserve as a form of insurance to be sold off in times of hardship. This has been documented elsewhere in Madagascar (Hänke & Barkmann, 2017), as well as in other countries in SSA (e.g. Karanja Ng'ang'a et al., 2016; Miura et al., 2012).

Production constraints and the "scattershot approach"

Despite having diversified farming systems, Manombo area farmers still rely on WPFs to meet their food needs. Furthermore, while much of the literature indicates that diversified farming systems (i.e. cultivating a large variety of crops and/or raising multiple livestock types) is associated with food security (e.g. Adjimoti & Kwadzo, 2018; Silvestri et al., 2015) and greater dietary diversity / improved nutritional status (e.g. Jones et al., 2014; Luna-González & Sørensen, 2018; Makate et al., 2016; Nkonde et al., 2021; Sibhatu & Qaim, 2018), we find that crop diversity does not necessarily equate to better FSN outcomes, as the results of the second model show increasing on-farm crop diversity to be associated with increased likelihood of WPF consumption. As consumption of certain WPFs can be considered an indicator of food insecurity (Ocho et al., 2012), this finding adds nuance to the crop diversification conversation and highlights the complexity of the food environment due to seasonality (see Supplementary Materials for a seasonal crop calendar).

While our analysis did not capture data on all of the underlying causes limiting local crop production, existing research documents three main reasons: low yields, small farm sizes and distant plots. Indeed, there exists a substantial "yield gap"[11] across all of Madagascar (e.g. Tucker et al., 2010). One of the reasons for this agricultural underperformance has been attributed to farm size. Herrera et al. (2021) report that over half of respondents in northeastern Madagascar ascribed their experiences of food insecurity to the limited size of their agricultural plots. Small farm size has also been found to have a significant negative effect on food security in other contexts as well (e.g. Ethiopia, Bogale & Shimelis, 2009). Alpízar et al. (2020) found that smallholders in Central America farming on "microplots," many small plots spaced apart, faced more food insecurity than farmers with one larger plot. In Madagascar, as land is traditionally passed down from parents to children, smaller and smaller parcels are typically carved out in the process (Laney & Turner, 2015), and as we have demonstrated in our case study of Manombo, often involve substantial amounts of time to reach by foot.

In addition to the constraints of "microplots," lack of productive land and appropriate technologies (e.g. climate-adapted seeds, organic fertilizers, grain storage), climatic conditions (e.g. moisture-stress; Waha et al., 2018), frequent natural hazards, such as cyclones (Harvey et al., 2014), fear of crop and livestock theft, and virtually no

[11] Arouna et al. (2021) found the average rice yield per hectare in irrigated lowland systems in Madagascar to be 2.5 tons per hectare compared to an average of 4.1 tons per hectare across 12 other countries in SSA.

agricultural extension services all contribute to low yields. Limited access to – or embeddedness in – local and national markets also affects food shortage responses (Minnis, 2021). For example, in their study of smallholder farmers in Malawi, Koppmair et al. (2016) suggest that access to markets and inputs to increase productivity may be more important to dietary diversity than growing a diverse array of crops.

Considering our finding that larger households were significantly more likely to consume WPFs, constraints in the Manombo area may be "forcing" farmers, to grow a greater diversity of crops for food (harvest) security; yet they are unable to produce enough to meet their needs and must "resort" to wild harvesting, even when the food (e.g. *via*) is undesirable. Thus, rather than focus their limited resources (e.g. land, labor) on cultivating crops alone, Manombo area farmers engage in what we refer to as a "scattershot approach," casting a wide net in terms of their food procurement options as a food insecurity coping mechanism under extremely risky conditions (Harvey et al., 2014). This scattershot approach is further evidenced by the average number of coping strategies employed (3.43), which is greater than has been reported elsewhere (e.g. average of 1.7 food insecurity coping strategies used after extreme weather events in Guatemala and Honduras; Alpízar et al., 2020). Therefore, where resources are extremely limited, traditional mixed farmer-forager approaches may be the best option, as foraging is more opportunistic (e.g. farmers can forage on their way to and from their fields) and often requires less time investment than farming. In their study among farming and foraging groups in southwestern Madagascar, Tucker et al. (2010) conclude that "more is not always better" (p.384) and that farming is a riskier activity than foraging due to the uncertainty of agricultural harvests.

They point out that, while agricultural harvests are limited to a certain number of days per year, one can hypothetically get up to 365 “harvest days” per year by foraging.

Contrary to adopting a scattershot approach, others have found that, in Madagascar, focusing more intensively on a smaller number of crops led to better food insecurity outcomes, particularly when those crops were sold. For example, Herrera et al. (2021) found that among smallholder farmers in northeastern Madagascar, half of their study population grew just two of the top crops (rice and vanilla) and that the probability of household food insecurity was lower when both of these crops had high yields. However, it is important to note that, as their study area is the leading region of vanilla production in Madagascar with a well-established international export market, these findings are not applicable to all parts of the country. It could also indicate that food security in this region is “market exposed” and subject to the vagaries of the global market. Indeed, there have been anecdotal reports of farmers in the northeast pulling up their vanilla vines to plant rice when the price of vanilla plummeted. Thus, as we have seen in our study of Manombo area farmers, increased crop diversity is not always protective from an FSN standpoint, though relying on too few crops may also be precarious.

Limitations to our study

There are several limitations to this study based on time constraints and other logistical considerations. As has been noted in other studies (e.g. Alpízar, 2020), the reporting of food insecurity experience can be subjective. However, the method used has been widely validated as a tool suitable for rapid assessment. Furthermore, we understand that a single 24-hour dietary recall provides only a snapshot into an individual’s dietary diversity and that recalls repeatedly collected over many months or seasons would provide a fuller understanding of variations in the diet (see Keding et al. 2012). In addition, no visual aids were used to assist respondents/enumerators, which might have alleviated any potential memory-related difficulties with recall. However, we feel confident that our results represent an accurate summary of dietary diversity for the study population during this time of year.

As Stone and Campbell (1984) lay out in their seminal work, there are always possibilities for misinterpreting the meaning of questions and responses in cross-cultural research, especially when using a survey developed by a Western researcher in one language (English) translated into another (Malagasy). We remain reflective about our translations (Helmich et al., 2017) and have attempted to reduce error by working closely with bilingual team members (two of the co-authors are fluent in both Malagasy and English) who are particularly familiar with the culture and context, and by employing Malagasy enumerators to conduct the survey. Furthermore, we recognize the role that social desirability bias may play in shaping some responses (e.g. not reporting certain behaviors, such as bushmeat consumption or collecting WPFs from within the PA). Lastly, while we did gather detailed information on land dedicated to paddy rice, our general assessment of diversified farm systems was limited to the number of different crops grown. A more robust understanding of the system would be gained through additional data on the extent to which each crop is cultivated (e.g. number of *carreaux* of cassava, avocado trees, or vanilla vines, etc.) and annual production/harvest amounts for all crops. Future data collection will more completely capture the underlying factors contributing to low yields, such as land size.

1.5 Conclusions

This paper provides additional evidence of the reliance on WPFs during periods of food shortage for certain forest-edge farming and fishing communities, and is the first to document the consumption of both nutritious (*tavolo*) and anti-nutritious (*via*) WPFs and the challenges experienced obtaining these foods – including inability to access certain WPFs from within protected areas (PAs) – in Madagascar. These results have policy implications for improving food security in Madagascar as well as in other countries where smallholders mix foraging with farming to meet their food security and nutritional (FSN) needs. Most notably, wild foods should be more fully integrated into FSN policies, such that agriculture is no longer the sole food procurement strategy considered, and WPFs are not denigrated as the "weeds of agriculture" (Grivetti & Ogle, 2000), but recognized for their important role in indigenous foodways (e.g. Barreau Daly, 2014; Huambachano, 2019). While much more research is needed to better understand the nutrient profile and preparation requirements of these often neglected plant foods, the Brazilian national *Plants for the Future* program is a successful example of how the creation of a nutritional composition database of native edible plants can be used to inform policies aimed at improving FSN while protecting biodiversity (Beltrame & Hunter, 2015).

However, as we have documented with *via*, not all WPFs are healthy to eat. Some may even be deadly, as is the recent case of five deaths attributed to consumption of toxic *veoveo* (*Dioscorea sansibarensis*) in the Manakara area of southeastern Madagascar after back-to-back cyclones decimated area food crops. Therefore, consumption of WPFs with deleterious health effects can be used to rapidly identify at-risk households and target interventions. Additionally, education campaigns informing communities about the dangers of consuming certain WPFs without proper preparation should be launched.

Furthermore, rather than adding new (and exotic) crops to a farmer's portfolio for better FSN outcomes, programs should support agriculturalists in increasing the yield potential of crops that they are already cultivating (Koppmair et al., 2016). This will, on the one hand, help diminish the need to eat foods that are harmful to human health, and on the other, prevent ecological damage like that described by Cheban et al. (2009) resulting from excavation of wild *Dioscorea* spp. We also recommend that programs promote cultivation of micronutrient-dense indigenous vegetables (Conti et al., 2021a), rather than more recently introduced vegetables (carrots, cabbage, etc.) that may not be adapted to local growing conditions or be culturally suitable. For example, nonprofit organizations in Madagascar are assisting in the cultivation of indigenous yams such as *bodoa* (*Dioscorea* sp.) which are good sources of fiber, potassium and other micronutrients (Jeannoda et al., 2010).

Other strategies to improve community FSN include national food policies supporting school-based food and nutrition programs sourcing local foods, which have been shown to improve FSN status of youth, while also providing support to farmers and increasing comprehension on components of nutritious diets. Successful examples of incorporating indigenous plants and local produce into school lunch programs include the Biodiversity for Food and Nutrition Project in Kenya (Hunter et al., 2017) and the Home-

Grown School Feeding model developed in Ethiopia and expanding to neighboring countries in SSA (Wineman et al., 2022). Furthermore, access to veterinary medicine has been associated with reduced odds of food insecurity (Niles & Salerno, 2018). This coupled with improved animal husbandry techniques can ameliorate FSN outcomes by increasing animal protein (meat and eggs) availability from healthier livestock, as well as augment an important source of household income. In Madagascar, projects are actively working to introduce nutrient-rich insects, already traditionally consumed, into more diets (e.g. Borgerson et al., 2021).

Towards both biodiversity conservation and food security outcomes

Not only is continued access to natural resources (including fisheries) important for FSN outcomes and preservation of indigenous foodways and food agency, but conservation efforts must work to ensure that WPF biodiversity is protected and that WPF harvesting is sustainable. This may be achieved by supporting the development and enforcement of community-designed, self-governed rules and regulations regarding the management of common-pool resources (Ostrom, 1990), as seen with *via*. Indeed, a substantial body of evidence indicates that community involvement in conservation projects has greater potential for achieving “win-win” outcomes for both biodiversity conservation and food security (e.g. Naidoo et al., 2019; Nielsen, et al., 2018; Oldekop et al., 2016).

Future research directions include looking more granularly at how various types of cultivated crops (e.g. seasonal, perennial, cash crops) contribute to food security and dietary diversity. In addition, as Lachat et al. (2018) describe, using dietary recall to document dietary species richness, a count of the number of different species consumed, would complement our understanding of the contribution of WPF biodiversity in diets among rural populations living near PAs, and their potential for semi-domesticated use. For example, Madagascar is thought to have more than 30 endemic species of wild yam (Columbus, 2017), with new ones still being described that are already threatened or endangered due to overharvesting and habitat degradation (Wilkin et al., 2008; 2009). In an age in which much of the world's agrobiodiversity has already been lost, this salvaged knowledge would equip conservation efforts with a deeper understanding of the array of nutritious wild plant species that rural populations are consuming, providing additional direction on which genetic resources are important to preserve for now and the future (Cantwell-Jones et al., 2022). Lastly, as there appears to be a general decline in the abundance of wild, indigenous plant foods in Madagascar (Rasoanaivo, 1990), as well as worldwide (FAO, 2019), documenting traditional ecological knowledge of WPFs is more crucial than ever.

1.6 References

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CHAPTER 2: GENDERED IMPLICATION FOR CLIMATE CHANGE ADAPTATION AMONG FARMERS IN MADAGASCAR

Ny toetr'andro tsy misy takon'omby.
(The weather has no zebu master)
- Malagasy proverb

2.1 Introduction

Across the world, farmers are being negatively impacted by changing climatic conditions (Karki et al., 2020a). This is especially true for the nearly 600 million smallholder farmers who rely on family labor for their food and livelihoods (Cornish, 1998; Lowder et al., 2016), many of whom depend on rain-fed agriculture (Fierros-González & López-Feldman, 2021). Thus, adaptation to climate change, defined as actions taken "to prepare for and adjust to both the current and projected impacts of climate change" (EPA, 2022), has emerged as an important strategy to mitigate its harmful impacts (Bedeke, 2023). While research on the topic is growing, more studies are needed in regions most vulnerable to climate change (van Valkengoed & Steg, 2019).

Traditional adaptation measures among smallholders include changing crop types/varieties (Karki et al., 2020b), altering planting timing (Ali & Erenstein, 2017; Shikuku et al., 2017; Simelton et al., 2013), and implementing rainwater harvesting techniques (Gandure et al., 2013). However, farmers face many adaptation constraints, defined by Klein et al. (2014) as "a factor or process that makes adaptation planning and implementation more difficult'' (p. 906). The implications of inaction are potentially devastating, as they can lead to increased food insecurity, disrupted livelihoods, and heightened poverty, particularly among women (FAO, n.d.). Consequently, researchers aim to understand the reasons for the persistent climate change adaptation deficit.

Barriers to climate change adaptation include poverty (Deressa et al., 2008; Etana et al., 2020), food insecurity (Carranza & Niles, 2019; Shikuku et al., 2017), farmer health (Hogan et al., 2011), access to credit, markets, and information (Deressa et al. 2008; Ringler, 2010), institutional barriers (Rodríguez-Cruz et al., 2021), as well as cultural factors (Adger et al., 2013; Karki et al., 2020a), such as attachment to traditional customs. Gender also influences climate change adaptation outcomes (Bessah et al, 2021; Carranza & Niles, 2019; Macgregor, 2010; Ravera et al., 2016), as female farmers face specific obstacles due to unequal access to resources, such as land, credit, and extension services (FAO, 2011). There are also gendered differences in the use of assistance to cope with climate change, and which adaptation strategies and types of support are preferred (Assan et al., 2018; Codjoe et al., 2012). Given the multitude of gender differentiated impacts of climate change (Codjoe et al., 2012; FAO, n.d.), more research is urgently needed to understand the elements that support climate change adaptation among women smallholders (Harvey et al., 2018).

Farmer recognition of climate change as a precursor to adaptation

Agricultural adaptation to climate change has been described as a two-step process: recognizing that changes are occurring (Adger et al., 2009) and/or having a personal experience with extreme weather events (Dessai et al., 2004; Li et al., 2017); followed by taking action to implement adaptation measures (de Matos Carlos et al., 2020;

Deressa et al., 2008). Therefore, a farmer’s recognition of climate change, defined as changes in weather over time (IPCC, 2007), is an important precursor to adaptation (e.g., Fierros-González & López-Feldman, 2021; Makuvaro et al., 2018; Simelton et al., 2013). However, societal gender norms often assign women to more “climate-sensitive” activities such as food, fuel and water provisioning, which may result in differential perceptions of climate change between women and men (Codjoe et al., 2012; Hitayezu et al., 2017).

Furthermore, in the absence of weather information services, farmers often rely on personal observations of temperature and precipitation patterns (Salerno et al., 2019). Studies in Global North and South contexts have examined farmers’ recognition of climate change to understand accuracy and its role in decision-making. There is ample evidence that farmers, especially those without irrigation, are acutely and accurately aware of changes (e.g., Fierros-González & López-Feldman, 2021; Nguyen et al., 2021; Roco et al., 2015). For example, Soubry et al. (2020) found that 87% of Global South papers reported farmers’ perceptions of climate change aligning with historical climate records.

Social connectedness and access to information

It is widely recognized that access to information, such as through advisory services and group membership (e.g., farmers’ associations), supports farmers’ decisions regarding adopting agricultural practices (Ali & Erenstein, 2017; Dang et al., 2019; Nguyen et al., 2021), and can shape climate change adaptation outcomes. For example, training support, what Kashem (1987) calls “[farmer] contacts with information sources” (p.128), can be an important predictor of farmer adoption of agricultural innovations (e.g., Genius et al., 2014; Meijer et al., 2015). As Ricker-Gilbert et al. (2008) found among farmers learning integrated pest management (IPM) techniques in Bangladesh, visits from extension agents and farmer field schools were instrumental to farmer adoption of IPM.

Furthermore, social networks, such as farmer cooperatives, which allow farmers to interact and develop trusted relationships, are recognized as vital for supporting farmers' capacity to adapt to climate change (Harvey et al., 2018; Hogan et al., 2011; Lubell et al., 2014; Niles & Hammond Wagner, 2019). However, female farmers generally have less access to information and agricultural extension services, as well as lower participation in associations (Jost et al., 2016; Roncoli, 2006). Enhancing social connectedness can be a valuable strategy to promote adaptation. Indeed, Kafeety et al. (2020) recommend interventions "rooted in social connection" be used to support behavioral adaptation to extreme heat events.

Farmers' perceptions of climate-related risk and adaptive capacity

Studies have also shown that both perceived adaptive capacity, defined as the "extent to which [actors] feel prepared to endure changes and take necessary steps to cope with them" (Seara et al. 2016), and objective forms of adaptive capacity, such as access to various assets or capital, play crucial roles in agriculture adaptation (Gardezi & Arbuckle, 2019; Shah et al., 2019; Singh et al., 2016). Smallholders, particularly in remote agrarian settings, often have very limited adaptive capacity (Adger et al., 2003; Klein & Nicolls, 1999). However, until fairly recently, most research primarily focused on resource limitations and overlooked the cognitive dimensions of climate change adaptation (Grothmann & Patt, 2005).

Furthermore, while there is a growing body of research looking at farmers' perceptions of climate-related risk in the Global North (e.g., Arbuckle et al., 2013; Schattman et al., 2016; Takahashi et al., 2016), less work has examined the role of perceived threat from climate change in the Global South. For example, in a systematic review on farmer decision-making related to climate change in the Global South from 2007-2017 (Waldman et al., 2020a), the authors find just 11.5% (n=17) of papers used cognitive approaches to examine adaptation behavior, indicating a clear need for more research among rural agrarian communities in low-income countries.

Therefore, the objective of this study is to fill this gap by applying the Protection Motivation Theory (PMT), a theoretical framework that combines assessment of both threat and adaptive capacity, to better understand climate change adaptation decision-making among male and female smallholder farmers in an extremely vulnerable context. Specifically, after establishing that farmers are experiencing changes in climate, we examine the direct role that threat and adaptive capacity play in forming intentions to adapt agricultural practices (Figure 2-1). We also examine how climate change perception, social connectedness and prior adaptation of agricultural practices predict intention to adapt practices in the future, as well as how the predictive power of social connectedness is moderated by gender.

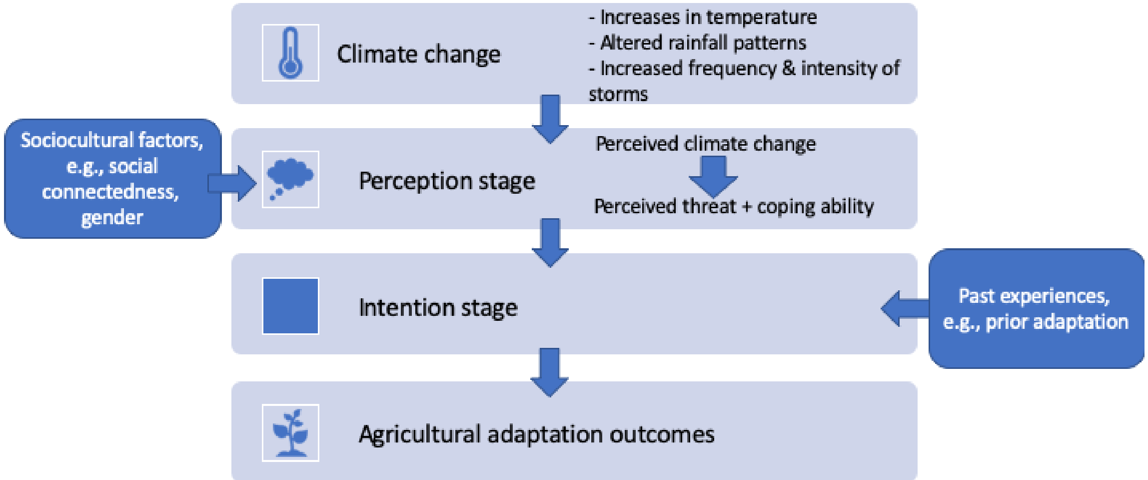

Figure 2-1. Conceptual framework for study.

Theoretical framework

Protection Motivation Theory (PMT; Rogers, 1983, 1975) attempts to explain the psychological processes behind behavior change in response to perceived threats. Originally applied to health-related self-protection behavior (Floyd et al., 2000; Milne et al., 2000), PMT has been used in the context of natural hazards such as floods, wildfires, and earthquakes (e.g., Babcicky & Seebauer, 2019; Bamberg et al., 2017; Grothmann & Reusswig, 2006; Westcott et al., 2017), and pro-environmental behavior (e.g., Bockarjova & Steg, 2014; Chen et al., 2020; Cismaru et al., 2011; Tapsuwan & Rongrongmuang, 2015) and human migration decisions (Mallick et al., 2022), in response to climate change. PMT is increasingly used in research on farmer adaptation to climate change in both the Global North (Buelow & Cradock-Henry, 2018) and South (e.g., Bagagnan, 2019; Dang et al., 2014; Feng et al., 2017; Grothmann & Patt, 2005; Luu et al., 2019; Nguyen et al., 2021; Truelove et al., 2015), and researchers have found PMT suitable for understanding factors motivating climate change adaptation behavior (van Valkengoed & Steg, 2019). In the past decade, quantitative studies on smallholder farmer decision-making processes incorporating a psychological approach have utilized PMT, or its variations, as a theoretical framework (Waldman et al., 2020).

PMT consists of two main constructs - *threat appraisal* and *coping appraisal* – that predict intentions and subsequent protective actions (Figure 2-2). Threat appraisal encompasses perceived risk (e.g., from climate change) and fear of the impacts, while coping appraisal is comprised of response efficacy, the belief that methods available are effective in protecting against the threat, and perceived self-efficacy (or adaptive capacity), the belief that one is capable of taking the actions necessary to reduce the threat (Plotnikoff & Trinh, 2010). Ordered PMT (Tanner et al., 1991) extends PMT by assuming a sequential relationship between threat appraisal, fear reaction, and coping appraisal. This leads to intention setting and protective responses based on levels of perceived threat and coping ability. While the literature often focuses on factors leading to intention-setting, PMT can also address the three stages of adaptation: perception, intention, and adaptation (Abid et al., 2019) .

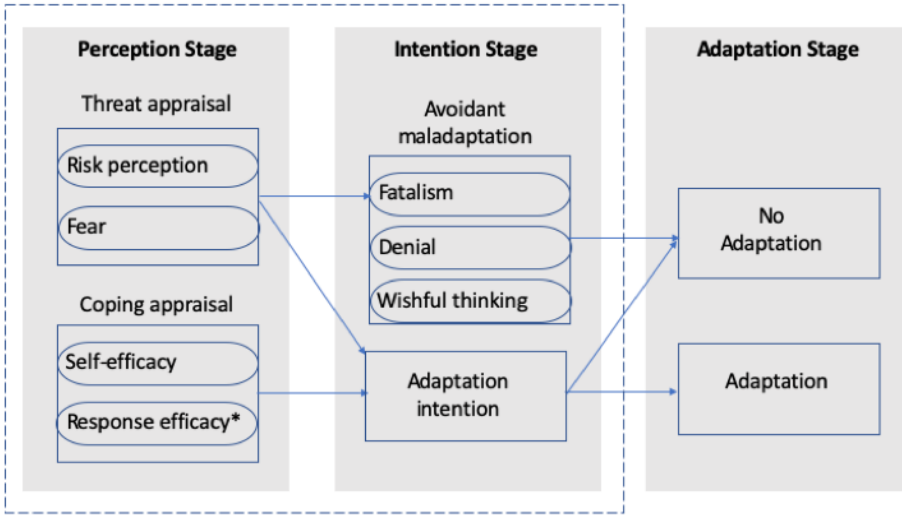

Figure 2-2. Theoretical framework using PMT applied to climate change adaptation, after Rogers (1983) and adapted from Abid et al. (2019), Babcicky & Seebauer (2019), and Grothmann & Patt (2005).

Note. Perception and intention stages (dotted outline) included in this study. *= not included in this *study*

The components of PMT have been found to support farmer decision-making in response to climate change (van Valkengoed & Steg, 2019). When farmers perceive climate change to be a threat (high threat appraisal) and have confidence in their coping abilities (high coping appraisal), they are more likely to intend to adapt their agricultural practices. However, while some studies find that higher levels of concern about changing conditions among farmers correspond to farmer adaptation (e.g., Luu et al., 2019; Woods et al., 2017), others maintain that if perceived threat is not met with sufficiently high coping appraisal, protection motivation may not occur (Babcicky & Seebauer, 2019).

Indeed, while there is debate in the climate change communication literature (e.g., Tannenbaum et al., 2015), research shows that threat-oriented fear appeals (e.g., Tunner et al., 1989), as well as fear-based messaging around climate change, are largely ineffective at influencing attitudes (e.g., Armbruster et al., 2022; Spence & Pidgeon, 2010; Stern, 2012). Furthermore, scholars applying PMT have described how fear reaches a plateau, becoming less effective at motivating behavior change (Westcott et al., 2017). There is also evidence that fear triggers protective motivation in acute emergencies (e.g., evacuations), but is less effective for crises with slower onsets (Babcicky & Seebauer, 2019). Thus, while PMT suggests that coping appraisal is a positive predictor of protective responses (Milne et al., 2000), threat appraisal (and induced fear) may lead to avoidant maladaptation stemming from fatalism,[17] denial, or wishful thinking (Babcicky & Seebauer, 2019; Grothmann & Patt, 2005).

Madagascar context

Madagascar, the world's poorest non-conflict country (USAID, 2022), has approximately 80% of its population relying on smallholder agriculture as their primary livelihood (World Bank, 2018; Rakotobe et al., 2016). However, the government provides minimal support,[18] and much of the island experiences high rates of food insecurity (Harvey et al., 2014). As climate change reduces rice production (Nematchoua et al., 2018), the main staple food of Madagascar, and increases disease and pest risks for crops like cassava (Niang et al., 2014), these rates will worsen. Additionally, with rising sea levels, warming waters, and air temperatures predicted to increase by more than 2.5 - 3 degrees Celsius in some parts of the island over the next ten years (Nematchoua et al., 2018; Tadross et al., 2008), as well as limited governance capacity to tackle these issues (Weiskopf et al., 2021), Madagascar is highly vulnerable to climate change (Harvey et al., 2014). The country is also extremely prone to tropical cyclones, which are becoming more frequent and intense as a result of climate change (Tadross et al., 2008; Weiskopf et al., 2021). In particular, this study focuses on southeastern Madagascar, characterized by food insecurity and high cyclone risk (Randrianarison et al., 2020).

Within this context of extreme vulnerability, this paper tests the suitability of the Protection Motivation Theory (PMT) as a framework to examine farmers' intention to adapt agricultural practices in response to climate change. Using a theory-informed latent variable path model, or structural equation model (SEM), the study explores the effects of cognitive processes (threat appraisal and coping appraisal) on farmer intention. No prior studies have attempted to identify how social connectedness, climate change perceptions, and gender link with threat and coping appraisal to predict climate adaptation behavior decisions from a PMT perspective among a population of highly vulnerable smallholder farmers in Madagascar / the Western Indian Ocean region. While this work focuses on the Madagascar context, the findings have broader implications for island nations and other countries with large numbers of farmers reliant on rainfed agriculture and/or increased vulnerability to cyclones due to climate change (e.g., Puerto Rico, Mozambique).

This research is guided by the following hypotheses (H), with proposed pathways for H1-H6 shown in Figure 2-3:

H1: Higher climate change perception is significantly associated with higher *a*) threat and *b*) coping appraisal.

H2: Greater social connectedness is significantly associated with *a*) reduced threat and *b*) higher coping appraisal.

H3: Greater social connectedness is significantly associated with stronger intention to adapt practices in response to observed changes in temperature and/or rainfall.

H4: Past adaptation of farming practices in response to observed changes in temperature and/or rainfall is significantly associated with greater future intention to adapt agricultural practices.

H5: High threat appraisal is significantly associated with reduced intention to adapt practices.

H6: High coping appraisal is significantly associated with greater intention to adapt practices.

H7: Gender moderates the relationship between social connectedness and PMT constructs (threat appraisal and coping appraisal), and therefore, intention to adapt practices.

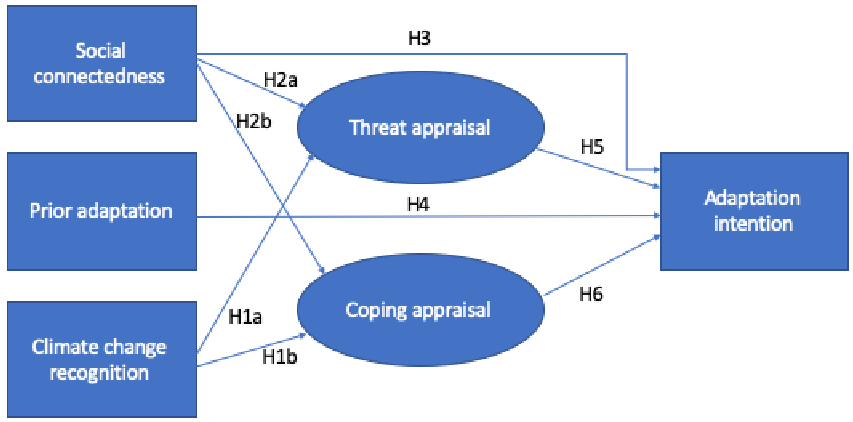

Figure 2-3. Model proposal with hypothetical pathways.

2.2 Methods

Study site

The sample frame for the study was approximately 750 households in 15 villages surrounding the Manombo Special Reserve protected area on the southeastern coast of Madagascar (Figure 2-4). Villages were selected from the target population of our partner NGO, Health in Harmony (HIH), considering security concerns due to heightened bandit attacks linked to ongoing drought conditions. Farmers in this region primarily practice small-scale rainfed polyculture, focusing on subsistence farming with rice and cassava as staple crops (Moore et al., 2022). Both men and women have central and "complementary" roles (Dahl, 1999, p.97) in agricultural production, though roles are often somewhat differentiated. The region faces high levels of poverty and food insecurity (Randrianarison et al., 2020), and is highly cyclone-prone. Limited market access and agricultural extension services, which tend to be male-dominated, further challenge farmers due to the area's remoteness.

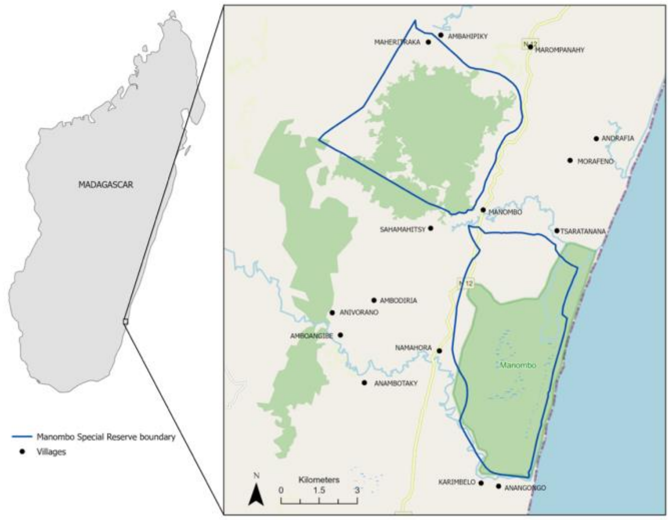

Figure 2-4. Map of Manombo area.

Data collection

A cross-sectional study of 328 small-scale rice farmers (64.3% female; 35.7% male) over the age of 18, each representing a separate household, was conducted in February 2021 by a team of five native Malagasy-speaking enumerators. Respondents included both participants in a rice-growing training given by HIH (60% of participants were female), as well as randomly selected non-training participants from separate households in the same villages to reduce self-selection bias (for more details see [authors]). Probability proportional to size (PPS) sampling (Skinner, 2014) was used, and a "within-household respondent selection procedure" was implemented to reduce gender bias. The questionnaire covered topics such as 1) perceived changes in temperature and rainfall in the last five years, 2) perceived threat and coping capacity in response to climate change, and 3) intended and actual changes to agricultural practices, and socio-demographic information. Data was gender disaggregated.[19] Paper survey responses were entered into Qualtrics, then analyzed using IBM SPSS Statistics (version 28) and MPlus Diagrammer (version 1.8). Informed consent was obtained from all respondents, and the study received exemption from the University of Vermont's Institutional Review Board (IRB; study #00001290).

Structural Equation Analysis

Structural Equation Modelling (SEM, Jöreskog, 1978; Bentler, 1980) is a statistical technique that combines factor and regression analysis to allow for more complex path models. It is useful in testing the relationships between the components of PMT (Babcicky & Seebauer, 2019). SEM consists of measurement and structural models; and incorporates both latent and observed variables.

Factor Analysis

To identify the measurement model, exploratory and confirmatory factor analyses were conducted to determine the latent constructs, or variables (LVs), for threat and coping appraisal. Supplemental Table 1 shows the results of the exploratory factor analysis[20] (EFA) conducted using maximum likelihood (ML) estimation in SPSS 28.0. Following the eigenvalues-greater-than-one rule (Kaiser, 1960), two factors were extracted explaining

62.1% of the total variance. Three items reported on a 4-point Likert scale loaded onto a single factor (threat appraisal construct), with standardized factor loadings ranging from 0.40 to 0.90. Two items regarding perceived ability to cope with future cyclones were used as a proxy for perceived ability to cope with changes in temperature and/or rainfall (aka climate change) and reported on a 5-point Likert scale loaded onto another factor (coping appraisal construct), with factor loadings from 0.62 to 0.65. Cyclones are a relevant and appropriate measure of perceived coping ability among this population, as they are highly visible. Factor loadings under 0.4, the generally agreed upon cut-off value (Costello & Osborne, 2005), were suppressed. One item, measured by the statement "Farmers like me are likely to be affected by climate change," did not load onto either factor. While there is debate on the use of Cronbach's alpha in the literature (e.g., Tan, 2009), we found alpha coefficients for the two latent constructs to be greater than 0.5, which can be considered acceptable reliability (Taber, 2018).

Following EFA, classical test theory (Jarvis et al., 2003), consisting of confirmatory factor analysis (CFA) and reliability testing, was used to validate the facture structure obtained from EFA. For the confirmatory factor model, we fitted a two-factor logit model using ML estimation with robust standard errors in Mplus Diagrammer version 1.8 (Supplemental Figure 1). All items had satisfactory standardized factor loadings of at least 0.5 and were significant. Given the distribution of the variables, ordinal variables were treated as categorical and model fit indices were given as AIC/BIC (2623.48/2710.72).

To test for reliability of the constructs in the measurement model, composite reliability (CR), considered more appropriate than Cronbach's alpha for SEM-based studies (Cheung et al., 2023), was calculated. CR was 0.84 (threat appraisal) and 0.69 (coping appraisal). According to Hair (2009), CR > 0.7 indicates good reliability. To test for convergent and discriminant validity (Campbell & Fiske, 1959), the Average Variance Extracted (AVE) and Discriminant values (DV) were determined. AVE for both constructs was above 0.5 (Fornell & Larcker, 1981): 0.64 for threat appraisal and 0.54 for coping appraisal. DV was 0.80 (threat appraisal) and 0.74 (coping appraisal). Both DVs were greater than the correlation (0.34) between the two LVs. Thus, the measurement model was found to be acceptable.

Structural Modeling

As the dataset contained missing data unrelated to the response values, full information maximum likelihood (FIML) was used, which treats missing data under the MAR (missing at random) assumption (Cham et al., 2017), to estimate the overall SEM with standardized latent factors. The best-fit model was selected by comparing neighborhood models and using Akaike information criterion (AIC), used to compare non-nested models with categorical variables (Akaike, 1987). Percentage of explained variance in the outcome variables is presented in Supplemental Table 2.

In addition, multi-group latent class analysis and ML estimation with robust standard errors were used to test the effects of gender as a binary moderator variable on the direct and indirect relationships between the exogenous variables, the two mediating variables (threat and coping appraisal) and the outcome variable.

Operationalization of constructs

A description of variables included in the model, their measurements and category of data are provided in Table 2-1. Three exogenous variables (climate change recognition, social connectedness, and prior adaptation to observed changes in temperature and/or rainfall) were selected based on the relevant literature and other survey instruments, such as the Climate Change, Agriculture and Food Security (CCAFS) 2010-2012 Household Baseline Survey (CCAFS, 2015) and that used by Rodríguez-Cruz and Niles (2021). Climate change recognition was measured by asking respondents about their observations of changes in temperature and/or rainfall in the last five years, as this timescale has been previously used to measure perceptions in climate change among smallholders in developing countries (e.g., CCAFS). Social capital has been documented as impacting farmer agricultural decision outcomes. To measure, a social connectedness variable was calculated by totaling the number of social connections via group membership and various forms of agriculture-related social interactions that a respondent had (e.g., belonging to a farmer's cooperative, participating in a farmer training program, having helped a farmer on their farm in the last year, having been visited by an extension agent or NGO worker, etc.; for a full list see Appendix 1). Frequency of social interaction by type was also calculated by asking respondents about who they spoke to regarding agriculture, and how often. The covariate, prior adaptation, which has been shown to influence farmers' future adaptation decisions (e.g., Etana et al. 2020), was included in the model as a control variable, and measured by reported implementation of agriculture adaptation practices based on observed changes in temperature and/or rainfall in the last five years, which has also been used frequently (e.g., CCAFS).

Table 2-1. Variable descriptions and measurements

Variable	**Description/question/statement**	**Measurement scale**	**Categorization of data**
Exogenous variables			
Climate change perception	Observations of changes in rainfall and/or temperature in the last five years	1=Recognized changes; 0=Did not recognize changes	Binary
Social connectedness	Total number of social connections/interactions that a respondent reported having (for a full list see Appendix 1)	Count (0-15)	Continuous
Prior adaptation	Previous adaptation to farming practices in response to changes in rainfall and/or temperature in the last five years	1=Yes; 0=No	Binary
Indicators of latent mediator variables			
<u>Threat appraisal</u>			
Perceived severity (risk) of climate change to food security	How much risk, if any, do you feel climate changes pose to your food security?	1=No risk 2=Low risk 3=Medium risk 4=High risk	Ordinal
Perceived severity (risk) of climate change to income/livelihood	How much risk, if any, do you feel climate changes pose to your income/livelihood?		
Worry/fear about changes in climate	How worried are you, if at all, about changes in climate?	1=Not worried 2=Slightly worried 3=Worried 4=Very worried	Ordinal
<u>Coping appraisal</u>			
Motivation/willingness to change	"I feel motivated to change my agricultural practices to prepare for future cyclones."	1=Strongly disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly agree	Ordinal
Perceived adaptive capacity	"I feel that I do have the capacity to change my agricultural		

	practices to prepare for future cyclones."		
Outcome variable			
Intention to adapt	Composite variable based on responses to Likert-scale questions investigating three agricultural adaptation behaviors	Integer scale ranging from 1 – 5, with 14 numerical outcomes	Continuous

The outcome variable in the models was intention to adopt climate change adaptation practices (protective response). A composite variable was created based on responses to Likert-scale questions investigating three specific agricultural adaptation behaviors (*i.* change timing of planting, *ii.* change types of crops planted, and *iii.* change the variety of crops currently cultivated) to the question "How likely are you to do any of the following in the next five years in response to changes in climate?" Cronbach's α (0.692) was used to test for internal consistency of the scale. Polychoric correlation was used to see the relationship between the variables; all were significantly and positively correlated. The average of the three intended strategies[21] was then used to create the new variable.

Social Connectedness Analysis

A nuanced analysis of the relationship between social connectedness and perceived threat to climate change was also conducted. Social connectedness levels (below average, average, above average) were determined based on the mean and one standard deviation. A Pearson Chi-Square test examined the effect of gender on social connectedness levels, and an Independent Samples t-test compared average social connectedness between male and female farmers. The frequency of farmer interactions by social connectedness type (e.g., government and NGO workers, other farmers) was also assessed, and Chi-Square tests examined gender differences.

2.3 Results

Demographics: Most respondents came from households with very low levels of education and assets. The highest level of education per household was 3.7 years (*SD* 3.07) on average. The mean number of household assets, on a scale from 0 to 30, was 4.8 assets (*SD* 2.86). Eighty percent (n=262) of households were male headed, with an average size of 6.2 people (*SD* 2.64).

Perceptions of climate change and attributions: As expected among a population of farmers predominantly reliant on rainfed agriculture, respondents were highly aware of climate changes (Figure 2-5a). Many (68.3%, n=224) reported that temperatures were getting hotter in the last five years. Similarly, 90.9% (n=289) of respondents noticed changes in rainfall, with the most common response being that rains come later (38.1%, n=122). Some respondents (24.4%, n=78) mentioned rains come earlier, while 19.7% (n=63) found the timing of rains to be less predictable. One farmer expressed frustration with changing rainfall patterns, stating that "[rain] does not come when it is needed, it comes when we do not need it."

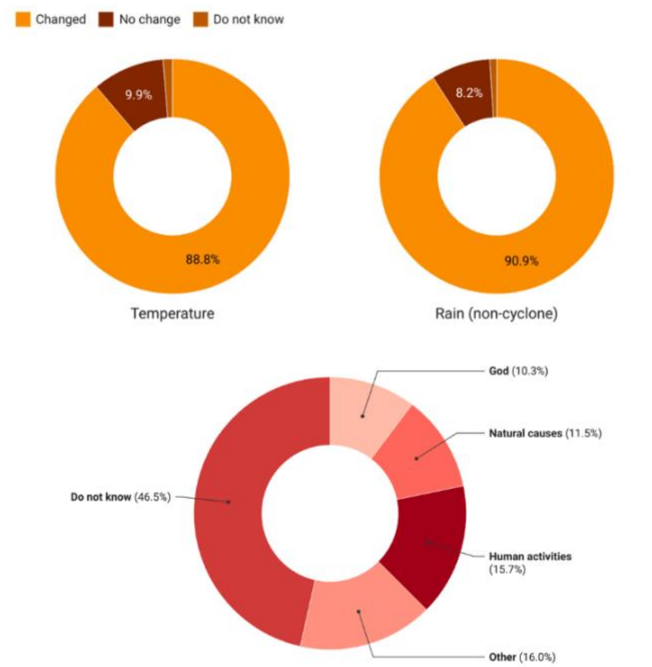

Figure 2-5. Climate perceptions: a) observation of changes in temperature and rainfall over the last 5 years, b) attribution of changes observed.

A chi-square test of independence was performed to evaluate the relationship between gender and climate change recognition. There was no significant difference in perception of changes in temperature (X^2 = 0.28, 1, p = .596) or rainfall (X^2 = 0.22, 1, p = .643) between men and women (

Table 2-2).

Table 2-2. Overall and gender-disaggregated mean statistics and standard deviations for climate change recognition, social connectedness, prior adaptation, threat and coping appraisal variables, and intention to adapt agricultural practices.

		Overall (n=328)		Male (n=117)		Female (n=211)		
Variable	Description	Mean	SD	Mean	SD	Mean	SD	Test statistic
Climate change perception	Observed changes in temperature	0.90	0.30	0.89	0.32	0.91	0.29	0.28[a] (n.s.)
	Observed changes in rainfall	0.92	0.28	0.93	0.26	0.91	0.28	0.22[a] (n.s.)
Social connectedness	Total number of social connections/ interactions	2.99	1.42	3.38	1.58	2.78	1.27	3.81[b] ***
Prior adaptation	Made changes in agricultural practices in the last five years.	0.15	0.36	0.19	0.39	.13	.34	1.45[a] (n.s.)
Threat appraisal	Worried about changes in climate	3.60	0.79	3.50	0.90	3.66	0.72	2.47[c] (n.s.)
	Feel that climate change poses a high risk to food security	3.91	0.40	3.86	0.46	3.94	0.36	4.47[c] *
	Feel that climate change poses a high risk to livelihoods	3.85	0.52	3.78	0.65	3.89	0.43	1.69[c] (n.s.)
Coping appraisal	Agreement with statement "I feel motivated to change my agricultural practices to prepare for future cyclones."	4.10	1.0	4.11	1.03	4.10	0.99	0.07 [c] (n.s.)

	Agreement with statement “I feel that I do have the capacity to change my agricultural practices to prepare for future cyclones.”	2.99	1.33	3.00	1.32	3.00	1.34	0.00[c] (n.s.)
Intention to adapt	Likelihood of making changes to agricultural practices in the next five years	4.16	0.86	4.03	0.91	4.22	0.82	-1.92[b] (n.s.)

Note: * = p <.05; ** = p <.01; *** = p <.001; n.s. = not significant
Statistical test used: a. Chi-square test, b. Independent samples t-test, c. Kruskal-Wallis H test

However, while awareness of changing climatic conditions was high, the attribution of these changes to anthropogenic activities was low (Figure 2-5b). Nearly half of respondents (46.5%; n=152) did not know the causes of the changes. Only 15.7% (n=52) attributed them to human activities, while 11.5% (n=38) attributed changes to natural causes. Interestingly, 10.3% (n=34) believed that changes were caused by *zanahary* (God), a belief also documented among Indigenous farmers in Bolivia (Boillat & Berkes, 2013). Similar supernatural attributions have been observed among the Vezo in southwestern Madagascar, where local fisherfolk sometimes blame adverse weather on the improper burial of a deceased mermaid (Muttenzer, 2020). In addition, of those that responded: “Other” (16%; n=54), open-ended responses attributed climate change to actions of foreigners and scientists (18.5%; n= 10) and the government (7.4%, n=4), as well as to forest loss (11.1%; n=6).

Threat appraisal (Fear and perceived risk from climate change): Most farmers (87.5%; n=287) expressed worry about perceived changes in climate, with 68% (n=223) strongly agreeing with the statement, “Farmers like me are likely to be negatively affected by climate change.” Respondents also reported high levels of perceived threat, feeling that climate change poses high risk to both food security (93.9%, n=307) and livelihoods (90.2%, n=295). Gender had no significant effect on worry about climate change (X^2 = 2.47, 1, p = .116) or perceived risk of climate change to livelihoods (X^2 = 1.69, 1, p = .194) based on results of Kruskal-Wallis tests. However, women’s perceived risk to food security was significantly higher than men’s (X^2 = 4.47, 1, p = .037) (

Table 2-2), possibly due to women’s traditional roles in food provisioning and preparation at home.

Coping appraisal (Self-efficacy): Around three-quarters (76%; n=248) of respondents expressed motivation to adapt their agricultural practices in order to mitigate damage from future cyclones. However, only 38.7% (n=127) felt they had the capacity to make these changes. There were no significant gender differences in willingness to change practices (X^2 = 1.09, 4, p = .895) or perceived adaptive capacity (X^2 = 0.17, 4, p = .997) (

Table 2-2).

Actual and intended adaptation measures in response to climate change: Despite farmers' awareness and concern about climate change, few had made changes to their agricultural practices in the last five years (

Table 2-2). However, a majority expressed intention to make changes in the next five years: 80.5% (n=264) planned to change the timing of planting, while 87.2% (n=286) and 87.5% (n=287) intended to change crop varieties and types, respectively. Notably, there were no significant gender differences in prior adoption or intended adoption of adaptation measures (

Table 2-2).

Social connectedness: In general, results showed farmers to have low social connectedness with an average score of 2.99 (*SD* = 1.42) on a scale of 0 to 15 possible social interactions. Male farmers had significantly higher social connectedness, scoring an average of 3.38 (*SD*

= 1.58), while female farmers scored an average of 2.78 (*SD* = 1.27), [t (324) = 3.81, p <0.001] (

Table 2-2). Female farmers were also significantly more likely to have below-average connectedness compared to male farmers, $X^2 = 12.83$, 2, $p = .002$.

In terms of types of social interactions, farmers reported very infrequent to no interaction with government workers and Madagascar National Parks (MNP) staff, and only slightly more frequent interactions with NGO workers, while interactions between farmers were more common (Figure 2-6a). Nearly 30% of farmers reported interacting with other farmers on at least a monthly basis, unsurprising given that farming is the predominant livelihood in these communities. In addition, over half of respondents participated in the recent rice-growing training (60.7%, n=199) and 15.5% (n=51) belonged to a farmer's cooperative. Additionally, when farmers were asked who they typically consulted with about farming-related decisions, only 4.6% (n=7) cited consulting with agricultural extension/NGO workers, while 57.1% (n=88) had consulted elders in the community and 6.5% (n=10) had sought out the advice of astrologers on propitious planting times, etc.

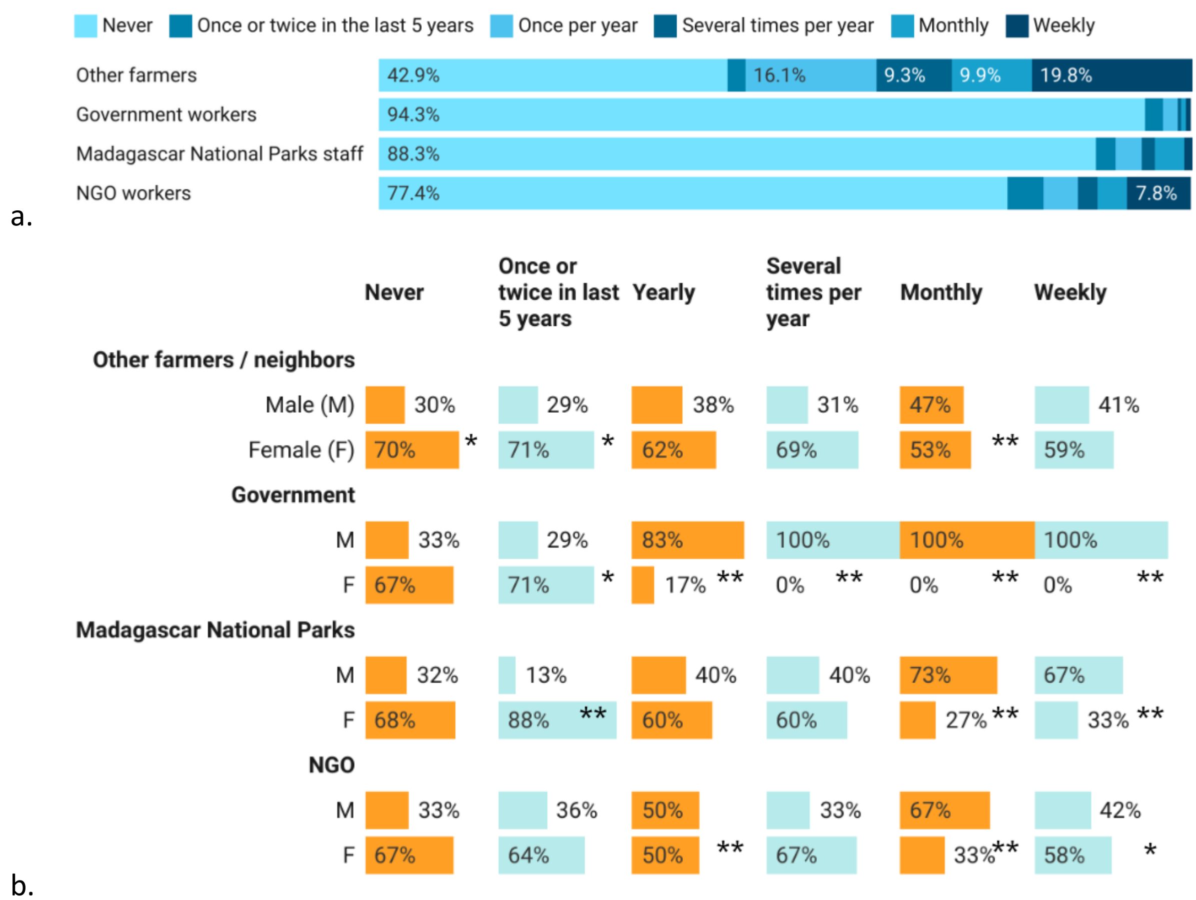

Figure 2-6. a) Frequency of farmer interactions with others, b) Frequency of interaction types by sex based on 64.3% female and 35.7% male respondents.

Note: * = *p* <.05; ** = *p* <.01

When examining the frequency of farmer interactions by gender, male and female farmer social connectedness is clearly different (Figure 2-6). For example, men were significantly more likely to have vertical ties with government ($p < .001$), MNP ($p < .001$), and NGO staff ($p < .001$), while women reported significantly less frequent interactions with other farmers ($p < .05$), government ($p < .05$) and MNP workers ($p < .001$). Women were also significantly less likely to consult with elders in the community about agricultural decisions than men, $X^2 = 4.57$, 1, $p = .032$. However, there were no statistically significant differences between men and women in terms of their membership in a farmer's cooperative (X^2 = 0.92, 1, p = .337) or their participation in the HIH agricultural training (X^2 = 0.13, 1, p = .723). Thus, group membership and trainings emerge as important ways that both male and female farmers can engage with other farmers about agricultural decisions and to share information.

Social connectedness reduces perceived threat of climate change

Figure 2-7. shows how various levels of farmer social connectedness (below average, average, above average) impact farmers' appraisal of climate change threat. Having average and above average social connectedness was associated with reduced perceived threat. Greater social connectedness was also associated with reduced fear (worry) that farmers had about the threat of climate change. We also identified significant relationships between social connectedness level and perceived risk of climate change to income (livelihoods) (X^2 = 18.57, 6, p = .005). However, social connectedness and perceived risk of climate change to food security (X^2 = 8.52, 6, p = .202) or worry about climate change (X^2 = 10.84, 6, p = .093) did not have significant associations.

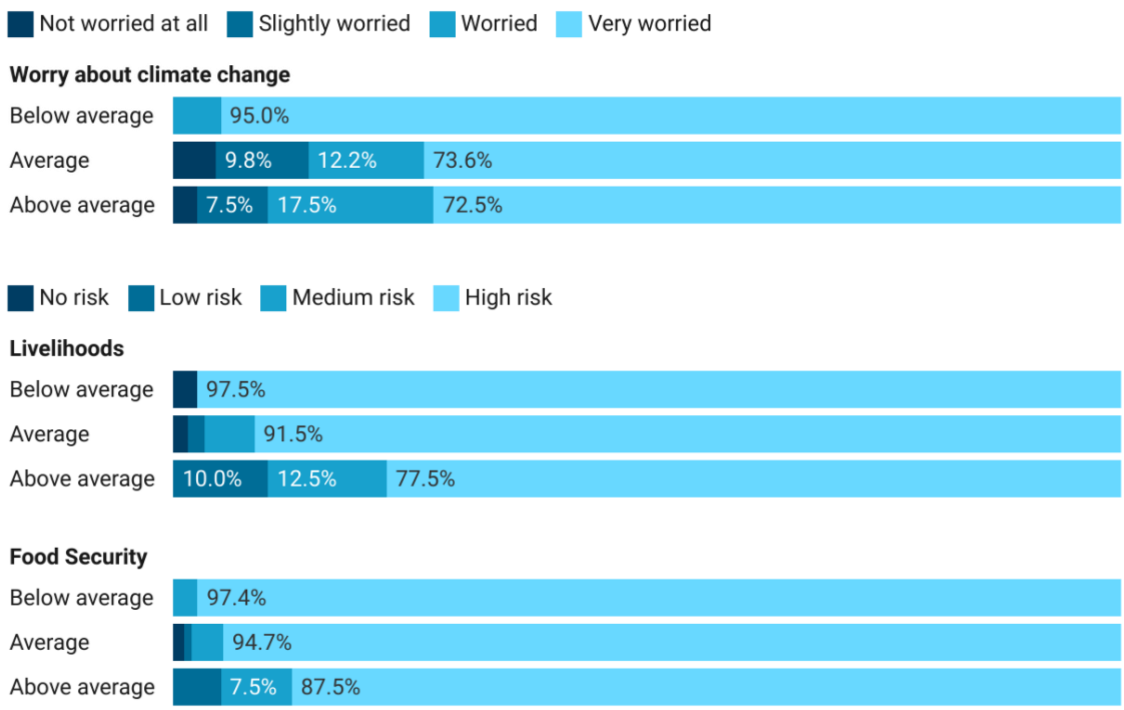

Figure 2-7. Perceived risk of climate change to a) income (livelihoods) and food security, and b) degree of worry about climate change, by level of social connectedness (below average, average, above average).

Structural Equation Modeling (SEM) Results

In exploring the two core constructs of the PMT (threat and coping appraisal), we find multiple predictors and relationships to intention to adopt practices. A diagram of the path analysis and measurement model from the overall and multi-group SEMs are shown in Figure 2-8, and unstandardized model estimates, standard errors, and significance levels are presented in Table 2-3.

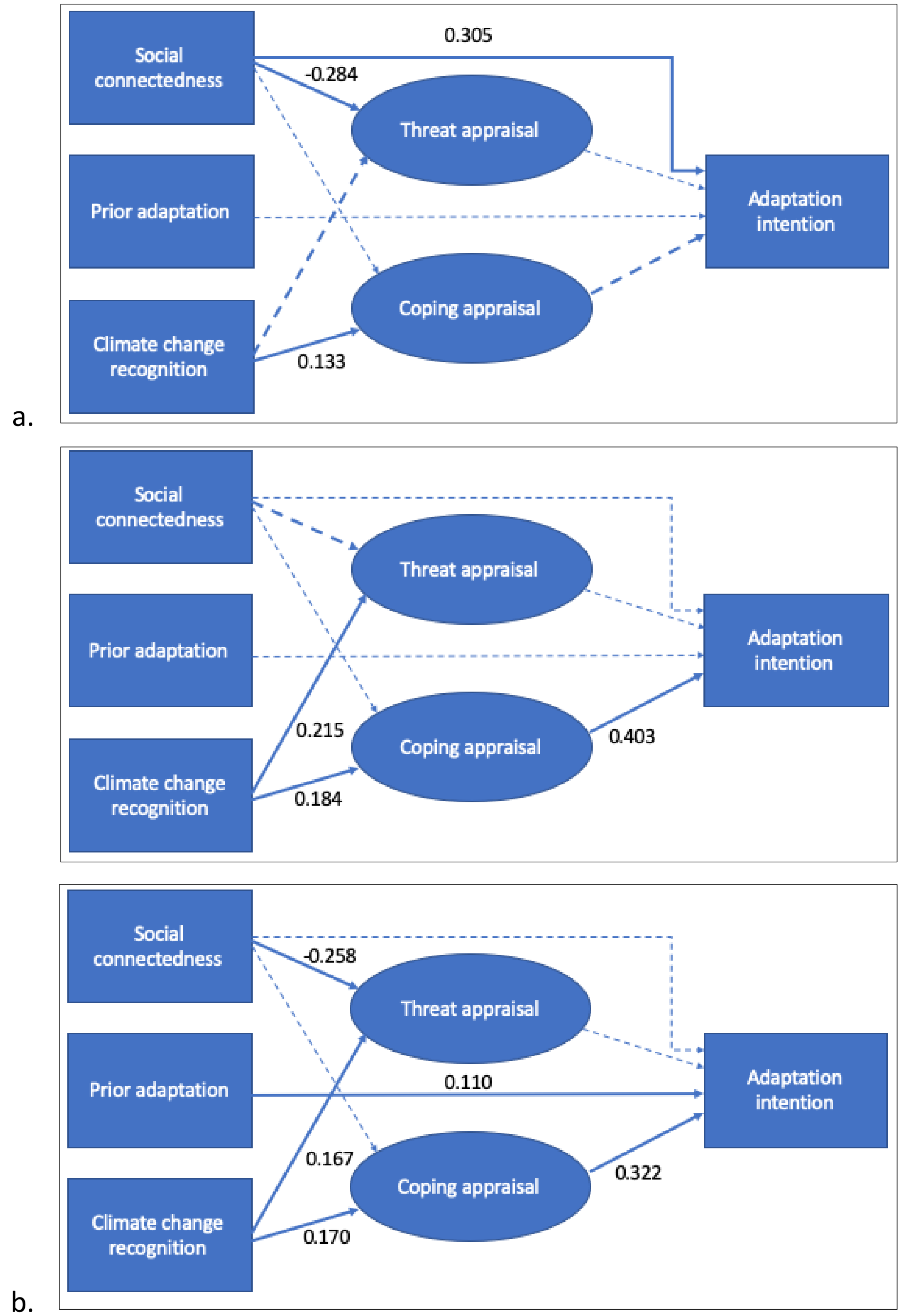

Figure 2-8. Path diagrams for a) overall and b) multi-group models (men and women) with standardized estimates. Circles indicate latent variables; squares indicate observed variables. Solid lines represent statistically significant relationships (p <.05). Dotted lines indicate non-significant pathways. Residual error terms are given for continuous outcome variable ‘Intention to adapt’

Table 2-3. Hypothesis testing results from SEM for overall sample and with multi-group (men vs. women) moderation effects.

		Overall			Group 1 Men (n= 117)			Group 2 Women (n = 211)		
Hypothesis	Relationship	Estimate	SE	*p*=	Estimate	SE	*p*=	Estimate	SE	*p*=
H1	Climate change recognition →									
	a) Threat	1.155 (*a*)	0.33	.000***	1.124	0.67	.094	1.283	0.34	.000***
	b) Coping	1.143 (*b*)	0.43	.007**	1.398	0.50	.005*	1.081	0.40	.006**
H2	Social connectedness→									
	a) Threat	-0.190 (*a*)	0.07	.003**	-0.190	0.09	.028*	-0.127	0.10	.222
	b) Coping	-0.007 (*b*)	0.07	.883	-0.065	0.06	.311	0.043	0.07	.544
H3	Social connectedness → Intention to adapt	0.035	0.04	.339	0.161	0.07	.017*	-0.044	0.04	.304
H4	Prior adaptation → Intention to adapt	0.255	0.12	.030*	0.353	0.20	.074	0.225	0.14	.105
Protection Motivation Theory										
H5	Threat → Intention to adapt	0.042	0.08	.619	0.098	0.22	.659	0.006	0.07	.936
H6	Coping → Intention to adapt	0.265	0.09	.002**	0.121	0.18	.504	0.329	0.09	.000***

Note: Effect sizes in table are unstandardized as recommended by Ockey and Choi (2015). * = p <.05; ** = p <.01; *** = p <.001

In support of H1, we find that climate change recognition is a significant, positive predictor of both coping (b = 0.170, p = .006) and threat appraisal (b = 0.167, p = .000). However, while social connectedness does not significantly predict coping appraisal (H2b), it is a significant, negative predictor of threat appraisal (b = -0.258, p = .002) (H2a).

Therefore, we find that being more socially connected is critical to lowering perceived threat and, in turn, reducing maladaptive response pathways.

Our results also support our fourth hypothesis (H4). Previous adoption of adaptation measures is a significant, positive predictor of intention to adapt (b = 0.110, p = .030). As predicted, those that have adopted agricultural adaptation practices in the past are more likely to intend to do so in the future.

In terms of PMT's validity, coping appraisal was found to be a stronger predictor of intention to adapt than threat appraisal. Coping appraisal is a significant, positive predictor of the 'Intention to adapt' outcome variable (b = 0.322, p = .001) (H6), while threat appraisal is not (b = 0.052, p = .621) (H5). This finding is supported by the work of Babcicky & Seebauer (2019), who found coping appraisal to predict protective behavior, while threat appraisal displayed "a non-protective route to non-protective responses."

The results of the multi-group SEM with gender as a moderator partially support H7. Coping appraisal was found to be a significant predictor of intention to adapt agricultural practices among women (b = 0.403, p < .001), but not men (b = 0.149, p = .504). We also find that that higher social connectedness is significantly associated with reduced threat appraisal in men (b = -0.284, p = .017), with no significant effect for women (b = -0.158, p = .213). Social connectedness is also a significant and positive predictor of intention to adapt agricultural practices among men (b = 0.305, p = .010) (and not women; b = -0.069, p = .312). Furthermore, social connectedness and intent to adapt were not found to be significantly correlated for the whole sample (r = .068 , p = .220) or for women (r = -.014 , p = .844), but it was for the men-only sample (r = .227, p =.014)

2.4 Discussion

Climate change perception

The study supports our hypothesis (H1) that climate change awareness is an important precursor for intention to adapt agricultural practices - results of the SEM show climate change recognition positively predicts both threat and coping appraisal constructs. In addition, despite low social connectedness on average, smallholder farmers in southeastern Madagascar are "climate-informed,"[22] aware of regional climatic changes such as increased temperature and more unpredictable rainfall. These findings align with other studies on farmers' perceptions of climate change (e.g., Fisher et al., 2015; Karki et al., 2020a; Nguyen et al., 2021), as well as reports by climate scientists (Tadross et al., 2008). However, it is noteworthy that few respondents attribute these changes to anthropogenic activity, which is consistent with findings from other Indigenous farming communities in Brazil (Funatsu et al., 2019) and Peru (Altea, 2020), for example.

Social connectedness

This study also emphasizes the role of social embeddedness (Granovetter, 1985), or the extent to which one's behavior is shaped by social relations, in smallholder farmer decision-making. Specifically, being more socially connected is a significant predictor of reduced threat appraisal (H2a) (i.e. farmers with greater social connectedness perceive climate change as less threatening). Thus, socially connected farmers feel better supported and less inhibited to take action. Similar findings have been reported in studies on agricultural technology adoption in Malawi (Kansanga et al., 2020) and China (Zheng et al., 2022). Yet, Manombo area farmers exhibited low social connectedness on average and expressed high levels of concern about climate change. Consequently, in highly vulnerable contexts, low social connectedness and high threat appraisal may hinder climate change adaptation behavior.

Furthermore, because farmers report more frequent interaction with other farmers/neighbors, and consulting with village elders rather than agricultural extension/NGO workers, it is important to consider the horizontal and vertical structure of Malagasy society as it relates to the transfer of information and knowledge spillover. For example, as Dahl (1999) points out, the assumption that pilot farmers will be emulated by neighboring farmers stems from Western norms which may not be reciprocated in this context. During fieldwork in Madagascar, Dahl observed that successful farmers were often met with suspicion, jealousy, or general disapproval from the community. However, those farmers willing to actively share their "know-how," Dahl writes, were able to restore *fihavanana* [horizontal solidarity], the social bedrock of Malagasy communities, and be considered as *ray aman-dreny* [parents] (p. 96). Thus, as only those willing to share their knowledge are transformed into respected elders and trusted to provide agricultural advice, interventions must carefully decipher whom to enlist as knowledge holders.

Moreover, our research provides further evidence that female farmers have lower social connections compared to their male counterparts. Additionally, our findings demonstrate that female farmers have less connectivity with perceived authority figures, such as government and parks officials, than compared to male farmers. However, group membership (e.g., farmer cooperatives, women's associations) serves as a crucial source of connection for female farmers. Based on these findings, we recommend that climate change adaptation policies and interventions specifically target women and other vulnerable groups that have traditionally been less socially connected.

Furthermore, while it is important to follow cultural protocols related to communication with village elders and local authorities, who are often men, it should not be assumed that information will effectively reach women through these channels. Instead, messaging should be directed through channels where women are more likely to communicate, such as women's associations, and delivered at times and locations most suitable for them.

Following gender-responsive agricultural development best practices, such as recruiting and training more female extension workers (Witinok-Huber et al., 2021), ensuring equitable access to training programs, tailoring advice to crops that women tend to focus on, and providing specific training for women on new tools will also help close the gender gap in agriculture and address the climate change adaptation deficit. Successful examples include the BRAC program in Uganda, which increased technology adoption among female farmers by establishing a network of female Model Farmers and community-based agricultural agents (Pan et al., 2018). In Madagascar, a Conservation International-led project on climate change adaptation among smallholders produced gender-sensitive training modules and an information exchange platform on climate risk reduction options as part of their Gender Action Plan (Conservation International, 2022).

In Mali, training women service providers on the use of the RiceAdvice app led to adoption of new rice-growing technologies by over 20,000 women and youth (AICCRA, 2023).

Coping appraisal is a stronger predictor than threat appraisal

This study supports the suitability of PMT in predicting smallholder intention to adapt agricultural practices to climate change. Consistent with previous research (Burnham & Ma, 2017; van Valkengoed & Steg, 2019), our results show that coping appraisal, or perceived adaptive capacity, is an important determinant of adaptation intent. Specifically, we find PMT's 'Coping appraisal' construct to be a stronger predictor of 'Intention to adapt' than the 'Threat appraisal' construct. Meta-analytic reviews of PMT among health-related studies (Floyd et al., 2000; Milne et al., 2000), as well as studies applying PMT to smallholder decision-making in the Global South (e.g., Truelove et al., 2015), have also found the coping appraisal construct to have greater predictive validity than the threat appraisal construct.

However, unlike studies linking higher concern to greater adaptation likelihood (e.g., Woods et al., 2017), our study suggests that threat appraisal alone does not lead to adaptation intentions. This finding is supported by recent research applying PMT to flood mitigation behavior (Babcicky & Seebauer, 2019). While some studies highlight risk perception as a motivator for intention and adaptation behavior among farmers (e.g., Azadi et al., 2019; Feng et al., 2017), other studies, particularly among resource-limited farmers and other vulnerable populations, find that concern does not always translate into behavior change (Etana et al. 2020; Rodríguez-Cruz & Niles, 2021; Tucker et al., 2010).

Rather, as high threat appraisal can lead to maladaptive behaviors such as fatalism, risk-aversion, and denial, as well as a *status quo* bias, farmers may be "paralyzed" by fear, thereby hindering the protection motivation that fear is assumed to evoke (Plotnikoff & Trinh, 2010). Indeed, fear of change and vulnerability has been found to inhibit farmers' adaptation in other Global South contexts (Bagagnan et al., 2019; Luu et al., 2019), and research emphasizes the importance of promoting hope, not fear, in achieving desired outcomes related to climate change policy (Nabi et al., 2018).

Intention setting does not necessarily lead to adaptive behavior

Despite research pointing to the importance of "intention strength" in behavioral change (Conner & Norman, 2022), we find that farmers had strong intentions but low rates of prior adaptation. This intention-behavior gap, or failure to translate intentions into action, is well-documented in various decision-making studies, from organic food purchases (Frank & Brock, 2018) to physical activity goal-setting (Rhodes & de Bruijn, 2013), and more recently among farmers (e.g., Niles et al., 2016; Rodríguez-Cruz et al., 2021). For example, farmers in resource-poor settings, such as Madagascar, may have the intention to change their practices, but they often lack the capacity to do so, as has been demonstrated among farmers in other parts of sub-Saharan Africa (e.g., Bryan et al., 2009; Deressa et al., 2008; Fisher et al., 2015).

Limitations

The strengths of this study are its large sample size relative to the population and rigorous sampling design, though we also acknowledge several limitations. Some of the multi-item scales used in this analysis have fairly low reliability. Additionally, several psychometric variables are measured by single items. Our survey also omitted questions related to response efficacy, a component of PMT's coping appraisal construct found to be a strong predictor of adaptation behavior (van Valkengoed and Steg, 2019).

Furthermore, while our results support our hypothesis (H4) that past adaptation of farming practices influences future intention to adapt, we were unable to examine the predictive power of intention on actual adaptation due to concurrent measurement. Future research should use longitudinal data to understand the predictive value of intention on adoption (and disadoption) of adaptation measures over time, as well as to study the adaptation learning process (Lamichhane et al., 2022).

In terms of limitations of the PMT framework, it does not consider variables such as social norms (Atta-Aidoo et al., 2022; van Valkengoed & Steg, 2019) or cultural dimensions (Adger et al., 2013) that influence smallholder farmer adoption of climate-resilient practices. Future expansions could integrate other behavioral theories that include normative beliefs, sociocultural perspectives and relationships (e.g., trust, cooperation), and individual personality variables, such as negative affectivity (van Valkengoed & Steg, 2019). For example, optimistic farmers in India were more likely to exhibit adaptation behavior than those who were pessimistic and had fatalistic outlooks (Singh et al., 2016).

2.5. Conclusion

Using a SEM approach to test PMT for predicting intention to adopt climate change adaptation practices among smallholder farmers, this study highlights the importance of considering the psychological aspects that lead to behavioral adaptation, specifically coping appraisal. However, while our study significantly explains adoption intention, we posit that high threat appraisal and low social connectedness, particularly among women smallholder farmers, may lead to non-protective behavior or avoidant maladaptation (e.g., risk aversion, fatalism, and wishful thinking) rather than desired agricultural adaptation outcomes, despite high intentions to adapt.

Given high climate change perception among smallholders (Soubry et al., 2020), and as threat alone appears to be non-motivational (Tunner, 1989), solely focusing on increasing awareness through fear-based approaches may not effectively drive climate change adaptation. Instead, interventions should prioritize enhancing adaptive capacity and addressing context-specific risks and uncertainties. Considering that social connectedness plays a critical role in reducing threat appraisal and recognizing that women are often less socially connected, future research on climate change adaptation should explore gender-specific access to social networks across contexts (Carranza & Niles, 2019; Macgregor, 2010; Ravera et al., 2016). Lastly, efforts should be directed towards strengthening existing social safety nets and communication channels, such as farmers' and women's associations, to better equip less socially connected and historically marginalized groups in coping with the precarity of climate change.

Notes

1. Fatalism, or the belief that it is futile to attempt changing things that are predetermined (a "why bother?" attitude), effectively the opposite of self-efficacy, is especially prevalent in the growing body of research on adaptation to climate change (e.g. Etana et al., 2020; Feng et al., 2017). However, fatalistic outlooks do not necessarily precure farmers from attempting to improve their future through actions such as prayer and other ritualistic methods (Roncoli et al., 2002).
2. Madagascar spends far less than most other countries on health and education. In 2014, less than 3% of Madagascar's GDP was spent on education; about 4-5% on Total Health Expenditure (UNICEF, 2014).
3. Respondents were marked as either *lelahy* (male; man) or *vehivavy* (female; woman). There is no distinction in the Malagasy language between sex and gender.
4. A Kaiser-Mayer-Olkin test (KMO's test; Kaiser, 1974; KMO = 0.56) and Bartlett's (1954) test of sphericity ($p < .001$) justified the application of EFA. Chi-square approximate = 163.77; DF=10; $p<.001$
5. The strategies *i)* to leave farming and *ii)* migrate elsewhere to find work were excluded from the analysis as they are not actual farming practices and were found to not be viable strategies for this population based on low level responses.
6. According to the definition given by Schattman et al. (2021), "climate-informed" farmers are those who "possess knowledge of climate change and related impacts" (p.766).

2.6. References

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CHAPTER 3: AN ANALYSIS OF THE ADOPTION OF THE "SYSTEM OF RICE INTENSIFICATION" (SRI): WHY A HOMEGROWN TECHNIQUE HAS YET TO TAKE SEED AMONG RICE FARMERS IN MADAGASCAR

Rehefa misy tanimbary hohadina dia miantso ny hafa; rehefa misy amalona sira atao sakafo hariva tsy manana namana fa ny maty.
(When there is a rice field to be dug, I call in others; when there is salted eel for dinner, I have no friends but the dead)
- Malagasy proverb

3.1 Introduction

Rice (*Oryza sativa*) is the principle staple food in Madagascar, grown by nearly 90 percent of Malagasy households and occupying an estimated 1,200,000 hectares of land (IFAD, n.d.; Senahoun & Nikoi, 2016). Despite this, the country remains a net importer of rice,[1] mainly from Pakistan and Thailand, production levels remain low, and food insecurity, even among farmers, is extremely high (Global Hunger Index, 2022). While the underlying reasons for Madagascar's rice "yield gap" is certainly more complicated, the Global Yield Gap Atlas (n.d.), which presents an industrialized perspective towards agriculture, attributes it to lack of quality seed, fertilizer to replenish poor and exhausted soils, and irrigation infrastructure, as well as challenges with weeds. Largely bypassed by the Green Revolution, use of external inputs such as high-yielding seed varieties and fertilizers is low, terracing is rare, and most of the country's rice production still relies heavily on ancestral non-mechanized farming methods (Minten et al., 2006), although traditional fallow periods have shortened (den Biggelaar & Moore, 2016; Hume, 2006).

[1] Despite producing nearly 4 million tons of rice in 2015, Madagascar still imported approximately 260,000 tons of rice that same year (FAO CountrySTAT, 2021).

Given the importance of rice agriculture to food security in Madagascar, the general objective of this paper is to understand rice technology adoption dynamics among Malagasy farmers. More detail and specific research questions are presented in section 1.4. Research methods and results are covered in sections 2 and 3, respectively. Lastly, in sections 4 and 5, we discuss findings and conclusions.

Agricultural intensification and conservation in Madagascar

As Madagascar is one of the most biodiverse places on earth (Myers et al., 2000), intense focus has been placed on reducing “slash and burn” (locally known as *tavy*), a pejorative term used for shifting agriculture methods traditionally used to clear forests and other natural vegetation, mainly for rice cultivation. However, Malagasy actions regarding land-use are often governed by strong adherence to ancestral commands, what von Heland and Folke (2014) have termed a “social-ancestral contract” between the living and non-living, rather than government authority (Jones et al., 2008). Thus, *tavy*,[2] despite being outlawed since 1868[3] (Scales, 2014), continues to be prevalent across the island’s rice-based agroecosystem (Dröge et al., 2022; Laney & Turner, 2015), and is largely blamed for the approximately 200,000 hectares of forest lost each year (Suzzi-Simmons, 2023).

To combat *tavy* in Madagascar, while simultaneously improving food security, many international conservation and development organizations, as well as recent government-led conservation policies (Rakotovao et al., 2021), have promoted an

[2] *Teviala* is the more specific term for using fire to clear primary forest (Dröge et al., 2022).
[3] An exception occurred in the mid-1970s when Ratsiraka’s famine alleviation policies legalized *tavy* for a period of time (Hardenbergh et al., 1995; Jones et al., 2021).

agroecological approach called *Système de Riziculture Intensifiée* or “System of Rice Intensification” (SRI) for several decades (Freudenberger & Freudenberger, 2009; Jones et al., 2021; Moser & Barrett, 2003; Whitman et al. 2020). SRI is a low-input intensification method consisting of a series of management principles originally developed in Madagascar to reduce the yield gap without extensification. Beginning in the 1960s, Henri de Laulanié, a French Jesuit priest living in the highlands of Madagascar and trained at the "Institut National Agronomique" in Paris, worked in conjunction with Malagasy farmers for 20 years to co-create the technique. By 1990, a national organization based in Madagascar’s capital, *Association Tefy Saina*, had formed with the mission of disseminating SRI.

Aiding in SRI’s spread to numerous countries and contexts is its ability to be adapted and customized to fit different situations (Beumer et al., 2022; Uphoff et al., 2011). By 2010, an estimated 1-1.5 million farmers were practicing SRI worldwide (Thakur, 2010), and a website, SRI-Rice, was launched by Cornell University to connect interested individuals and institutions. Today, an estimated 10 million farmers in over 60 countries across the world practice some iteration of SRI (Prasad, 2020; Uphoff & Thakur, 2019), which has progressed more into a set of agronomic principles than simply a list of practices (Uphoff, 2023). SRI has even been listed by Project Drawdown as one of nearly 100 solutions to avert climate catastrophe, with predictions that adoption of SRI could reduce carbon dioxide emissions by 2.9 to 4.4 gigatons by 2050 (Hawken, 2017).

Considered a “paradigm shift for rice production” (Uphoff et al., 2011), SRI is a knowledge-intensive technology rooted in agroecological principles that address the biophysical requirements of plants, both above and below ground (Uphoff, 2023; Stoop et al., 2002). Emphasizing low external-input agriculture, it is especially useful for farmers in drought-prone regions (Taylor & Bhasme, 2019). Able to be practiced with any variety of rice[4], SRI differs from traditional paddy rice cultivation in a number of ways - including defying the common misconception that rice requires permanently flooded conditions (Uphoff et al., 2011). It involves a series of synergistic steps, as summarized in

Table 3-1, encompassing improved soil and water management, more frequent weeding, and specific instructions on how to care for and transplant young rice seedlings to minimize transplant shock, minimize competition between plants, and facilitate weeding (Uphoff, 2023). The core components of SRI can vary according to the context and iteration. For instance, Noltze and colleagues (2012) identify the first four steps as the essential components, while SRI-Rice (n.d.) considers step five to be critical. Furthermore, as non-flooding allows for more weed growth (Moser & Barrett, 2003), step six is recommended but not mandatory.

[4] However, some varieties may perform better under SRI than others (Uphoff, 2023).

Table 3-1. Comparison of SRI to traditional rice-growing methods with color coding to reflect gender roles (yellow for women's, blue for men's) typically associated with each step in the Madagascar context (Achandi et al., 2018)

Note. Table adapted from Randriamiharisoa & Uphoff (2004), cited in Perera et al. (2007).

Traditional methods	**SRI**
1. Transplant rice seedlings at 3-4 weeks	1. Very carefully transplant seedlings early at the two-leaf stage (less than 15 days, preferably 7-10 days), with very careful handling
2. Transplant in clumps of 3-4 seedlings	2. Transplant seedlings singly into level, unflooded field
3. Seedlings transplanted densely and 'scatteredly' (Graf & Oya, 2021)	3. Spacing seedlings 25-40 cm apart (along line and in a square grid pattern)
4. Continuous flooding (CF) of rice paddy	4. Alternative wetting and drying (AWD) of paddy
5. Add fertilizers, if available	5. Maintain soil fertility by adding organic compost
6. Control weeds by flooding and infrequent weeding by hand (1-2 times)	6. More frequent and earlier weeding (3-4 times), preferably with a *sarcleuse*

It is also crucial to recognize that due to the presence of defined gender roles within the rice-growing process, in Madagascar as in other rice cultures, the adoption of innovative techniques like SRI can have distinct implications for men and women. This can potentially lead to changes in responsibilities and workloads. For example, shifting from hand weeding to the use of sarcleuse could transfer the role from women to men (Uphoff, 2023), as women are typically responsible for weeding by hand while men typically oversee the use of mechanical tools (Achandi et al., 2018; Taylor & Bhasme, 2019). Additionally, the use of a *sarcleuse* (mechanical weeder) can alleviate physical discomfort associated with hand weeding by allowing an upright position (Mrunalini & Ganesh, 2008).

3.1.1 Benefits and adoption of SRI methods

Notwithstanding early skepticism and significant criticism - dubbed the 'Rice Wars' (Ho, 2004), particularly over "spectacular grain yield(s)" (Deb, 2020), there is ample empirical evidence of SRI's capacity to greatly augment rice yields - sometimes as high as 100% or more (K. Takahashi & Barrett, 2014; Norman Uphoff, 2007). This could contribute to alleviating poverty and lowering food prices (Minten & Barrett, 2008). In Madagascar, Barrett et al. (2004) documented average gains of over 84% compared to traditional methods, while Styger and Traoré (2018) reported similar yield increases across 13 countries in West Africa. Research has further revealed that SRI enhances rice plant resilience to pests and diseases, as well as to abiotic stresses such as low moisture (Uphoff, 2007). SRI also reduces the quantity of inputs (seed, water,[5] and fertilizer) needed (Berkhout & Glover, 2012; Win et al., 2020). Additionally, because it promotes alternative wetting and drying, rice paddies are flooded for shorter periods of time, thereby reducing

[5] Under climate change, as water scarcity becomes increasingly challenging for irrigated rice production, water-saving techniques like SRI are predicted to become increasingly important (Win et al., 2020).

the presence of greenhouse gas-generating microbes (Thakur et al., 2022).[6] There is also evidence that rice cultivated following SRI principles has higher levels of micronutrients (Uphoff, 2023), and has the potential to improve dietary diversity outcomes as well. For example, SRI techniques have facilitated conversion of rice paddies into fishponds, and freed up land for poultry raising, and fruit and vegetable production in Cambodia (Uphoff, 2007), as well as crop rotational methods and intercropping adoption in China and India (Uphoff, 2023).

Despite its many advantages, including short-term benefits important for adoption (Piñeiro et al., 2020) such as growing more rice with less water and job creation (Graf & Oya, 2021), SRI adoption rates remain low (and "disadoption" after initially adopting remains high) in sub-Saharan Africa (SSA; Jain et al., 2023; Kamara et al., 2023; Katambara et al., 2013), including Madagascar (Moser & Barrett, 2003; Rakotovao et al., 2021; Razafimahatratra et al., 2021; Whitman et al., 2020). As of 2012, only an estimated 3,000 hectares of Madagascar's rice fields (out of a total of 1.2 million hectares) were under SRI (Berkhout & Glover, 2012). This low rate of uptake among Malagasy farmers over the last 40 years remains unclear, as SRI is not a "research station technology" (Muzari et al., 2012), but what has been called "an unusual case of extension taking lead over research" (Goud, 2005). While there are reports of up to 30% adoption in some areas (SRI-Rice, n.d.-a), the true percentage is likely less than 5% (N. Uphoff, *personal communication*, December 8, 2020). For example, fewer than 2% of farmers in the Itasy region, just north of Madagascar's capital, were reportedly practicing SRI (Rakotovao et al., 2021).

[6] Rice paddies account for an estimated 19% of global methane gas and 11% of global nitrous oxide emissions (Win et al., 2020).

In addition, when SRI is adopted, it is often only partially adopted, either in terms of intensity of adoption, the entirety of fields converted (Graf & Oya, 2021; Moser & Barrett, 2003; Noltze et al., 2012), or depth of adoption (where only certain aspects of the innovation are adopted) (Ly et al., 2012; Noltze et al., 2012; Palanisami et al., 2013; Tezer, 2012). For instance, Brown (1998) reported that farmers near Ranomafana, Madagascar, adopted the line-transplanting technique but did not follow the guidelines on minimum spacing recommended to facilitate weeding with a *sarcleuse*. Additionally, farmers may discontinue a technique after adoption if they perceive it to be ineffective (Jain et al., 2023), and even when successful yields are achieved (Taylor & Bhasme, 2019). In Madagascar, Moser and Barrett (2003) found that 40% of early adopters across five communities abandoned SRI five years after it had been promoted by extension agents.

Elsie Black (*personal communication*, December 2020), a former Peace Corps volunteer working in Madagascar, shared a story about one particular model farmer, Adolfo, who proved to be very influential in introducing SRI to the farmers in his community. Other farmers expressed admiration for Adolfo, noting that "his land is the same as ours, his water problems are the same as ours, and he has a motorcycle!" However, while early adopters like Adolfo may serve as opinion leaders in their communities, exerting normative influence over potential late adopters, these farmers are rare in Madagascar, and farmer-to-farmer knowledge transmission of information tends to be low (Hume, 2006).

3.1.2 Studies on SRI adoption

The global adoption studies literature is rich with research seeking to understand SRI adoption dynamics. Factors identified as influencing its adoption include risk aversion (Mariano et al., 2012), strong institutional support networks (Basu & Leeuwis, 2012; Durga & Kumar, 2016), farmer age and farm characteristics such as size and income (Sita Devi & Ponnarasi, 2009), access to credit and type of income source (Nguyen & Hung, 2022; Moser & Barrett, 2003), irrigation systems (Noltze et al., 2012), as well as extension-related variables (Durga & Kumar, 2016; Mariano et al., 2012). For example, across multiple countries in South Asia, SRI adoption has been linked to training exposure magnitude (Barrett et al., 2021; Sita Devi & Ponnarasi, 2009; Perera et al., 2007). Furthermore, as SRI requires frequent field visitation, Noltze et al. (2012) found that farmers whose rice fields were closer to their homesteads were more likely to adopt.[7] Other research has pointed to subjective norms - concerns about what neighbors will think and actions of "important others" - influencing SRI adoption (Perera et al., 2007; Tezer, 2012). Lastly, although one study in India found that labor input was reduced under SRI (Sinha & Talati, 2007), labor availability, especially during transplanting and weeding, has been identified as a major constraint in numerous contexts[8] (e.g. Graf & Oya, 2021; Kamara et al., 2023; Ly et al., 2012; Moser & Barrett, 2003; Nguyen & Hung, 2022; Waris, 2017). However, despite ample evidence that gender often plays a role in adoption of agricultural

[7] In some regions of Madagascar, farmers often stay in *lasy*, or makeshift dwellings closer to fields, during peak labor periods, so distance to rice field may be less of a factor in this context.

[8] An estimated 500 hours/hectare additional time required for SRI practices was calculated as part of a project evaluation carried out in Morandava, Madagascar (Rabenandrasana, 2002).

technologies (e.g., Achandi et al. 2018), most SRI adoption studies did not consider farmers' gender.

Furthermore, while a growing body of research on SRI adoption exists, particularly in South and Southeast Asia, SRI adoption research in Madagascar remains relatively slim. Additionally, of the SRI adoption research carried out in Madagascar, most have looked at SRI among farming communities in the High Plateau (e.g., Berkhout & Glover, 2012; Moser & Barrett, 2003; Serpantié & Rakotondramanana, 2014; Tezer, 2012; Tsujimoto et al., 2009; Whitman et al., 2020), the central mountainous region constituting a large part of Madagascar's interior and where the climate is more temperate. To our knowledge, there are no publications in the peer-reviewed literature examining SRI adoption among Madagascar's coastal farming communities, areas which experience greater cyclone exposure and where the tropical climate and soil types present different growing challenges.

Of the studies looking at the factors contributing to farmer adoption of SRI in Madagascar, a range of constraints have been hypothesized. These include the prevalent belief among farmers that SRI is more labor intensive (Moser & Barrett, 2003), particularly at the onset (Uphoff, 2007), the prohibitive cost of hiring labor (Serpantié & Rakotondramanana, 2014), limited access to resources such as manure and other organic fertilizers (Rakotovao et al., 2021; Serpantié & Rakotondramanana, 2014), challenges with controlling paddy water levels (Berkhout & Glover, 2012; Minten & Barrett, 2008; Stifel et al., 2003), limited extension services (Minten & Barrett, 2008), as well as land tenure (M. Freudenberger, *personal communication*, December 2020). In addition, ethnic tribe affiliation (Moser & Barrett, 2003), as well as deep attachment to customary ways of rice production[9] (Hume, 2006; Moser & Barrett, 2003; Uphoff, 2007) and a general hesitation to divert away from ancestral agricultural practices (Styger et al., 1999) may also be strong contributing factors. Indeed, the role of culture is increasingly acknowledged within the agricultural technology adoption studies literature (Ruzzante et al., 2021).

In terms of depth of adoption, in Madagascar and around the world, it has been observed that farmers adopt aspects of a technological "package" that they find most suitable to them (e.g., Ly et al., 2012), but few studies have looked at the reasons why some components of SRI are adopted over others (Tezer, 2012). Research in Madagascar has shown that transplanting seedlings singly, followed by transplanting young seedlings, are the components most often adopted, while transplanting along a line/grid pattern was the least likely step to be followed (Moser & Barrett, 2003; Tezer et al., 2012) - all of which are steps typically carried out by women and children. Lastly, weeding, considered a major obstacle to intensification in general (Leonardo et al., 2015), is often omitted due to the considerable extra labor required (Rakotomalala,1997; cited in Takahashi & Barrett, 2014).

Furthermore, due to the gendered division of labor of rice production, men and women have different needs and attitudes, which may shape their willingness to adopt various components of SRI (Jost et al., 2016; Resurreccion et al., 2008). For example, in Madagascar, men prepare the rice paddies using zebu (fatty humped cattle) or spades, while women and children are heavily involved in transplanting and harvesting (Achandi et al., 2018). There has been some research conducted on the social implications of adopting SRI,

[9] The Malagasy term for traditional rice growing practices is "fomban-drazana" [ways of the ancestors].

such as the work of Hansda (2017) which examined the effects of SRI adoption in India on social dynamics along the lines of gender, class and caste, and Takahashi and Barrett (2014) examined implications of SRI adoption on children. However, only a small number of studies have given specific attention to gender dimensions of SRI adoption (e.g. Resurreccion et al., 2008; Waris, 2017), pointing to the need for more gender-disaggregated research in order to more thoroughly understand these dynamics.

3.1.3 Theoretical frameworks

The process of technology adoption is complex and multi-faceted. In order to better comprehend the factors that contribute to people's decisions to accept or reject an innovation, a range of theories, collectively known as adoption-diffusion theories, have been developed. Since the 1970s, these theories have been applied to farmer adoption of agricultural technologies, defined by Ruzzante et al. (2021) as the “equipment, genetic material, farming techniques, and agricultural inputs that have been developed to improve the effectiveness of agriculture” (p. 2).

3.1.3.1 Intention-Behavior theories

Various theories propose that behavioral intention, such as decisions to adopt an innovation, serve as the precursor to behavioral change, with the intensity of intention seen as a predictor of the likelihood of behavioral change occurring. Two prominent sociopsychological theories that address this relationship are the Theory of Planned Behavior (TPB; Ajzen, 1991) and the Technology Acceptance Model (TAM; Davis, 1989), developed in the computer science field to specifically address drivers of technology adoption. Over the last decade, these theories have been increasingly used to study farmer decision-making around agricultural technology adoption, facilitated by advances in structural equation modeling (SEM; Rosário et al., 2022). For example, research applying SEM to a TPB framework found that intention significantly predicted the number of sustainable agricultural practices adopted among farmers in Ethiopia (Mutyasira et al., 2018). Similarly, authors using SEM with a TAM framework to explain farmer technology adoption decision-making among smallholders in Thailand found attitudes to significantly predict adoption intention (Saengavut & Jirasatthumb, 2021).

TPB and TAM, both extensions of the Theory of Reasoned Action (TRA; Ajzen & Fishbein, 1980), are closely related and share some overlap. Both models acknowledge the role of attitudes, the favorable or unfavorable views towards a behavior, in adoption decisions (Figure 3-1). Indeed, within the smallholder farmer adoption literature, positive attitudes towards a particular behavior have been shown to strongly influence intention to adopt that behavior (e.g., Lalani et al., 2016). However, whereas TPB considers the role of perceived behavioral control (or self-efficacy) and social influences, such as subjective norms (SN),[10] in shaping individuals' intentions to adopt a particular behavior, TAM focuses on perceived usefulness (PU) and perceived ease of use (PEOU) as central factors in forming attitudes on technology adoption. PU is the degree to which an individual believes that adopting an innovation will be useful to them, while PEOU is the degree to which an individual believes that using an innovation will be easy to use or learn.

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[10] There are two subdimensions of subjective norms (SN): injunctive norms (perceptions of "others" approving of behavior) and descriptive norms (perceptions of actions of others) (Ajzen & Fishbein, 2010).

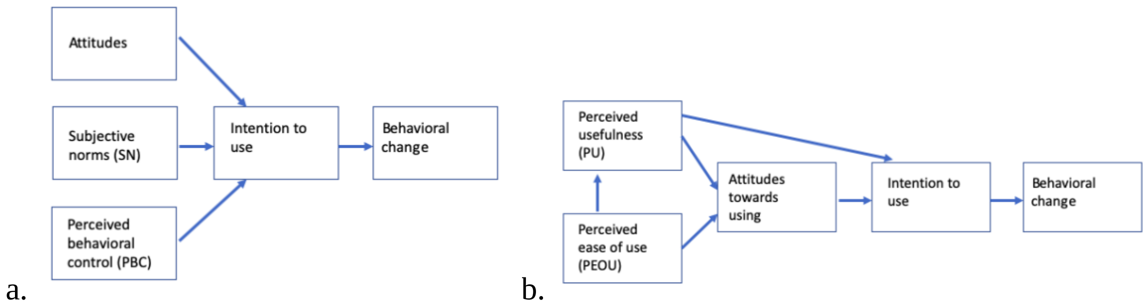

Figure 3-1. Conceptual frameworks for a) the Theory of Planned Behavior (TPB) and b) the Technology Acceptance Model (TAM).

3.1.3.2 Integrated TPB and TAM framework

While some argue against combining the two theories (e.g., Cheng, 2019) blended TPB-TAM frameworks are increasing in popularity as a way to provide a more comprehensive view of adoption behavior across various disciplines (e.g., Alam et al., 2018; Troise et al., 2021; Wang et al., 2022). Recently, researchers have utilized these integrated frameworks to investigate the adoption of agricultural technologies among farmers in various regions, including China (Dong et al., 2022), Indonesia (Laksono et al., 2022), and Ethiopia (Zeweld et al., 2017). Thus, for this study we developed a blended TPB-TAM framework to empirically examine the influence of perceived usefulness and perceived ease of use (TAM factors) in lieu of attitudes, as well as subjective norms and perceived behavioral control (TPB factors), on both intention to adopt and actual adoption of SRI (Figure 3-2).

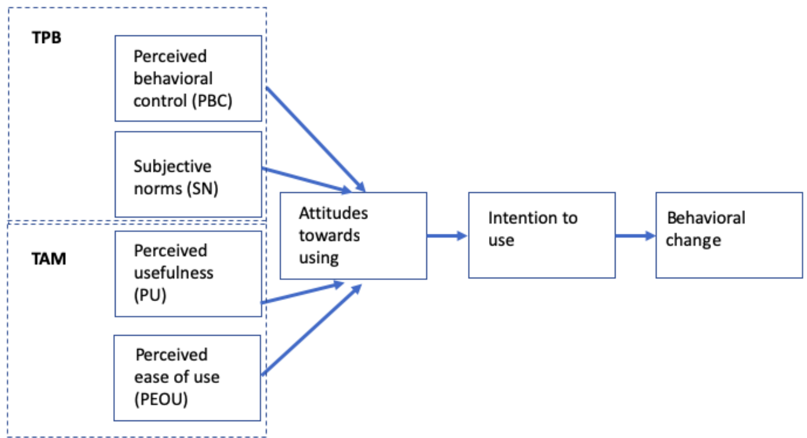

Figure 3-2. Integrated TPB-TAM framework

3.1.4 Objectives of this study

In this study, we sought to fill the gap in the understanding of SRI adoption dynamics among farmers in Madagascar, by taking a behavioral approach and applying a combination of the Theory of Planned Behavior (TPB) and the Technology Acceptance Model (TAM), which is novel in this context. Furthermore, despite SRI originating in Madagascar, there are no studies to examine who registers for and participates in SRI rice-growing trainings, the effectiveness of the trainings, and how identities impact SRI adoption decision-making. Using a case study of park-adjacent farmers living in southeastern Madagascar, we examine who signs up for SRI trainings, conduct a gendered analysis of adoption of certain components of SRI and not others, as well as look at differences between "adopters"[11] and non-adopters within the sample population.

Specifically, this study is guided by the following research questions:

1) What are farmers' perceptions in relation to SRI (perceived usefulness, perceived approval by others, perceived ability to successfully implement), do they differ between men and women, and do perceptions change after practicing the technique?
2) What are the factors that make farmers more likely to sign up ("registrants") for SRI trainings, and barriers to attending them?
3) Which factors predict intention to adopt, and does intention to adopt SRI predict actual adoption?
4) What are the characteristics of "adopters"?
5) Which factors predict which steps in the SRI package will be implemented, and what are possible reasons for not implementing certain SRI steps?

   - As there are defined gender roles within the rice-growing process, we also ask if there is a significant difference between men and women regarding the various components of SRI practiced?

   - Do farmer preferences for certain steps correspond to the SRI steps practiced?
6) What are the characteristics of non-adopters, and what are the barriers to adoption?

[11] As various steps within the SRI package are adopted, it is difficult to define an "adopter" (Tezer, 2012). In this study, farmers are asked to self-identify as to whether they consider having practiced SRI or not.

3.2. Methods

3.2.1 Study area

The study took place in 15 communities around Manombo Special Reserve and straddling paved Route National (RN) 12 in the Farafangana District of southeastern Madagascar, an area prone to cyclones with alarming levels of both chronic and seasonal food insecurity (Randrianarison et al., 2020; Rousseau et al., 2023). The population consists primarily of small-scale farmers and fishers, who grow rain-fed rice on hillsides as well as in lowland paddies one to two times per year. The primary rice-growing season (*vatomandry*) is from December to May, while the off-season rice (*varihosy*) is from June to November. Farmers have limited access to extension services, credit, irrigation infrastructure (Achandi et al., 2018), and inputs such as improved seeds and fertilizers, with degraded soils prevalent across the island (Berkhout & Glover, 2012). The general food environment is poor, with rural weekly markets located in communities along the paved road only. Off-farm work opportunities are scarce, and community members spoke of people migrating to as far away as Diego at Madagascar' northernmost tip to look for seasonal agricultural work. Additionally, there has been a rise in crime (e.g. incidents of theft and cattle banditry), partially driven by several years of drought conditions (De Berry, 2023).

Since 2019, the NGO Health in Harmony (HIH) has partnered with Manombo area communities to provide healthcare and support local conservation efforts. After listening to community members express interest in improving their rice production and techniques, HIH provided a free-of-charge training on organic SRI from October 2020 to

January 2021. The training used a hybrid model of agricultural trainers and demonstration plots to teach improved techniques during the *varihosy* rice-growing season. A total of 213 subsistence rice farmers, of which an estimated 70% were women, registered for the SRI training across five demonstration sites (Figure 3-3). During the training period, one of the two male agricultural agents visited each site once or twice per week. Participants were provided with rice seeds (three-month variety) and mechanical weeders (*sarcleuses*) were available to borrow from each of the demonstration sites. Lunch was also offered during the training.

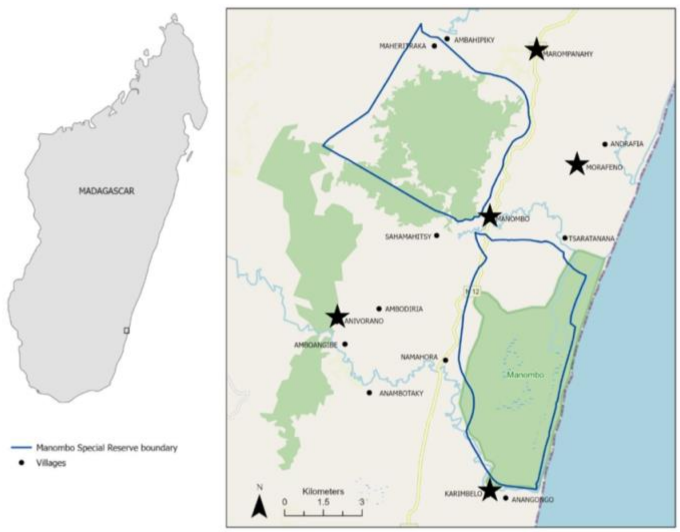

Figure 3-3. Map of study area.

Note: Green area is remaining forest. Blue lines demarcate Manombo Special Reserve. Yellow line is RN12 (paved national road). Stars indicate SRI demonstration sites.

3.2.2 Study design & data collection

An experimental design of treatment (SRI training registrants) and non-treatment (control) farmers from the same villages was conducted, and a pre-post, or repeated measures, design was used to measure the same individuals at two timepoints. To this end, two rounds of surveys were carried out; the first round in February 2021 post-training/prior to farmers practicing SRI, and the second round in April 2022. In 2021, 328 rice farmers were surveyed, 199 who had registered[12] for the HIH SRI training program (based on sign-up sheets provided by HIH), and 129 non-registrants that were selected as control in 15 participating villages. The number of "control" respondents per village was determined using PPS (percentage proportional to sample) of remaining eligible farmers in each of the villages. To collect information on actual adoption of SRI, including depth and intensity of adoption, as well as changes in perception of SRI among adopters, 277 (84.5% return rate) of the same farmers were re-interviewed in 2022 (repeated measures of the same individuals). The University of Vermont's Institutional Review Board (IRB; study #00001290) approved the study.

Survey data was collected on a number of time constant and time varying variables related to individual, household and farm characteristics, including household size (proxy for labor), education levels and assets (proxy for wealth), as well as details related to the SRI training (e.g., name of trainer, number of trainings attended). Gender-disaggregated data was collected on intention to adopt SRI (Survey 1), as well as actual adoption and depth (number of steps) of adoption (Survey 2). In addition, psychosocial (intrinsic) factors, commonly used in the TPB and TAM frameworks, such as perceived

[12] When asked the number of training days attended, it became apparent that a portion of respondents (20.1%, n=40) had signed up for trainings but indicated not actually attending any training days.

behavioral control (PBC), perceived usefulness (PU) and perceived opinion of others (subjective norms) were measured using Likert scale agreement (Supplemental Table 1).

In both surveys, open-ended questions were used to collect qualitative data. The first survey inquired about participants' intentions to adopt SRI and the aspects of the rice-growing process they least preferred. The second survey asked why non-adopters had not adopted SRI and why adopters had adopted certain steps[13] and not others, as well as advantages and disadvantages of the technique.

While the two more quantitatively focused surveys form the basis of the analysis, findings were further contextualized by qualitative data collected through focus groups (FGs) following an explanatory sequential mixed methods design (Creswell & Clark, 2018). Seven FGs with SRI training participants were carried out in August 2022 in six villages (one FG per village with the exception of Marompanahy in which two were conducted). These meetings were also an opportunity to share initial findings with community members and to validate results (“member checking”; Creswell & Miller, 2000). FGs were conducted in Malagasy, and recordings were then transcribed and translated into English.

3.2.3 Data analysis

3.2.3.1 Qualitative data

[13] Seed selection and management, while not unique to SRI (see Uphoff, 2023), was included because it comprised a major component of Manombo farmers understanding of SRI and was highly pertinent to focus group discussions.

Qualitative data from the focus groups, as well as responses to open-ended responses in the survey, were manually coded in NVivo Mac (release 1.7.1) as a way to both reflect and interact with the data (Savage, 2000), as well as to sort (recurring) responses into relevant categories for thematic analysis (Nowell et al., 2017). The thematic analysis was reviewed by two Malagasy and English-speakers to ensure its accuracy.

3.2.3.2 Quantitative data

Quantitative data was analyzed using SPSS version 28.0 (IBM Corp, 2021) and Mplus diagrammer version 1.8 (Muthén & Muthén, 2011), a latent variable modeling program.

As Ruzzante et al. (2021) point out, it is possible that trainers may purposely identify those farmers thought to be more likely to adopt, or vice versa. Therefore, a logistic regression in Mplus was used to analyze predictors of registering for the 2020 SRI training. Independent variables in the model included household education, wealth and size (a proxy for household labor availability), as well as land tenure, and gender. Independent sample t-tests were used to examine the statistical differences between adopters and non-adopters; chi-square tests were used to conduct a gender analysis on intention to adopt, adoption and depth of adoption. Following Noltze et al. (2012), a continuous variable model looking at the predictors of depth of adoption was also run using total number of steps implemented as the dependent variable. As research shows that farmers' actions are often based on past experiences (e.g., Denny et al., 2019; Liu & Brouwer, 2022), adopters were also asked about future intention to continue practicing SRI, and a Wilcoxon signed-ranks test in SPSS was used to conduct a paired difference test of repeated measurements to examine changes in perceptions of SRI among those that practiced in 2022.

Lastly, structural equation modeling (SEM) was used to test causal relationships on intention to adopt and actual adoption of SRI using a blended TAM-TPB framework. Confirmatory factor analysis using maximum likelihood (ML) estimation was used to create the latent constructs for perceived usefulness (PU) and perceived behavioral control (PBC) from a set of statements, as recommended by Foguesatto et al. (2020). Two factors with acceptable internal consistency ($\alpha > 0.7$; Guielford, 1965) were extracted explaining 63.9% of total variance (Supplemental Table 2). All retained items were significant with factor loadings of at least 0.40 (variables with loadings under 0.40 were excluded; Stevens, 1992). The PEOU construct was not included in the model due to large amounts of missing data on the single statement construct, nor were attitudes specifically measured *per se*. However, PEOU has been found to influence PU (e.g., Schaak & Mußhoff, 2018), and PU can be a proxy for attitude (N. Nguyen & Drakou, 2021).

Full information maximum likelihood (FIML), which treats missing data under the MAR (missing at random) assumption (Cham et al., 2017), was used to estimate the full SEM. In addition to the TAM-TPB constructs of PU, PBC and subjective norms (PEOU variable was not included in the final model because it contained a large amount of missing data), other variables in the model were those related to the SRI training (e.g., number of training days attended), demographic variables such as household size, assets owned (on a scale from 0 to 30), and highest household education level, as well as gender and land ownership/tenure. As Tezer (2012) found that Malagasy households in more isolated villages to be more strongly tied to traditional techniques, we also included village remoteness (coded as binary on/off paved road) as a variable in the model.

3.3 Results

3.3.1 Descriptive statistics

3.3.1.1 Characteristics of respondents

In the 2021 round of the survey, 35.7% (n=117) of farmers interviewed were male; 64.3% (n=211) were female (Supplemental Table 3). In the 2022 round of the survey, 35% (n=97) were male and 65% (n=180) were female. Of those interviewed in the 2021 and 2022 rounds of the survey, 60.7% (n=199) and 58.5% (n=162) had signed up for the SRI trainings provided by Health in Harmony, respectively, while 39.3% (n=129) and 41.5% (n=115) had not.

3.3.1.2 Farmer and farm characteristics

Slightly more than half of farmers (52.4%, n =172) reported cultivating lowland paddy rice once per year, mostly during *vatomandry* (96.5%, n=166). Additionally, before adopting SRI, nearly all farmers (97.9%, n=318) stated that they grew rice in the traditional way of the ancestors (*fomban-drazana*). In terms of identity and cultural beliefs, most respondents agreed that Malagasy farmers must grow rice (88.4%, n=289), and according to traditional methods (56.3%, n=184). However, only 14.4% (n=47) agreed that the ancestors would be upset if they did not grow rice in the same way as they once did. Rice plots were scattered and small, with the average distance (measured in minutes walking) from households to rice fields ranging from around 30 minutes for the nearest fields to almost 60 minutes for the farthest ones.

3.3.2 Perceptions related to SRI in the blended TAM-TPB framework

3.3.2.1 Perceptions of SRI attributes

In general, 2021 respondents perceived SRI to be extremely useful (Figure 3-4a). However, 42% of the respondents (n=136) agreed that SRI would be more time-consuming than traditional rice production. Additionally, most of the survey respondents found SRI easy to understand. Among those who responded "yes" to having some prior knowledge of SRI (n=145) before the 2020 training, 40% (n=58) found SRI easy to understand, while 30.3% (n=44) found it difficult to moderately difficult. Only a small percentage (9.7%, n=14) found the technique very complex, defined by Rogers' (1995) as the perception of being difficult to understand. A Mann-Whitney U test was conducted to determine if perceived ease of understanding differed by gender. The results indicated that there was no significant difference between men and women ($z = -0.01$, $p = .990$).

3.3.2.2 Perceived behavioral control

In 2021, 49.4% of respondents (n=162) expressed confidence in their ability to implement SRI successfully, while slightly fewer respondents (39.1%, n=128) felt confident in their knowledge about SRI (Figure 3-4b). However, the majority of respondents (92.9%, n=298) felt that they lacked the necessary tools to implement SRI successfully. Furthermore, while there was no significant difference between men and women in terms of perceived knowledge of SRI (z = -1.61, p = .107) or perception of having the necessary tools (z = -0.00, p = .997), there was a significant difference in their perceived confidence to implement it (z = -2.03, p = .042).

3.3.2.3 Subjective norms

Figure 3-4c. shows that before implementing SRI, the majority of survey respondents (83.8%, n=275) believed that their community would approve of them practicing SRI. Only a small number (2.4%, n=8) thought that their community might disagree or strongly disagree with it. There was no significant difference in perceived approval of others between men and women (z = -1.85, p = .064) .

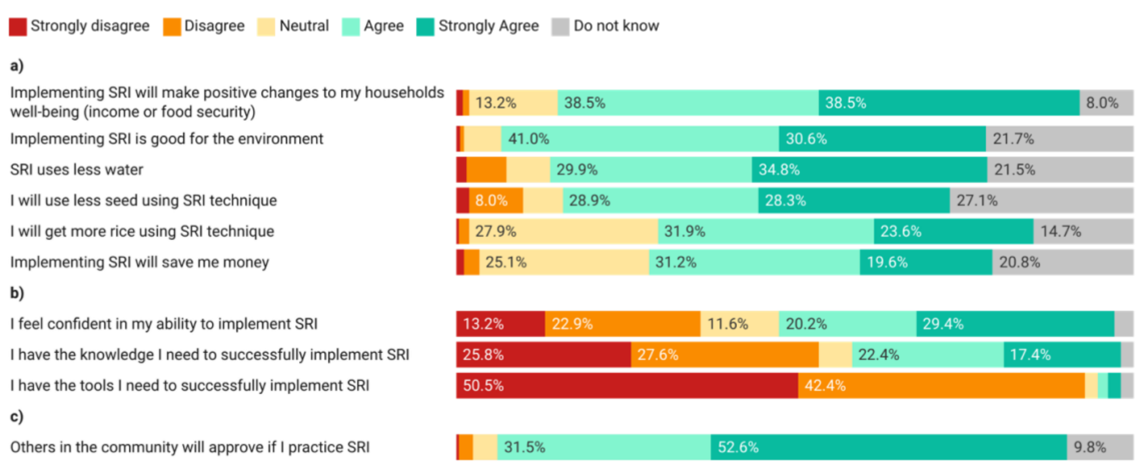

Figure 3-4. Agreement with statements to measure a) Perceived Usefulness (PU) of SRI, b) Perceived Behavior Control (PBC), and c) subjective norms

3.3.3 Predictors of training registration

The results of the logistical regression model showed household wealth to be a significant, positive predictor of training registration (p =.050). The odds of registering for the training increased by 10.4% (95% CI [0.998, 1.222]) for each additional asset (Supplemental Table 4). Other factors, such as gender, household education level and size, as well as land tenure, were not significant predictors of training sign-up.

3.3.3.2 Factors inhibiting attending trainings

Among those who had signed up for the training ("registrants"), 20.1% (n=40) were unable to attend the 2020 training sessions due to various factors, with caregiver responsibilities at home being the most common obstacle given. For example, one survey respondent said, “I took care of my ill spouse so I could not attend the training.” We also learned from focus groups that poorer families and those with younger children struggled to attend trainings because of needing to prepare food for those at home. One participant explained how her children are grown, enabling her to attend the training because when she returns home, the children already have food from working *joriny* [day labor]. Another participant shared, “Sometimes I cannot come [to the training] because I am busy looking for our food.”

Results of the statistical analysis from the quantitative survey data supported these lived experiences, indicating that lack of time, or "bandwidth," was a more important factor in attending trainings than wealth. For example, the number of training days attended and household assets (wealth) were not correlated (-.031, 95% CI [-.173,.112]). However, gender was not found to inhibit training participation; women did not attend significantly less training days than men (t = .781, p =.436).

3.3.4 Intended and actual adoption of SRI

3.3.4.1 Intention

Of the farmers interviewed, 89.7% (n=291) stated that they intended to practice SRI generally, regardless of training participation. One-fifth (21%, n=61) of respondents planned to implement the technique on all of their fields, while 79% (n=230) planned to implement it on a portion of their fields (Figure 3-5). Less than 1% (n=3) said that they did not intend to practice the technique in the future, and 9.2% (n=30) were still undecided. Additionally, because many more women (7.7%, n=25) than men (1.5%, n=5) were still undecided, women were significantly less likely to express intentions to adopt SRI than men were (χ^2= 4.96, p =.026).

3.3.4.2 SRI adoption

After one year, 21.9% (n=60)[23] of farmers indicated that they had tried SRI in the past year (though the number of steps implemented varied), compared to 89.7% who

[23] However, 101 respondents indicated practicing at least one of the steps in SRI.

expressed intention to adopt in 2021. There was no significant relationship found between respondents' intention to adopt SRI in 2021 and actual adoption in 2022 (χ^2= 3.98, p =.137).

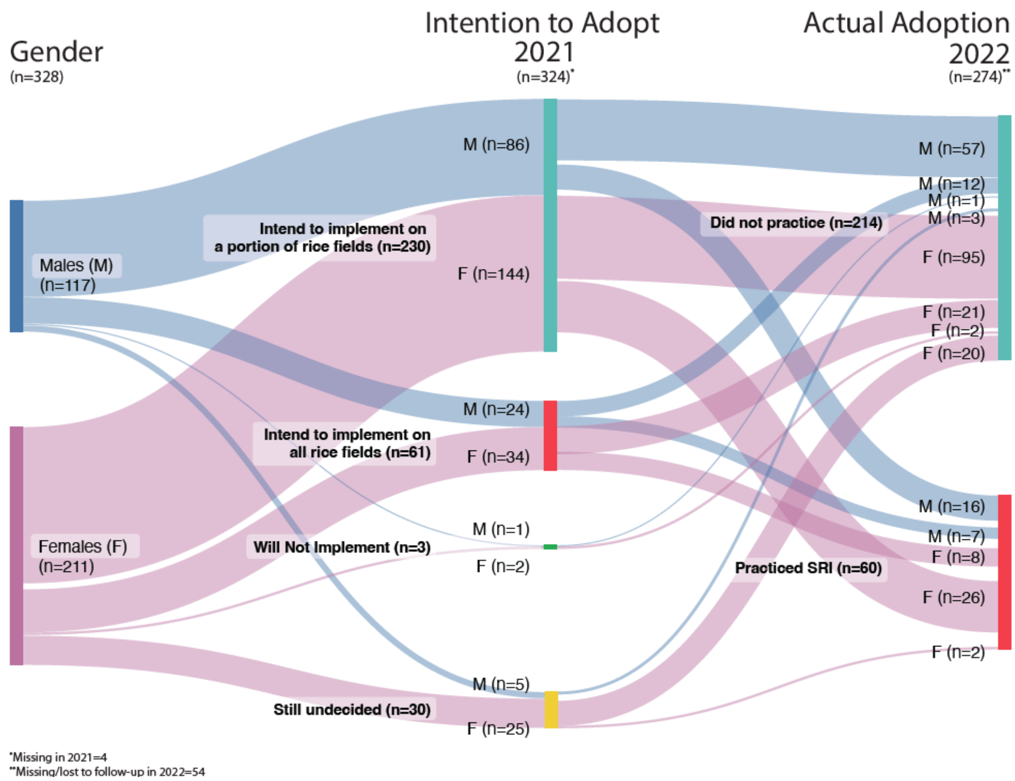

Figure 3-5. Number of farmers (gender-disaggregated) that stated intention to practice in 2021 compared with those that responded affirmatively to practicing SRI in 2022.

3.3.4.3 Future intended adoption

Results show that experience practicing SRI supported farmers' intentions to practice in the future, but regardless of adoption in 2022, nearly all respondents (91.7%, n=252) expressed willingness to practice at some point in the future. Of those that stated intention to practice in the future, 28.3% (n=60) were SRI practitioners who plan to continue, and 70% (n=190) would be new adopters.

3.3.5 Characteristics of adopters

"Early adopters" were spread across 12 of the 15 villages surveyed and came from both "on road" and more remote villages. Adopters were 61.7% (n=37) female and 38.3% (n=23) male. Using a chi-square test, women were not significantly more likely to implement the technique than men ($\chi^2 = 0.29$, $p = .591$). Furthermore, while only 35.4% (n=57) of registrants trialed SRI on a portion or all of their fields (Table 3-2), nearly all (95%, n= 57) of the 60 adopters were training registrants (less than 3% of control group trialed SRI).

Table 3-2. *Percentage of respondents who adopted SRI in 2022*

Respondent category	Adopt	Non-Adopt	Total
Training registrants	35.4% (n=57)	64.6% (n=104)	161
"Control"	2.7% (n=3)	97.3% (n=110)	113
	60	214	274

Note. Total $N = 274$.

3.3.6 Depth and Intensity of adoption

3.3.6.1 Intensity of adoption

While 12% (n=7) of adopters practiced SRI on 100% of their rice fields, the majority of adopters (85%; n=50) stated implementing SRI on 50% or less of their fields (Figure 3-6). One practitioner reported practicing SRI on 0% of their own fields, indicating that they were likely hired as a day laborer to cultivate on another's fields, a practice which was echoed in focus group discussions.

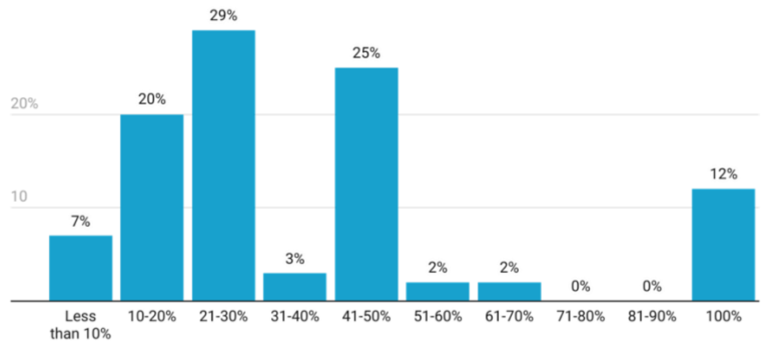

Figure 3-6. Percentage of rice fields on which SRI adopters trialed the technique

3.3.6.2 Depth of adoption

Very few households (n=4, 6.7%) were able to follow all of the recommended steps in SRI. Among adopters, an average of 6.7 SRI steps (SD=1.5) were practiced. Although 60 farmers self-identified as being SRI adopters, 101 respondents reported implementing at least one or more of the SRI steps, such as seed selection, soil preparation and water management – steps which may be less specific to SRI (Uphoff, 2023).

Transplanting young seedlings singly was the least implemented practice, with median days of transplanting for all adopters of 30 days (SD=17.2). Weeding with a *sarcleuse* was only implemented by about one-third (35%; n=21) of SRI practitioners; weeding was primarily done by hand. Of those that used organic fertilizer, most used zebu manure; very few made compost. Soil preparation, water management, selection and care of seeds and transplanting seedlings in a line were among the steps more commonly practiced. Despite predictions, no significant differences between men and women in terms of the steps implemented were identified using chi-square tests (Table 3-3). This could be a result of respondents answering for the whole family rather than their individual experience with SRI. Furthermore, in non-polygamous regions of Madagascar, research has shown that agricultural decisions are typically made jointly within the husband-wife dyad (Achandi et al., 2018).

Table 3-3. Summary table of SRI steps implemented among all respondents and "adopters" (gender-disaggregated)

Steps measured	Percent respondents (n=101)	Percent adopters (n=60)	Percent male adopters (n=23)	Percent female adopters (n=37)	Test statistic
Transplant young seedlings	N/A	15.0	8.7	18.9	1.16 (n.s.)
Weed with *sarcleuse*	23.8	35.0	30.4	37.8	.34 (n.s.)
Transplant singly	54.5	75.0	78.3	73.0	.21 (n.s.)
Weed often	62.4	78.3	78.3	78.4	.00 (n.s.)
Use organic compost	60.4	85.0	82.6	86.5	.17 (n.s.)
Transplant in a line	64.4	95.0	95.7	94.6	.03 (n.s.)
Selection and care of seeds	79.2	95.0	95.7	94.6	.03 (n.s.)
Water management	80.2	95.0	95.7	94.6	.03 (n.s.)
Soil preparation	80.2	96.7	95.7	97.3	.12 (n.s.)

Note: n.s. = not significant at p =.05

Multiple linear regression was used to test which factors (gender, training days, household education, assets, size, and land tenure) significantly predicted depth of adoption (n=101). The overall regression model was significant, $F(7,255) = 13.84$, $p < .001$, $R2 = .28$. Participating in more trainings ($\beta = .409$, $p < .001$), as well as households with greater assets ($\beta = .219$, $p < .001$) and higher education levels ($\beta =.127$, $p = .036$), were associated with implementing more SRI steps (Supplemental Table 5).

3.3.6.3 Reasons for not adopting certain steps

In addition, we heard from FG participants that transfer of knowledge to other family members presented an obstacle to implementing SRI recommendations surrounding both transplanting and weeding. For example, one farmer told us that, although he attended the training, he was not able to transmit the information to his wife and children, those responsible for transplanting. As a result, they did not transplant early/singly along a line. Thus, as smallholder farms rely heavily on family labor, family inclusion in trainings is likely a more effective way to diffuse a new technique.

Table 3-4. Focus group (FG) participant explanations for not implementing particular SRI steps

Steps least practiced	**Exemplar quotes from FGs**
Transplanting seedlings singly/early	"If the rice field is too flooded, the small seedling will rot in the water." "The transplant is too small after eight days. It seems small for us." "We transplanted by two, not singly, because I worry that one is too risky. It might not survive. If one dies, at least the other one will grow."

Weeding with a *sarcleuse*	"It's a bit difficult to use this machine…if you are not used to use it, it's difficult to push it if the soil is too hard, so we just weed with hands instead." "It's difficult to push, sometimes it is blocked, it does not work properly. If you hire someone to weed with HIH sarcleuse, it does not work well. It is even faster for people to weed with hands instead. "I can use [*sarcleuse*], but my kids don't know [how to]. But I cannot work alone on the field. To finish work faster, we did the traditional technique."
Weeding often	"If you have money, you can hire people to weed it often."

3.3.7 Non-adoption

3.3.7.1 Adopters vs. non-adopters

"Non-adopters" account for 78.1% of surveyed farmers. Results from independent sample t-tests showed adopters having significantly greater mean household education levels, mean household assets, and average number of trainings attended than non-adopters (Supplemental Table 6). Of note, adopters attended an average of 4.81 training days compared to 1.63 days for non-adopters. In addition, there was no significant difference between men and women (χ^2 =.29, p =.591), or between landowners and non-landowners (χ^2 =.75, p =.387), in terms of SRI adoption. However, respondents living in remote (off road) villages were significantly less likely to adopt SRI than respondents living in less remote (along road) villages (χ^2 = 8.25, p =.004).

3.3.7.2 Reasons for non-adoption

During the April 2022 survey, respondents cited a lack of special "SRI seeds"[15] as the main reason they had not practiced SRI despite intending to do so. Many complained of either not receiving seeds or having them damaged/lost due to pests, fire, or theft. One respondent shared having eaten the seeds due to food insecurity. Other reasons included limited financial and human capital (labor, "know how"), and perceived time/labor-intensiveness of the new technique. There was no indication that the two back-to-back cyclones which struck the region in early 2022 played a role in the lack of adoption.

Focus groups (FGs) conducted in August 2022 revealed further complexities as to the reasons why SRI was not practiced. FG participants shared that, in addition to lack of appropriate seeds, access to fertilizer and water were the main challenges to implementing SRI. They also noted that SRI is viewed more as a supplemental practice meant to augment, not replace, traditional rice growing methods, and clarified that the significant amount of additional labor required for SRI was a major factor hindering its implementation during the primary rice cultivation period (*vatomandry*), such that most preferred to grow it during *varihosy*.

> If we also do SRI [along with traditional rice-growing methods] during *vatomandry* season, the [three-month] SRI rice is harvested while we are still working for the *vatomandry* [which typically takes 5-6 months].

[15] It is important to note that SRI itself does not require a specific type of seed (Barrett et al., 2021).

> During vatomandry, the hunger is very hard. You have to weed your cassava. If you use all your time for *vatomandry* only, other crops like cassava and sweet potatoes will be left behind.

However, farmers also shared their hesitation regarding practicing SRI during the *varihosy* season. Specifically, they expressed a “fear of standing out,” which appears to be less based on subjective norms (what others will think) and more related to increased vulnerability. For example, respondents mentioned concern that their rice fields would be more vulnerable to pests, such as rats and birds, if fewer farmers grew rice during *varihosy*. Several also expressed concern about exposing their rice harvest to increased risk of theft if they were to be among a handful of farmers growing rice during that season.

Moreover, the region has been plagued by a severe drought (ReliefWeb, 2021). Consequently, some farmers expressed apprehension about the drought-resistant capabilities of SRI. In the face of the changing climatic conditions, one farmer pointed out, “We should change to SRI, but due to lack of water, we just change the [variety] of sweet potatoes." Due to food insecurity exacerbated by the drought, FG participants repeatedly requested the provision of fast-growing seeds.

In addition to seasonal labor availability and climatic considerations, geographical location/distance of rice fields was also an important factor affecting farmers’ decisions. One respondent explained, “[Farmers practiced SRI] because these people have paddies with water around the village. But we do not have rice paddy with water, and our rice paddy is very far.” In more southern communities, farmers explained that they prefer to practice SRI during *vatomandry* because their rice paddies do not drain well and have too much water during *varihosy*. Because of risk of theft, some FG participants stated preferring that the SRI training be held on their individual plots rather than in collective demonstration sites, while others preferred learning first at the demo site, but wishing that the trainers would then provide individualized support by visiting trainees' plots separately. Overall, a desire for increased training support was expressed. "We need monitoring in the practice to check what we have done…the trainer should monitor the practice."

3.3.8 Changes in perceptions among adopters

A Wilcoxon signed-ranks test was used to determine the change in perceptions of all SRI practitioners before and after implementing SRI. The results indicate that perceptions of usefulness of the technique (e.g. increased well-being, SRI takes more time) did not significantly change. However, perceived approval from others decreased significantly (z = -4.40, p <.001) compared to 2021, while perceived ability to successfully implement the technique (perceived behavioral control) increased significantly (Supplemental Table 7). This implies that practicing SRI for one growing season had a positive effect on one's perceived ability to successfully implement SRI as well as changed their perception of how others viewed their behavior (Figure 3-7). Indeed, one focus group respondent shared that she was mocked by others for her sparse rice transplants.

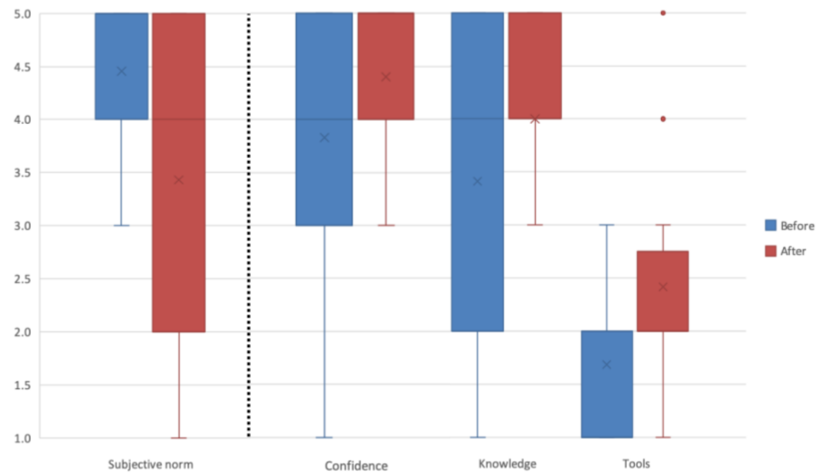

Figure 3-7. Median scores on a five-point Likert scale (1=strongly disagree; 5=strongly agree) for subjective norm and PBC (confidence, tools, knowledge) among adopters before (2021) and after (2022) practicing SRI.

The results were also gender-disaggregated to see if practicing SRI had similar impacts on both men and women. Women's perceived opinion of others significantly decreased (z = -4.03, p < . 001), while perceived confidence (z = -2.95, p = .003), knowledge (z = -2.52, p = .012), and perception of having sufficient tools (z = -2.35, p = .019) significantly increased. For men, only perceptions of having necessary tools to implement SRI significantly increased (z = -3.35, p < .001). There were no significant differences in men's perceived confidence (z = -1.08, p = .281), knowledge (z = -1.36, p = .173), or opinion of others (z = -3.35, p = .101).

3.3.9 Perceptions of SRI after adoption

Adopters primarily highlighted the benefits of SRI with regards to rice yield and harvest timing (Supplemental Figure 2). Specifically, as the three-month rice variety provided in the HIH SRI training program has a shorter growing period than local varieties, it was ready to harvest during the "hunger season," thereby reducing its duration and severity ("Harvest faster, eat rice early"). One focus group participant said:

> We try [the SRI technique], [because] we want to eat food. The climate is changing, the cultivation is also changing…Hopefully it will give us food faster. Food is the most important to us.

However, while some participants mentioned being able to sell excess rice due to improved food security, there was comparatively little discussion about economic aspects. Only three respondents noted that SRI decreases the need for rice seeds, and one participant recognized that it saves money. There was no mention of environmental benefits.

Among the 60 adopters, the majority (68.3%; n=41) did not find SRI difficult to implement, while 21.7% (n=13) found it difficult or very difficult. For those that found aspects of SRI difficult to implement, the main reasons given were not being accustomed to the technique (attachment to tradition/*status quo*) and lack of know-how, as well as the increased time and labor required. Similarly, the main disadvantages cited were that SRI is more labor intensive and time consuming.

3.3.10 Structural Equation Model (SEM)

A SEM was implemented to predict the factors supporting intention and adoption of SRI (Table 3-5). According to the final model (lowest AIC), household education level (β = .066, p = .014) and subjective norms (β = .435, $p < .001$) were significant predictors of perceived usefulness (PU) of SRI, while the number of training days attended (β = .104, $p < .001$) was a significant predictor of perceived behavior control (PBC) (Supplemental Figure 3). PBC (β = .687, $p < .001$) and land tenure (β = .483, p = .026) emerged as significant predictors of intention to adopt SRI, while PBC (β = .222, p = .028), the number of training days attended (β = .140, $p < .001$), and household assets (β = .091, p = .001) were significant predictors of adoption. Gender, household education level, geographical isolation/remoteness of villages and household size did not have any significant effects on SRI adoption.

Table 3-5. Structural equation model results using latent constructs of perceived usefulness (PU) and perceived behavioral control (PBC) as predictors of intention and actual adoption of SRI

	Standardized Estimate	Standard Error	p-value
Perceived Usefulness (PU) on			
- Gender	-0.143	0.146	.329
- Village remoteness	-0.119	0.180	.508
- Number of trainings	0.015	0.022	.486
- Education	0.066	0.027	.014
- HH assets	-0.014	0.027	.610
- HH size	-0.034	0.030	.248
- Land tenure	0.441	0.233	.059
- Subjective norm	0.435	0.099	.000
Perceived Behavioral Control (PBC) on			
- Gender	-0.186	0.138	.180
- Village remoteness	0.090	0.174	.605
- Number of trainings	0.104	0.020	.000
- Education	0.019	0.026	.484
- HH assets	0.040	0.026	.124
- HH size	-0.028	0.028	.307

- Land tenure	0.250	0.221	.258
- Subjective norm	0.141	0.095	.139
Intention to practice SRI on			
- PU	0.128	0.120	.286
- PBC	0.687	0.134	.000
- Gender	-0.036	0.223	.169
- Village remoteness	-0.029	0.274	.915
- Number of trainings	0.057	0.053	.285
- Education	0.018	0.039	.644
- HH assets	0.033	0.050	.515
- HH size	0.025	0.042	.548
- Land tenure	0.483	0.217	.026
- Subjective norm	0.098	0.118	.405
Actual adoption of SRI on			
- PU	0.018	0.101	.862
- PBC	0.222	0.101	.028
- Gender	0.039	0.156	.802
- Village remoteness	0.175	0.180	.333
- Number of trainings	0.140	0.025	.000
- Education	0.041	0.027	.130
- HH assets	0.091	0.027	.001
- HH size	-0.053	0.033	.108
- Land tenure	-0.452	0.239	.059
- Subjective norm	-0.123	0.113	.277

3.4 Discussion

Our study reveals that Manombo area farmers perceive SRI as relatively easy to implement and understand, as they recognize its benefits, especially in terms of increased food supply. This positive perception results in a high willingness to practice it. However, farmers face a range of constraints that hinder their adoption efforts. These include vulnerability to crop loss, limited access to essential tools and inputs, difficulties in managing irrigation and field drainage, and inadequate training for all family members involved in rice cultivation. Additionally, labor shortages during peak periods of labor, food insecurity and limited financial resources for hiring laborers have an impact on the overall adoption of SRI, as well as the specific SRI components practiced. As our research has demonstrated, farmers tend to exhibit selective adoption of specific aspects of SRI that align with their existing farming systems, particularly when they have strong cultural ties to tradition. Conversely, they are more inclined to reject elements perceived as less feasible.

SEM results showed that attending trainings and higher perceived behavioral control (PBC), as well as household wealth, were significant predictors of SRI adoption. Attending trainings and practicing SRI for one season also increased farmer PBC (confidence, know-how, tools) to successfully implement SRI – particularly for women. However, it is still important to consider what may be lacking in the trainings, and areas for improvement to achieve higher take-up of the technique.

Furthermore, while we did not find gender[16] and farm characteristics, such as household education level and size, to play significant roles in adoption decisions, households with higher education levels were more likely to register for trainings, and wealthier households were more significantly likely to adopt SRI, and to a greater depth. In addition, households in more remote villages were significantly less likely to adopt SRI than those in more accessible villages. Thus, access to trainings, either physically or because of financial and human capital, is an important consideration.

[16] This could be a reflection of women farmers in Madagascar being comparatively more empowered than women in neighboring SSA countries (Achandi et al., 2018).

3.4.1 Reducing barriers to adoption

Despite the intention-behavior framing of both TPB and TAM, our study reveals an intention-behavior gap similar to what has been recently reported in other agriculture practice adoption studies (e.g., Niles et al., 2016; Rodríguez-Cruz et al., 2021). While most respondents expressed very strong intentions to trial SRI on all or a portion of their rice paddies, very few actually practiced, especially among those that did not register or attend trainings. Many factors contribute to this gap, and it is therefore important to consider strategies to lower the entry point and reduce the barriers to SRI adoption.

For example, while farmers in our study traditionally practice local seed exchange, lack of access to quality seeds deemed suitable by farmers was the most commonly cited reason for not adopting SRI (since HIH gave out a fast-growing rice variety to SRI trainees, it is understandable that farmers would believe that SRI required a specific type of rice). Soil infertility and limited access to fertilizers and irrigation infrastructure were also reported as major obstacles, providing further evidence that farmers simply do not have the resources needed to adopt SRI (Freudenberger & Freudenberger, 2009). Farmers also expressed perceived inability to implement SRI successfully due to insufficient tools. Thus, in extremely limited resource settings such as rural Madagascar, it is crucial to support community seed networks, with access to farmers' preferred seed varieties (Hume, 2006), provide basic tools in an equitable manner, while also bolstering farmers' capacity to rebuild healthy soils and construct improved water systems. From a technology "fix" perspective, Jain et al. (2023) suggest that adopting improved varieties of rice is the best strategy for increasing rice production in sub-Saharan

Africa, especially drought-tolerant and pest-resistant varieties. However, as research has shown female farmers to be less likely to purchase fertilizer and drought-resistant seeds (Carranza & Niles, 2019; Voss et al., 2021), additional supports should be oriented towards them.

Multiple authors (e.g. Kamara et al., 2023; Loukes, 2015; Moser & Barrett, 2003) highlight that SRI's additional labor requirements during an already labor-intensive period can deter many farmers. Furthermore, labor scarcity during crucial stages of rice development can harm yields due to the time-sensitive nature of SRI and careful attention required. For instance, rice seedlings older than 7-10 days when transplanted may underperform, and uncleared weeds can impede rice plant growth (Loukes, 2015). To lessen labor demands, a flexible pedagogical approach is recommended, whereby farmers are encouraged to experiment with adaptations through participatory processes, although Noltze et al. (2012) caution against expecting excessive experimentation from farmers.

Examples of alternatives to SRI include Modified SRI (MSRI), which promotes transplanting seedlings at 14-16 days old (Duary et al., 2021), *Système de Riziculture Ameliorée* (SRA), considered by some as a "stepping stone" to SRI (Berkhout & Glover, 2012), and MAFF (*Mitsitsy Ambioka sy Fomba Fiasa*), developed in western Madagascar and translating to "saving seeds and cultural practices" (Vallois, 2005). Additionally, direct seeding or broadcasting rice seeds, rather than transplanting seedlings from a nursery, reduces labor and water management requirements (Ali et al., 2014; Uphoff, 2023), while also eliminating concerns regarding increased head carrying loads for women due to SRI nurseries being farther from fields (Waris, 2017). In fact, despite evidence suggesting that omitting specific core SRI components may affect the accrual of benefits farmers receive (Palanisami et al., 2013; Uphoff & Randriamiharisoa, 2002), Uphoff (2023) emphasizes that transplanting, for instance, is not mandatory for SRI. There is also research currently being conducted in China on a perennial rice variety (PR23), which would reduce labor, but not without potential drawbacks (Stokstad, 2022).

3.4.2 Reducing risk aversion

There is general agreement in the literature that risk-aversity among smallholders inhibits behavioral change (e.g., Kashem, 1987; Livingston et al., 2011; Pattanayak et al., 2003; Waldman et al., 2020). Thus, despite perceiving SRI to be beneficial in terms of food security (i.e. increased food supply, reduced hunger season) and relatively easy to understand and implement, Manombo farmers were deterred from implementing certain aspects of SRI, such as transplanting single, young rice seedlings, due to perceived risks. Similar risk-related reluctancies have been reported among farmers in the central highlands of Madagascar (Berkhout & Glover, 2012), south India (Taylor & Bhasme, 2019), as well as in Java where farmers discontinued the SRI planting method after snails ate their young seedlings (Arsil et al., 2019). Such high levels of food insecurity and reliance on rice to meet metabolic needs creates a situation in which risks outweigh any potential benefits (Taylor & Bhasme, 2019). Therefore, some form of crop insurance might enable farmers to take additional risks and trial SRI. However, it should be noted that female farmers are often more insurance-averse than men (Sibiko et al., 2018). Thus, as Jain et al. (2023)

recommend, it may be more effective to couple farming insurance with other risk reduction strategies.

3.4.3 Perceived behavior control (PBC) and training effectiveness

In this study, PBC was the strongest predictor of both intention and adoption of SRI, with the number of training days attended having a significant impact on both PBC and adoption. The number of trainings attended was also a significant predictor of the number of steps adopted – providing evidence of the effectiveness of repeated exposure to messages. Indeed, the treatment effect (registering for trainings) was also highly significant for adoption. However, while about one-third of registrants surveyed practiced SRI in 2022, training exposure did not result in spill-over effects to "untreated" farmers as Barrett et al. (2021) suggest in their research on SRI adoption among farmers in Bangladesh. Rather, our results support the assertion that natural spread of SRI is not a common phenomenon in Madagascar (Hume, 2006).

Therefore, in light of our finding that household wealth significantly predicted training registration and adoption, as well as recent research showing that SRI trainings had a significant positive impact on rice yields and household income among farmers (Barrett et al., 2021), it is vital that trainings are made especially accessible to those from more resource-poor households. Moreover, the primary reason for not attending trainings among registered farmers was related to caregiving duties. To address this issue, providing support such as childcare and meals for family members who are not attending the training sessions could help women, who often bear the burden or household reproductive duties, to participate more fully in productive roles, as well as simultaneously boosting their confidence in implementing SRI successfully.

Our study also echoes the recommendations made in previous studies of Malagasy farmers for more frequent, continuous and individualized technical support for farmers (Achandi et al., 2018; Moser & Barret, 2003; Tezer, 2012). As farmers living in remote villages were significantly less likely to adopt SRI, providing additional support and oversight for remote farmers, such as on-farm trainings, is essential. While expensive to implement (Dearing, 2009), the importance of extension-intensity in the adoption of agricultural technologies is well-established (e.g., Moser & Barrett, 2003). Indeed, extension agents, what Dearing (2009) calls "paid change agents," can exert enormous influence over farmer behavior. In the Madagascar context, extension agents play a critical role in disseminating information, and a higher ratio of extension agents to farmers would allow for more individualized support. Additionally, Manombo farmers expressed interest in cross visits (e.g., visiting other demonstration sites or other farmers' fields), what Black (2016) considers a "key learning tool" for the diffusion of SRI.

As women were significantly less confident in their ability to implement SRI, particular focus should be placed on increasing their perceived confidence through increased training opportunities. Furthermore, as women and men have specific training needs based on the roles that they play in rice cultivation, tailoring trainings and considering their differential daily schedules is critical. For example, as women in Madagascar are predominantly responsible for transplanting, trainings on transplanting of young, single seedlings in a line should be directed towards them. Women could also be trained as farmer-leaders; Berkhout and Glover (2012) report some female farmers in Madagascar becoming experts in SRI transplanting methods and traveling from community to community teaching others, which has been shown to facilitate transfer of information to other women (Achandi et al., 2018). Waris (2017) also recommends "harnessing the potential" of women's groups. Lastly, given the importance of family labor dynamics within the rice-growing process, trainings could also be more effective if they were multigenerational and family-inclusive, with a focus on empowering youth leaders. This could be accomplished through a series of cascade trainings as well.

3.4.4 Intensity and depth of adoption

In terms of intensity of adoption, our finding that only slightly more than one-tenth of adopters reported implementing SRI on all of their rice fields is not surprising. It reflects the conservativeness commonly observed among farmers (in both the Global North and South) during initial trials of a new innovation (Pannell et al., 2006). Similar findings were reported by Moser and Barrett (2003) among SRI adopters in central and eastern Madagascar. Another study conducted by Graf and Oya (2021) among SRI farmers in Ghana revealed that the intensity of adoption was dictated by labor availability for transplanting (e.g., financial resources to hire day laborers and/or number of children in the household). In addition, the authors point out that poorer farmers were able to adopt with greater intensity due to having smaller land parcels.

As the Diffusion of Innovation (DOI) theory states, perceived attributes of an innovation, such as compatibility with existing worldviews and systems, are importance for adoption (Rogers, 1983; 2003). For instance, researchers have attributed low SRI adoption rates in Indonesia to farmers' perceptions of its incompatibility with traditional farming practices (Arsil et al., 2022). Likewise, in terms of depth of adoption, only aspects of the technological "package" that farmers find suitable will be adopted (Ly et al., 2012). Thus, our finding that farmers did not practice frequent weeding or use a *sarcleuse* often, documented in other contexts as well (e.g., Deb, 2020; Ly et al., 2012), may be attributed to our discovery that weed control was farmers' least preferred aspect of the rice-growing process. This is also in line with Uphoff (2001) who reported that farmers in the Ambatondrazaka region of Madagascar considered weeding, and weeding with a *sarcleuse* in particular, to be the most challenging aspect of SRI. Weeding is also among the most time-consuming components; Rakotomalala (1997) report that weeding constitutes 62% of the extra labor required by SRI. Making *sarcleuses* more easily accessible (Uphoff, 2001), easier to use, and adapted to local rice paddy conditions, could reduce barriers to adopting this step. For example, an alternate version of the *sarcleuse* has been developed in India using bicycle parts (Prabu, 2016), and the organization Earth Links has been developing open-source blueprints to make it less expensive for farmers to craft their own SRI tools (Carnevale Zampaolo et al., 2022).

In addition to weeding, transplanting young seedlings singly was also among the least practiced steps. While these findings differ slightly from earlier research in Madagascar, which showed that planting singly was the most commonly implemented step while planting along a line was seldom practiced (Moser & Barrett, 2003; Tezer et al., 2012), they align with findings from several studies in Asia (Arsil et al., 2019; Palanisami et al., 2013) and West Africa (Graf & Oya, 2021). The lower rate of transplanting single seedlings could be partially attributed to the training approach used, as some participants reported being taught to plant two seedlings at once.

Moreover, similar to challenges encountered in India regarding skilled labor needs (Channa & Syed, 2017), both SRI transplanting techniques and weeding with a sarcleuse require the acquisition of new skills, which have a learning curve. For instance, Malagasy farmers have reported initial difficulties in learning to transplant young plants (Berkhout & Glover, 2012; Moser & Barrett, 2003). These are also two of the most laborious aspects of SRI (Berkhout & Glover, 2012; Rakotomalala, 1997), although this may be context dependent, as multiple studies from Cuba to Cambodia have found transplanting to be quicker under SRI (Graf & Oya, 2021; Perez, 2002; Resurreccion et al., 2008).

Furthermore, SRI has been shown to increase yields when steps are employed in harmony (Moser & Barrett, 2003; Palanisami et al., 2013; Varma, 2019), but the challenges associated with implementing the entire package may overwhelm and discourage potential adopters. To address this, extension agents can employ a “salami-slice strategy” by gradually teaching steps incrementally based on farmers’ experience and comfort level. This pragmatic approach allows adopters to acquire new skills while reaping additional benefits with each added step (Berkhout & Glover, 2012; Palanisami et al., 2013). For example, although weeding may reduce some wild food diversity in rice fields (Deb, 2020), each additional weeding delivers increased yields (Katambara et al., 2013). The essential is to provide farmers with a foundational understanding of the basic SRI principles, such as the importance of early transplanting to establish healthy plants, transplanting singly to minimize competition among plants and weeding with a *sarcleuse* to improve soil quality by increasing oxygen to the roots (Uphoff, 2001). By establishing this foundation, farmers will better comprehend the significance of each step and the advantages of incorporating them.

3.4.5 Critique of sociopsychological models

While underscoring the significance of trainings and farmers' perceived behavioral control in the adoption of SRI, this study also highlights the limitations of sociopsychological models in fully encapsulating adoption dynamics among smallholder farmers in resource-poor settings such as rural Madagascar. Notably, this research clearly demonstrates that intentions do not drive behavior change, casting doubt on the applicability of Western-developed frameworks in this setting. Furthermore, the role of subjective norms on farmer decision-making is more complex than the theoretical models allow for – i.e., while other community members may approve, there is real vulnerability to crop loss from theft, as demonstrated in our FGs results.

Additionally, as much is out of the control of individuals in agroecosystems that are collectively managed and linked to community agriculture structure, rather than individual ownership structure (e.g., affecting the ability to irrigate/drain fields or the desire to add organic fertilizer when rice paddies are conjoining), there is a need for a more integrative approach that goes beyond the focus on individual and household decision-making. Therefore, future work should encompass the more nuanced factors shaping adoption decisions such as social relations (Dearing, 2009; Taylor & Bhasme, 2019), seasonal labor bottlenecks (physical and financial), gender dynamics, and cultural beliefs regarding relationship to land and land-use, which are often overlooked (Ruzzante et al., 2021). Moreover, to complicate the concept of relative advantage, the analysis should take into account conflicting worldviews, such as a tendency to value tradition and age-old practices (*argumentum ad antiquitatem*) over new ones (*argumentum ad novitatem*). Participatory Action Research (PAR) and similar approaches, which require longer time periods and a constant presence in communities, would help to further elucidate the best way for farmers to adopt SRI, given its flexibility and emphasis on working with farmer communities to resolve challenges (Castellanet & Jordan, 2002; Kindon et al., 2007; Méndez et al., 2017).

3.4.6 Study Limitations

To comprehensively grasp the complexity of the adoption-diffusion process, it is necessary to view adoption as a continuum rather than a binary decision at a specific point in time (Feder et al., 1985; Han & Niles, 2023). It is therefore crucial to move beyond a pro-adoption bias inherent in adoption-diffusion theories (Straub, 2009), and to consider where farmers are in their individual decision process or stage of change (Dearing, 2009), taking into account the possibility of disadoption. As Rogers (1983; 2003) explains, the spread of a new technology through a population, or diffusion, occurs as a sequence of individual adoptions over time (aggregate adoption). Thus, diffusion involves a series of implementer phases based on the timing of adoption relative to others in the community – ranging from innovators (first adopters) and early adopters to late adopters, and even nonadopters. As SRI has only recently been introduced into the Manombo area by HIH, our study likely only captured the early phase of its diffusion. Therefore, a longer exposure horizon is needed to account for the time lag associated with the uptake of new practices. For instance, based on the favorable response towards intentions to implement SRI at a later point in time, we might expect to see additional adoption by so-called "latecomers."

Furthermore, it has been observed in previous studies that while incentives (such as free seeds) may initially boost adoption rates, farmers often abandon practices once the incentives are discontinued (Andersson & D'Souza, 2013; Moser & Barrett, 2003). Therefore, future research should consider conducting longitudinal cohort studies that track the "true" adoption process, including monitoring the number of "droppers" among adopters, as well as identifying adoption latecomers over an extended period of time, preferably after the conclusion of a project (Andersson & D'Souza, 2013). Additionally, since smallholder farms are typically family-operated with multiple decision-makers within the same household, it is crucial to consider the role of the family in the innovation adoption process (Salamon et al., 1997; as cited in Perret & Stevens, 2006). Further research is also needed to understand the drivers of innovativeness, beyond any possible incentives, which may encourage early adoption relative to others in the community. Additionally, it is critical to examine the social implications that arise after adoption, as highlighted by Theis et al. (2018).

Our study also had several field-level limitations that could have affected results. First, time constraints prevented us from conducting farm site assessments which would have allowed for examination of plot-level factors affecting SRI adoption, such as biophysical constraints (e.g., proximity to water sources, ability to drain fields, soil types). Given the long distances to reach rice fields (30-60 min), plot-level analysis /geographic characteristics of adopter and non-adopter rice fields would be important to include in future analysis. Additionally, although we kept track of why some participants were not available for interviews (e.g., in the fields, went to town, migrated north, etc.), logistical constraints limited us to just one day per village, possibly biasing results towards those who were physically present and available for interview. Lastly, while our finding that intention to adopt SRI practices does not lead to adoption is not uncommon in the literature, our results could have also been influenced by confirmation bias, where respondents over-indicated their intention to adopt SRI practices.

3.5 Conclusion

This study highlights the importance of extended trainings and farmers' perceived behavioral control in promoting the adoption of sustainable intensification practices, such as SRI, over other factors such as perceived usefulness and perceived ease of use. Consequently, interventions should not only seek to comprehend the underlying motives behind farmers' decision-making but also prioritize enhancing farmers' confidence, knowledge, and skills through more intensive and inclusive trainings, along with ongoing support. It is particularly important to provide targeted support to women, whose perceived behavioral control can be enhanced through practical experience with the technique. At the same time, increasing incentives offered and employing methods to reduce perceived risks of trialing a new agricultural practice, as well as considering the structural barriers to adoption, such as infrastructure and institutions, are critical. This work is important because it not only adds to the academic conversation in adoption studies, but from an applied standpoint, it can also inform conservation and development policies and interventions to achieve better outcomes for smallholder farmer food security and livelihoods.

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CHAPTER 4: FORGOTTEN FARMERS AND THE RISKY ROAD AHEAD

Ataovy dian-tanalahy: jereo ny aloha, todiho ny afara
(Behave like the chameleon, one eye on the future, one eye on the past)
- Malagasy proverb

The objective of this dissertation was to understand food (production) system resilience among smallholder farmers in Madagascar by examining farmer decision-making. In this concluding chapter, I first summarize the lessons learned vis-à-vis the complexities of adaptive behavior among smallholders and the challenges to smallholder food system transformation and resilience in Madagascar, as well as situate Manombo area farmers within a 'surviving to thriving' resilience continuum. I then consider farmers' individual and collective characteristics of resilience using the 7 C's of resilience as a framework. Lastly, I examine the particular vulnerabilities within this low-resource context that affects these elements of resilience, to highlight who is coping or has the capacity to adapt and potentially transform, as well as offer some reflections and general recommendations on how these 'forgotten' farmers might be supported in moving towards a more resilient food future.

4.1 Challenges to adaptive and transformative change

Across chapters, we have observed the ways in which Manombo area farmers approach the various agricultural pathways recommended to build the resilience of food production systems (i.e., agroecological diversification, climate-resilient agricultural practices, and sustainable intensification) when food security and nutrition (FSN) is the goal. That is, we see how cognitive and socio-cultural factors, as well as farmer and farm-level characteristics, influenced farmers' intentions and actions to procure food during periods of food shortage (Chapter 1), autonomously adapt their agricultural practices in the face of climate change (Chapter 2), or trial a new agroecological approach to rice farming after receiving NGO-sponsored training (Chapter 3). However, in doing this analysis, it becomes clear that a look at individual characteristics alone is not sufficient, as farmers are limited in their ability to enact many changes on their own, absent larger structural alterations. In addition, there is an underlying persistent tension between individual decision-making and sociocultural constraints.

In the first chapter, already diversified farming systems (a fundamental condition and form of 'insurance' for most smallholder farmers; Chayanov, 1986; Santiago-Vera et al., 2021) prove insufficient to ensure year-round FSN for Manombo area farmers. In a similar vein, Perfecto et al. (2019) report that agroecological diversification practices among Puerto Rican coffee farmers were not resilient to the extreme disturbance caused by category 4 Hurricane Maria. Thus, an emphasis on agrobiodiversity to enhance food production system resilience, as well as measurements of farm production diversity, is limiting. Rather, a broader understanding of the importance of both cultivated and wild food diversity in food procurement strategies to meet FSN needs is warranted.

Furthermore, pluriactivity (aka income diversification), defined as a blend of both agricultural and non-agricultural activities (Moumenihelali et al., 2020), is an essential coping strategy for Manombo area farmers as well as smallholder farmers worldwide (White, 2020). For example, female respondents explained how they typically engage in extra production of traditional handicrafts, such as weaving mats and baskets, during the lean season, while men may migrate north to look for wage labor, a common phenomenon reported throughout Madagascar (e.g., Mariel et al., 2023). Therefore, simplistic categorizations of occupation (e.g., farmer) fail to recognize the complex strategies which have evolved to assure survival in these systems.

In Chapter 2, we see clearly that farmers' belief in problems (e.g., climate change) and acknowledgement of risks (e.g., threat to food security and livelihoods) is not the issue. Despite expressing strong desires to adopt practices, farmers face numerous constraints that hinder their ability to adapt (Chapter 2) and transform (Chapter 3) their agricultural systems. This underscores how the responsibility for change cannot solely rest on individual farmers or farm households, as there exist a multitude of factors (e.g., sociocultural, socioeconomic, and sociopolitical) beyond their control. Thus, using behavioral intention theories, which center on individual choices, overlooks the complex web of influences that shape and govern decision-making at various levels. In Table 4-1, I use the example of SRI to illustrate how farm management decisions can be influenced or impeded by factors from the micro to macro levels. In Table 4-1, I use the example of SRI to illustrate how farm management decisions can be influenced or impeded by factors from the micro to macro levels.

Table 4-1. Adoption of various SRI steps as an example of how farm management decisions are affected across levels

	Micro level (Individual/household)	Meso level (Community)	Macro level (Markets & institutions)
Seed selection	Farmers can seek out desired seeds that are available	Community seed exchange	Dictates what seeds are available on the market

Organic compost	Farmer can make compost, but often limited by lack of zebu and distance to fields	Insecurity, farmers are afraid to have too many zebu; farmers worried that adding organic fertilizer to their fields will just wash into neighbors' fields	Lack of affordable organic fertilizers available for purchase
Water management	Men primarily responsible for water management	Conjoining rice fields make it difficult to add water or drain fields	Infrastructure projects, such as irrigation canals
Transplanting decisions	Household labor availability, women and children responsible for transplanting	Opinions of others	
Weeding decisions	Household labor availability, dislike of weeding		Sarcleuses not available for purchase locally

Furthermore, rather than adapting existing practices or shifting to new approaches, most farmers in the Manombo area are fixed at the 'surviving' end of the resilience continuum, primarily concentrating on coping strategies to obtain food.[24] Thus, it becomes evident that fulfilling basic human needs, particularly the need for food, is a driving force behind agricultural practices and decision-making processes in resource-poor, food-insecure contexts in which individuals are both producers and consumers. This observation aligns with theories put forth by human needs theorists, such as Abraham Maslow's hierarchy of needs theory (1954), which suggests that individuals can only address higher needs once basic consumption needs are satisfied. Similarly, Chayanov's theory of peasant economy (1986) asserts that smallholders are focused on meeting their subsistence needs,

[24] Some of these coping strategies are negative, such as when food has deleterious health effects, as is the case with *via*.

and therefore have little incentive to grow a surplus. So while increasing self-sufficiency may be a recommended path to resilience among other food systems (e.g., Toth et al., 2016), it is not always applicable in food systems in which consumers and producers are one and the same.

As Jones et al. (2021) write, “the inability of poor Malagasy farmers to take the risk of investing in new approaches may have been underestimated” (p.8). Certainly, as this research demonstrates, in contexts where high subsistence risk and food insecurity intersect with a strong cultural emphasis on respecting ancestral traditions, such as Madagascar, a ‘perfect storm’ arises. Individuals and households focus on maintaining stability by upholding the *status quo* (as well as conserving their physical energy[2]), despite its imperfections. Consequently, they find themselves metaphorically situated at the bottom rung of the resilience ladder, relying mostly on coping strategies to provision their households, and unable to ascend towards adaptive and transformative change. Furthermore, as we embark into a completely “new risk landscape” (Rockström et al., 2023), understanding the underlying factors beneath farmers’ production risk-sensitive decisions regarding adaptation and transformation will be more critical than ever.

Labor time and ‘drudgery of labor’ are additional aspects to consider among smallholder farming systems. Chayanov (1986) argues that, in systems where household members are both laborers in agricultural production and consumers of the produced goods, labor becomes a limiting resource, and the allocation of time becomes essential for ensuring subsistence. Thus, the Chayanovian balance, the ability of family-based

[2] A conscious reduction in physical activity and energy expenditure during food insecure periods is common (Morell-Hart, 2012).

agricultural systems to adjust consumption and labor[3] in response to changing conditions and external shocks, is a further coping strategy in these systems. In the context of the Manombo smallholder food system, where farmers are already engaged in labor-intensive agricultural activities, the availability of time to explore adaptive or transformative changes is constrained due to the interplay between limited labor resources and the demands of subsistence. Simply put, farmers are 'maxed out' and lack the bandwidth to take on additional tasks, let alone attend trainings. Thus, under conditions of extreme food insecurity, "time related to anything but food-related activities soon approaches zero" (Dirks 1980:28, cited in Morell-Hart, 2012).

4.2 Elements of resilience

As we begin to unearth the barriers that smallholder farmers face towards coping and adapting their agricultural practices, it is crucial to examine the constituents of their resilience, including whether they are fixed or dynamic (Darnhofer, 2021), as the ability to change these elements is pivotal. Additionally, if agricultural adaptation and adoption of new technologies are considered the means to moving farmers along the resilience continuum from 'surviving to thriving,' we must then search for the elements that support these behavioral change decisions.[4]

[3] Certainly, the ability to hire labor introduces additional considerations, as demonstrated with SRI in Chapter 3. However, it is worth noting that Chayanov's assumption that there is no market for labor in these systems holds some validity. This is supported by the experiences of wealthier respondents in some communities who reported a reduction in their previous ability to hire laborers due to economic hardship resulting from COVID-19.

[4] We also recognize the importance of understanding which elements communities consider to be essential for their own resilience (see Payne et al., 2021), rather than, what Santiago-Vera et al. (2021) call "top down diagnoses of resilience." In their "four Qs" to framing resilience, Helfgott, (2018) asks, "Resistance from whose perspective?"

As this research heavily focused on measuring the perceptions and characteristics of individual farmers and farming households, I draw upon the 7 C's of resilience framework developed by Dr. Kenneth Ginsburg, which considers the characteristics of competence, confidence, connection, character, contribution, coping and control as "building blocks" which enable individuals to thrive under adverse conditions. While cognizant of its flawed presumption that there is a universal human condition, several of the 7 C's do surface as important for resilience among farmers in our studied food system: coping (Chapter 1), connection (Chapter 2), and competence, confidence and control (Chapter 3). This approach also allows for bridging across disciplines, as food systems research is inherently transdisciplinary. The findings from the three chapters as to which characteristics are important for resilience also overlap with the ABCDs of food system resilience: Agency, Buffering, Connectivity and Diversity. Furthermore, while these elements of resilience are measured at the individual level, they are shaped by socio-cultural and historical factors. For example, the finding in Chapter 3 that confidence to successfully implement the SRI technique was lower among women than men may stem from cultural gender constructs.

4.2.1 Coping

In Chapter 1, the various coping strategies that Manombo area households employ during periods of food shortage were examined, including working as a day laborer on other farms when possible, reducing the number of meals per day and the amount eaten per meal, obtaining food from relatives, and selling livestock. Prominent among these strategies is eating foods not normally eaten, including foraging for particular wild plants during the ‘hunger season,’ as well as weaving baskets and mats from natural fibers such as *mahampy* to generate additional income. Thus, while it is important to differentiate between healthy coping strategies (eating ‘good food’) and negative coping strategies (eating ‘bad food’), having “[natural] resources to fall back on in the face of shocks and stressors” (buffering; de Steenhuijsen Piters et al., 2021) is incredibly important for food system resilience among forest-adjacent communities.

Furthermore, as diversity in food sources is important, even among farming populations, there is a need to expand our understanding of diversification beyond just cultivated crops to incorporate wild, foraged foods. There is also a need to more fully recognize the pluriactive character of smallholder food systems within concepts of food systems resilience, a coping strategy often not adequately captured by census and other large-scale surveys due to singular occupation-related questions (White, 2020). For example, asking about primary and secondary occupation, as we did in our surveys, is not sufficient to depict smallholder realities.

4.2.2 Connection

As we have seen in Chapter 2 with farmer intention to autonomously adapt traditional agricultural practices in response to a changing climate, social connection is an important factor supporting decision-making. Social connectedness not only provides a safety net, but also a sense of security which can reduce threat appraisal linked to maladaptive outcomes. As others have shown in similar contexts (e.g., Sabin et al., 2022), when smallholder farmers are more socially connected, they are also better able to engage in creative problem-solving. Conversely, a lack of connection, as we saw with female smallholders, can negatively influence their resilience. Therefore, strengthening Manombo area farmers' social connectedness, especially for women, can be an effective means of enhancing their resilience.

4.2.3 Competence, confidence & control

Given the centuries of external, often exploitative, intervention into smallholder agricultural practices and food systems, having a sense of control over decisions and actions is an especially poignant component of resilience (aka peasant resistance) in the Madagascar context. As demonstrated in Chapter 3, both perceived behavioral control (or agency) and confidence, believing in one's own abilities, surfaced as critical to the adoption of a 'homegrown'[5] agricultural practice. Specifically, perceived control was the strongest predictor of both intention and adoption of the System of Intensified Rice (SRI) among Manombo area farmers. Furthermore, participating in trainings and having experience trialing the new technique increased one's confidence in their ability to successfully implement SRI, especially among women. Additionally, providing farmers with the opportunity to participate in training programs and develop new skills also fostered competence. Thus, getting farmers over the initial 'hump' of resistance to trial the technique is hugely beneficial in developing their sense of competence and confidence, which then encourages continued practice of the technique.

Ultimately, this research indicates that strengthening farmers competence, confidence and perceived behavioral control will better enable them to make the changes

[5] It would be interesting to apply this same lens to the uptake of a 'lab grown' agricultural innovation to see if there were similarities or differences in how Malagasy farmers viewed it, though to be honest, I have a feeling that farmers were unaware that SRI was developed in Madagascar. I know this because one of the most dynamic community members asked me about it over lunch.

that they desire in their farming practices, and that trainings can be effective in enhancing these sentiments. However, to enhance the likelihood of adoption (and lower chances of future disadoption), training programs should be ongoing and with a higher ratio of extension agents to farmers, allowing for more individualized support. Furthermore, the temptation to rush into providing solutions must be avoided. While there is an inevitable iterative process of 'learning by doing' within the intervention design phase, every effort should be made at the onset to fully understand the risk landscape so as to avoid potential pitfalls and reduce frustration and disappointment among farmers early on. This can be achieved through the co-production of trainings and workshops over an extended period of time, as short-term top-down trainings have proved to be less effective in meeting desired farmer behavioral change outcomes (Lubell & Niles, 2019).

In addition to strengthening capacities, reducing risk[6] to farmers through strengthened support of social safety net programs (see Rockström et al., 2023; Toth et al., 2016) is critical to assist in escaping the 'rigidity trap' (Hodbod & Eakin, 2015) and having the freedom and flexibility to experiment on their own land, trialing out different techniques to find what ultimately works best for them. One way to lower the barrier to entry to SRI, for example, would be to provide insurance mechanisms guaranteeing rice to farmers in the case that their SRI fields are not successful.

However, even with increased capacity and reduced risk, it is unlikely that farmers on the 'surviving' end of the resilience continuum will be able to realize many of these

[6] Reducing risk is no easy feat, as there are multiple types (production, market, institutional, personal/human, and financial) and farmers often face multiple risks at the same time (Komarek et al., 2020).

changes, absent changes to broader structural factors, such as improvements to education and healthcare access, as well as road and irrigation infrastructure. Furthermore, some of these changes may be viewed as countering conservation goals set by local and international NGOs, as was the case when Manombo area farmers requested a 'dam'[7] be built.

4.3 Vulnerabilities embedded within these elements of resilience

As resilience, alone, does not adequately address power dynamics within food systems (Santiago-Vera et al., 2021; Zurek et al., 2022), many scholars have sought to understand how shocks and stressors differentially impact individuals, households, and communities based on their unique social vulnerabilities. For example, as vulnerability is place-based and context-specific, political ecologists like Blaikie et al. (1994) underline the importance of addressing the deep-seated causes of social vulnerability, rooted in historical processes and power dynamics, in order to reduce disaster from natural hazards (e.g., cyclones, droughts). As part of their food system resilience assessment framework, Fonteijn et al. (n.d.) recommend, after defining the food system, identifying key actors and determining the indicators of resilience, to then identify the vulnerable groups within the food system. However, a number of authors point out that, while it may be practical to maintain a 'from vulnerability to resilience' perspective, vulnerability is not simply the flipside of resilience. Rather, vulnerability refers to the degree to which different groups/institutions are 'at risk' (Harris & Spiegel, 2019), and being vulnerable does not mean one is not resilient (Béné et al., 2012).

[7] In the end, there was a miscommunication in translation and what NGO workers thought was a request for a 'dam' was really a request for an irrigation canal.

At the community level, all Manombo area farmers can be considered vulnerable, facing high risks from cyclones, drought, zebu theft, and other factors. Therefore, agroecological practices can serve as one way to reduce vulnerability across the entire community, including among poor rural rice-farming households (Uphoff, 2007). However, within each community, there are households with varying degrees of assets; those that are extremely poor and lack land may be more vulnerable than wealthier landowners, for example. There are also intrahousehold vulnerabilities. For example, for a variety of sociocultural reasons, women and children are often more vulnerable to certain stressors, such as climate change, than men are. Nonetheless, due to broader structural factors, even those that are less vulnerable and more resilient may be constrained in their abilities to adapt and transform their practices.

Access to natural areas

As we have seen in Chapter 1, reliance on wild plant foods (WPFs) during periods of food shortage is a critical coping strategy for certain forest-edge farming and fishing communities. Thus, there is an urgent need for more research documenting the specific wild plant species consumed by local people, detailed dietary information that household nutrition surveys have historically failed to capture. Furthermore, while protected areas (PAs) have proven effective in conserving wild plant biodiversity, any inability to access WPFs from within PAs can seriously jeopardize the resilience of the most vulnerable. Ultimately, a new conservation paradigm is essential—one that honors both local diets and biodiversity, as well as addresses the conflicts which have traditionally arisen between local people and parks.

Gendered vulnerabilities

While it is generally accepted that female-headed households are more vulnerable than male-headed households, there are also within-household disparities in vulnerability. For example, women smallholders face their own vulnerabilities within the agri-food system[8] which can influence their ability to participate in sustainable livelihood interventions and adapt their agricultural practices (Call & Sellers, 2019). Thus, the application of a stronger gender lens in food systems transformation research is needed (Visser & Wangu, 2021), with data disaggregation to better recognize these unique vulnerabilities (Fanzo et al., 2021) and identify the different supports needed for men, women and children.

It is also widely recognized that access to information, such as through advisory services and group membership (e.g., farmers' associations), supports farmers' decisions regarding adopting agricultural practices. However, female farmers generally have less access to information and agricultural extension services. In the context of our research, we find gendered vulnerabilities related to magnitude and types of social connectedness (Chapter 2). For example, female respondents reported fewer social connections than men, and had less interaction with authority figures than men did. Higher social connectedness was also significantly associated with reduced threat appraisal in men, indicating that men may be more likely to adapt their agricultural practices as a result. These findings underline the importance of ensuring that information reaches women and other hard-to-reach

[8] One example is that, in some contexts, women smallholders are predominantly the producers of perishable goods, making them more vulnerable to loss from crop spoilage and damage during transport than men (Livingston et al., 2011).

populations through channels suitable and culturally appropriate for them.

In Chapter 3, we found that women were significantly less confident in their ability to implement SRI. Therefore, as confidence is one of the important elements for resilience identified in this food system, particular focus should be placed on increasing women's perceived confidence through more frequent and accessible training opportunities so that women have the opportunity to gain additional practical experience with the technique. Furthermore, as women are often tasked with childcare and other household care-related duties, providing support (e.g., childcare, meals for children) to alleviate these responsibilities during training sessions could be an effective strategy to enable increased women's participation in trainings.

4.4 Conclusions

This dissertation sheds light on the challenges faced by 'forgotten' farmers, for as Fanzo et al. (2021) write, "What is not visible is neither valued nor viewed as a viable part of food system transformation" (p. 7). It also emphasizes the need to understand the elements that contribute to moving the needle towards more resilient and just smallholder food systems in the face of external stressors, while also identifying vulnerabilities (and for whom?) within these elements, as well as the need to re-examine some of the linear cause-effect assumptions embedded within recommendations for cultivating food production resilience.

Thus, to foster resilient smallholder food systems and address the barriers to the adoption of agricultural practices, it becomes crucial to evaluate the suggested pathways for resilient food production systems, including their costs and benefits (Wood et al., 2020), and identify potential flaws and areas where each approach falls short. There is no 'one size fits all' approach (Queiroz et al., 2021); recommended pathways to food system resilience should be culturally sensitive, adapted to the local context, and tailored to the needs of different types of farmers, each with their diverse starting points, rather than ascribing to a particular didactic agenda (e.g., agroecology vs. productionist).

In addition, solutions must align with, not only the requests of farmers but also with their capabilities. For example, whether it be autonomous adaptations in response to climate change in Chapter 2 or 'imposed' solutions by external actors in Chapter 3, Manombo area farmers express interest in change but struggle to implement it for a variety of reasons, including structural factors. For example, even if farmers state intentions to grow more drought-resistant crop varieties or weed with *sarcleuses*, these items are not readily available to them. Therefore, narrowly focusing on individual limitations and attributes leaves out a deeper understanding of the larger structural factors inhibiting farmer behavior change.

Furthermore, as Rice (2020) writes, "the potential for food system failure increases as powerful external actors become involved in the organization of the system for purposes unrelated to food provisioning" (p. 213). Thus, we can see in the case of Madagascar where international (and national) conservation organizations have become heavily interested in protecting remaining rainforests and other natural ecosystems, there is huge potential for conservation interventions to negatively impact local food systems (e.g., "fortress approach" when rural population is heavily dependent on natural resources). While there has been a great deal of progress in considering human needs when designing conservation interventions (e.g., shift from protected areas with strict exclusion to incorporating utilization zones for local communities), much more remains to be done in terms of carefully considering the resilience context of the local population,[9] particularly food insecure populations reliant on wild biodiversity. To achieve this, partners must engage in constructive dialog so that consensus, and the inevitable negotiated compromises between both internal and external food systems actors, with their diverse and unique agendas, can take place.

Furthermore, from the case of SRI, we see that outside theories of change may result in a mismatch between the need for transformation and farmers' ability to do so (Knickel et al., 2009), not to mention a clash of worldviews (Santiago-Vera, 2021). In one worst case scenario, smallholder farmers in Rwanda became less resilient to climate shocks as a result of top-down agricultural intensification interventions (Clay & Zimmerer, 2020). Therefore, there is a need for a much more smallholder-centric approach that fosters and encourages co-created solutions that are more bottom-up (Sandhu, 2021) than top-down (or outside-in) to avoid what Geertz (1963) called agricultural "involution," when well-meaning interventions worsen the situation (e.g., increase farmers' vulnerability to hunger; Rice, 2020).

As Giller (2020) points out, the science exists to increase crop yields sustainably. However, the achievement of sustainable and increased crop yields relies not only on

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[9] Participatory Action Research (PAR) and mixed quantitative and qualitative methods are useful strategies for understanding the complexities of lives of smallholder farmers.

individual farmers but also on addressing power dynamics and limited political representation of small farmers. Rural Malagasy farmers, who are the most affected by conservation policies, have minimal voice and influence in government decision-making, as highlighted by Jones et al. (2021). To bring about meaningful change, governments and policymakers must prioritize the needs and interests of small farmers, promoting inclusive decision-making processes. This will ensure that the knowledge and experiences of small farmers are recognized and incorporated into agricultural policies and programs, ultimately creating conditions for sustainable and resilient agricultural practices.

According to the 2023 SOFI report (FAO et al., 2023), time is running out to avoid 600 million being chronically undernourished in the next decade, while others point out just how few growing cycles remain for farmers to transform their production systems before 2050 (e.g., Hunter et al. (2017). Therefore, some ‘techno fix’ solutions may also be required, in addition to supporting African-led agroecology movements. For example, water investments will be increasingly necessary as rain patterns shift and droughts become more frequent (Rockström et al., 2010). Blaustein (2008) calls irrigation the “great equalizing force in agriculture” (p. 9). Additionally, rice farmers in India (Bullock et al., 2017) and maize farmers in Kenya and Uganda (Blaustein, 2008) have enhanced their resilience to drought by breeding stress-tolerant varieties.

Thus, while necessarily looking ahead to prepare for the compounding shocks that a changing climate will inevitably bring (ideally with generational thinking, perhaps hundreds of years into the future), it is equally vital to, as the Malagasy proverb suggests, be like the chameleon and keep an eye on the past. Rather than solely subscribing to a

Western vision of progress, that "encourages us to forget our ancestors" (Santiago-Vera et al., 2021, p.12), future production strategies should consider "peasant resiliences" (Santiago-Vera et al., 2021) through a return to traditional adaptive strategies and "historically dependable" crops (van Eeckhout, 2015), and embrace indigenous worldviews in which the past, present and future may comingle. For instance, instead of promoting food system diversity through non-indigenous vegetables and varieties, policies should explore the efficacy of traditional crops. However, as Bullock et al. (2017) point out, traditional farming practices are not a panacea, especially as growing conditions become altered beyond historical experience. Therefore, what is truly needed is a "new-old way" (Santiago-Vera et al., 2021, p. 14), for a 'new normal' cannot exist in a world in which the only constant is change…For example, local seed banks could be established to preserve crops vital to the preservation of indigenous foodways, which can then be propagated using techniques based on newer scientific understandings regarding growing in more desert-like conditions.

Lastly, it is my hope that this reflection on cultivating resilience within smallholder food systems will help inform how research and action should be considered in the Malagasy context. Malagasy farmers are strong and accustomed to enduring great hardship, simultaneously resilient and vulnerable, but they are resistant to changing ancient practices, especially if it involves risking their lives or that of *havana* (kin). In this way, they have a very conservative 'play it safe' approach to change, what Laney and Turner (2015) call a "cultural norm ensuring subsistence security." Certainly, this risk aversion seems to be higher in terms of adapting practices to staple crops, such as rice, than to introducing cash crops, such as vanilla, pepper and cloves. This is perhaps related to the link between rice and survival, versus cash crops being seen as an ‘add-on’ tied to a mysterious market that they know little of and have even less control over (recall Osterhoudt’s description of Mananara farmers in disbelief that vanilla was not native to Madagascar). They are also wary of outsiders, and for good reason, given the long history of extraction by Westerners. But, as the world rapidly changes, they are at risk of being left behind to grapple with the threats of the Anthropocene alone, even if they are, as Richard (2022) writes of early ships in the Indian Ocean missing Madagascar entirely, “hidden in plain sight.”

4.5 References

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APPENDIX A: Chapter 1 Supplementary Materials

1. Supplementary Tables

Supplementary Table 1-1. Subset of questionnaire and response options

Variable	**Question**		**Response options**
	English	**Malagasy**	
Household (HH) size	How many people live in your household (people that eat and sleep in HH)?	Firy ny olona amin'ny tokantranonao (ireo olona izay misakafo sy matory ao amin'ny tokantrano)?	*No. of people in HH (adults and children)*
Type of HH	Describe HH type	Faritana ny karazan'ny tokantrano (iza ny olobe amin'ny tokatranonao ato?)	__*Male headed, with a wife or wives,* __*Male headed, divorced, single or widowed,* __*Female headed, divorced, single or widowed,* __*Female headed, husband away* __*Other, specify*
HH assets	Which of the following items does your household possess?	Moa ve misy ao anatin'ny tokantranonao ireto fananana ireto:	__*Radio* __*Cellphone* __*Watch* __*Bicycle* __*Motorcycle* __*Dugout canoe (pirogue)* __*Motorboat* __*Fishing net* __*Car/truck* __*Sewing machine* __*Generator* __*Table* __*Chair* __*Bed* __*Sofa (couch)* __*Television* __*CD/DVD Player*

			__*Improved cookstove* __*Outhouse* __*Bank account* __*Solar panels*
HH assets (agricultural tools)	Do you have any of the following agricultural tools:	Moa ve ianao manana ireto fitaovam-pamokarana ireto	__*Machete* __*Shovel* __*Hoe* __*Mechanical weeder* __*Plow* __*Watering can* __*Rake* __*Hatchet* __*Zebu-drawn cart*
Farm production diversity	In a typical year, which crops did you grow?	Anatiny taona mahazatra, inona avy ny voly ambolenao?	*Rice (hillside and/or paddy), cassava, yam, banana, breadfruit, jackfruit, litchi, beans, avocado, citrus, pineapple, leafy greens, other:* ___
Distance to rice fields	*Approximately how many minutes (walking) does it take to reach:* - your nearest rice field from your house? - your farthest rice field?	*Fo hoe amin'ny firy minitra eo ho eo ny lalana (mandeha tongotra) makany amin'ny:* - tanimbarinao akaiky indrindra miala eo amin'ny tranonao? - {*Raha mihoatra ny iray ny tanim-bary*}, ny lavitra indrindra?	*Time in minutes*
Dietary diversity (Adequate nutrition)	Please describe the foods (meals and snacks) that you ate or drank yesterday during the day and night, whether at home or outside the home.	Mba fariparito ny sakafo (sakafo na solo-tsakafo) nohaninao na nosotroanao omaly nandritra ny andro sy alina, na tao an-trano na tany ivelany.	*Open-ended*

Food insecurity (12 months)	In which months, if any, does your household tend to not have enough food to consume or have struggled to acquire food.	Amin'ny volana inona, raha misy, no tsy ampy ny sakafo hohanina ao an-tokantranona na tena manahirana ny mitady sakafo.	*Check all of the months (12) that apply.*
Food insecurity (30 days)	*In the past 30 days,*	*Tao anatin'ny 30 andro (4 herinandro) lasa teo,*	*Yes/No*
	Have household members ever had to eat meals without rice?	moa ve nisy fotoana ny olona tao an-trano nihinana sakafo tsy misy vary?	
	Have you ever feared that your food supply would run out?	moa ve ianao efa natahotra hoe tsy ho ampy ny tahirin-tsakafo. (Hoe tsy ho ampy ny sakafo hoan'ny olona ao an-trano)?	
	Have you ever lived without food in the household?	moa efa nisy fotoana ianao nipetraka tao an-trano tsy misy sakafo?	
	Have household members ever gone to bed hungry at night?	moa ve efa nisy fotoana ianareo tato an-trano nandeha natory nefa noana (satria tsy ampy ny sakafo)?	
	Did household members spend a full day and night without eating?	moa ve ny olona tato an-trano nisy fotoana tsy nihinana nandritra ny alina tontolo na ny andro tontolo (satria tsy ampy ny sakafo)?	
Food insecurity coping strategies	In the last **12 months**, during times that you did not have enough to eat, what did you do?		*__Eat less food per meal* *__Eat fewer meals per day* *__Collect forest resources* *__Ate foods that you would not normally eat/normally avoid (e.g. tavolo, via)*

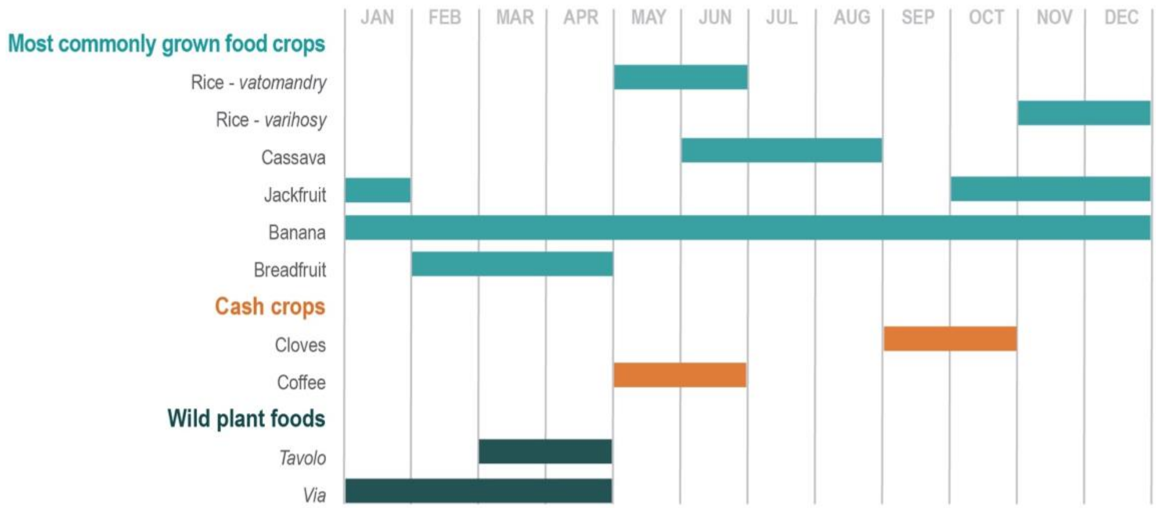
		__Obtain or borrow food from relatives *__Borrow from local shop on credit* *__Work as agricultural worker on other farms* *__Sell livestock* *__Sell land* *__Sell household belongings* *__Other:______*

Supplementary Table 1-2. Frequency of individual foods reported in 24-hour dietary recall and frequency of at least one reported food by individuals in each of the 13 food groups.

Food Groups	**Examples**	**Distinct Foods Reported**
Cereals (n=293)	Corn/maize, rice, wheat, sorghum, millet or any other grains or foods made from these (e.g. bread, noodles, porridge or other grain products)	Rice* (n=291) Wheat** (n=9)
White roots & tubers (n=254)	White potatoes, white yam, white cassava, or other foods made from roots	Cassava*** (n=76) *Tavolo* (n=5) Breadfruit (n=196)
Dark green leafy vegetables (n=243)	Dark green leafy vegetables, including wild forms + *locally available vitamin A rich leaves such as amaranth, cassava leaves*	Leafy greens (n=75) Cassava leaves (n=163) Sweet potato leaves (n=96)
Other vegetables (n=39)	Other vegetables (e.g. tomato, onion, eggplant) + *other locally available vegetables*	Onion (n=33) Cucumber (n=2) Eggplant (n=3) Tomato (n=17) Mushroom (n=1)
Vitamin A rich vegetables & tubers (n=1)	Pumpkin, carrot, squash, or sweet potato that are orange inside	Pumpkin (n=1)

Vitamin A rich fruits (n=40)	Ripe mango, ripe papaya, dried peach + *other vitamin A rich fruits*	Mango (n=35) Papaya (n=5)
Other fruits (n=76)	Other fruits, including wild fruits and 100% fruit juice made from these	Jackfruit (n=22) Coconut (n=3) Guava (n=36) Banana (n=19) *Via* (n=3)
Legumes, nuts, and seeds (n=19)	Dried beans, dried peas, lentils, nuts, seeds or foods made from these (example: peanut butter)	Lentils (n=2) Beans (n=14)
Eggs (n=1)	Eggs from chicken, duck, guinea fowl or any other egg	Eggs (n=1)
Fish and seafood (n=62)	Fresh or dried fish or shellfish	Fish (n=57) Shrimp (n=4) Crab (n=1)
Flesh meat (n=8)	Beef, pork, lamb, goat, rabbit, game, chicken, duck, other birds, insects	Chicken (n=5) Beef (n=3) Pork (n=1)
Organ meat (n=0)	Liver, kidney, heart or blood-based foods	*None reported*
Milk and milk products (n=0)	Milk, cheese, yogurt or other milk products	*None reported*
		Sugarcane (n=7)****

2. Supplementary Figures



Supplemental Figure 1-1. Seasonal calendar

APPENDIX B: Chapter 2 Supplementary Materials

1. Supplementary Tables

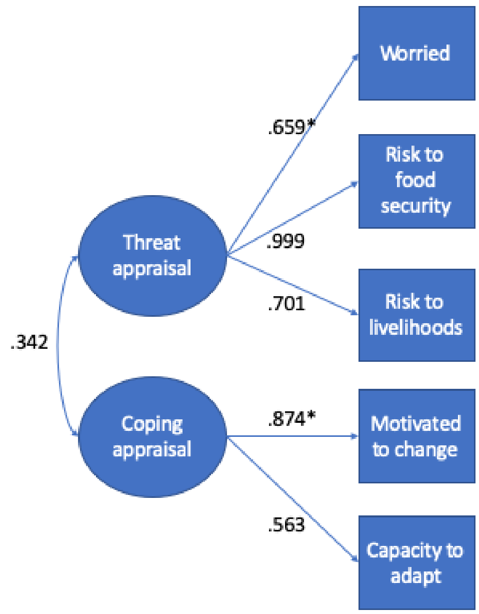
Supplemental Table 2-1. Results of Exploratory Factor Analysis (Factor Matrix[a])

Item	**Factor Loadings (Threat)**	**Factor Loadings (Coping)**
Perceived severity (risk) of climate change to food security	.90	
Perceived severity (risk) of climate change to income/livelihood	.40	
Worry/fear about changes in climate	.47	
Motivation/willingness to change		.62
Perceived adaptive capacity		.65
Cronbach's alpha, α (α based on standardized items)	0.53 (0.60)	0.57 (0.59)
% of explained variance	34.44	27.66
% of total variance explained	62.10	
Extraction Method: Maximum Likelihood a. 2 factors extracted. 14 iterations required.		

Supplemental Table 2-2. Percentage of variance in outcome variables explained by the models

		Outcome variables	
	Intention to adapt	Threat appraisal	Coping appraisal
Overall model	13.4%	8.9%	2.9%
Multi-group model:			
- Class 1 (Men)	15.8%	8.6%	2.5%

2. Supplementary Figures



Supplemental Figure 2-1. Measurement model for threat and coping appraisal constructs.

APPENDIX C: Chapter 3 Supplementary Materials

1. Supplementary Tables

Supplemental Table 3-1. Survey questions on farmer perceptions in relation to SRI

Item	Statement/question	Measurement scale
Perceived behavioral control (PBC)	I feel confident in my ability to implement SRI I have the knowledge I need to successfully implement SRI I have the tools needed to successfully implement SRI	1= Strongly disagree 2 = Disagree 3 = Neutral 4 = Agree 5 = Strongly Agree
Perceived usefulness (PU)	Implementing SRI will make positive changes to my household's well-being (income or food security) Implementing SRI is good for the environment SRI uses less water Implementing SRI will save me money Implementing SRI will take more time than traditional rice production does* I will get more rice using SRI technique I will use less seed using SRI technique	
Subjective norm (SN)	Others in the community will approve if I practice SRI	
Perceived ease of use (PEOU)	How difficult, if at all, do you find the steps in SRI to understand?	1 = Very difficult 2 = Difficult 3 = Somewhat difficult 4 = Not difficult

Note: * Item is reverse-coded.

Supplemental Table 3-2. Factor matrix[a]

Item	Statement	Measurement scale	Factor 1	Factor 2
Perceived usefulness (PU)	Implementing SRI will make positive changes to my household well-being (income or food security)	1= Strongly disagree 2 = Disagree 3 = Neutral 4 = Agree 5 = Strongly Agree		.568
	Implementing SRI is good for the environment			.582
	Implementing SRI will save me money			.661
	I will get more rice using SRI technique			.690
Perceived behavioral control (PBC)	I feel confident in my ability to implement SRI		.576	
	I have the knowledge I need to successfully implement SRI		.999	
	Cronbach's alpha, α (α based on standardized items)		.724	.793
	% of explained variance		42.6%	21.3%
	% of total variance explained		63.9%	

Extraction Method: Maximum Likelihood.

a. 2 factors extracted. 18 iterations required.

Note: Several PU variables were dropped because they did not load onto either factor. These included variables measuring agreement with statements: “SRI/SRA uses less water,” “I will use less seed using SRI technique,” and “Implementing SRI will take more time than traditional rice production does.” One PBC variable was also dropped: “I have the tools I need to successfully implement SRI.” Subjective norm was measured using a single variable. Specifically, we measured the injunctive norm subdimension of subjective norms (perceptions of “others” approving behavior) using agreement with the statement: “Others in the community will approve if I practice SRI.”

Supplemental Table 3-3. Characteristics of 2021 and 2022 survey respondents

	2021 survey		2022 survey	
Respondents	Male	Female	Male	Female
Registrants	70	129	66	96
“Control”	47	82	31	84
Total M/F per survey	117	211	97	180
Total all respondents	328		277	

Supplemental Table 3-4. Logistic regression model on likelihood of training registration

Effect	OR	*SE*	95% CI		*p*
			LL	*UL*	
Gender	1.26	0.31	0.778	2.041	.346
Household (HH) education	1.02	0.04	0.932	1.107	.720
HH assets	1.10	0.06	0.998	1.222	.050
HH size	1.06	0.05	0.964	1.170	.220
Land tenure	1.06	0.38	0.526	2.139	.869

Note: CI = confidence interval; *LL* = lower limit; *UL* =upper limit. Bolded predictors indicate significance at the $p \leq 0.05$ level.

Supplemental Table 3-5. Results of linear regression on depth of adoption

Variable	Beta	*SE*	β	*p*
Gender	.08	.33	.01	.817
Village remoteness	.04	.40	.01	.930
Number of trainings	.37	.05	.41	<.001
Household (HH) education	.13	.06	.13	.036
HH assets	.22	.06	.22	<.001
HH size	-.09	.07	-.08	.173
Land tenure	-.14	.50	-.02	.780

Supplemental Table 3-6. Summary results of independent sample t-tests between SRI adopters and non-adopters

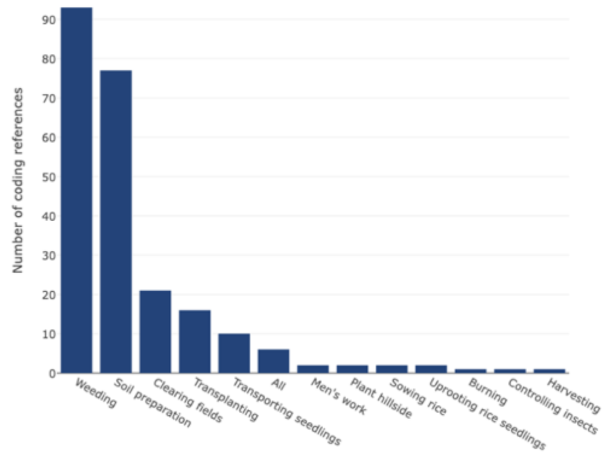
	Adopters		Non-adopters		
	Mean	SD	Mean	SD	test statistic
Highest education level	5.14	3.4	3.34	2.9	-3.72, p <.001
Household assets	6.56	3.9	4.45	2.4	-3.99, p <.001
Household size	6.47	2.7	6.11	2.5	-.931, p =.354
Number of trainings attended	4.81	4.3	1.63	2.4	-5.47, p <.001

Note. Adopters (n=60), Non-adopters (n=214)

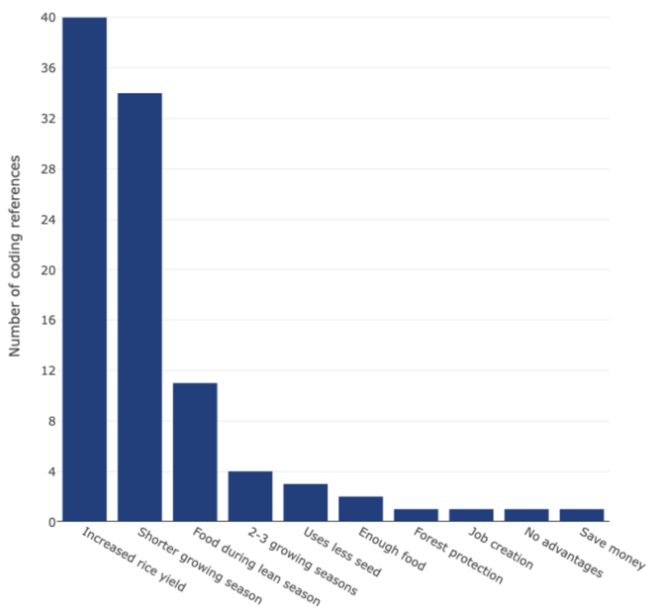
Supplemental Table 3-7. Summary of Wilcoxon signed-ranks test results

Construct	**Statement**	**Test statistic (Z-score)**	**p-value**
Subjective norm (SN)	Others in the community will approve if I practice SRI	-4.398	<.001
Perceived usefulness (PU)	Implementing SRI will make positive changes to my household's well-being (income or food security)	-.852	.394
	Implementing SRI is good for the environment	-.840	.401
	SRI uses less water	-.129	.897
	Implementing SRI will save me money	-.975	.329
	Implementing SRI will take more time than traditional rice production does	-1.060	.289
	I will get more rice using SRI technique	-1.258	.208
	I will use less seed using SRI technique	-.360	.719
Perceived behavioral control (PBC)	I feel confident in my ability to implement SRI	-3.059	.002
	I have the tools I need to successfully implement SRI	-3.885	<.001
	I have the knowledge I need to successfully implement SRI	-2.796	.005

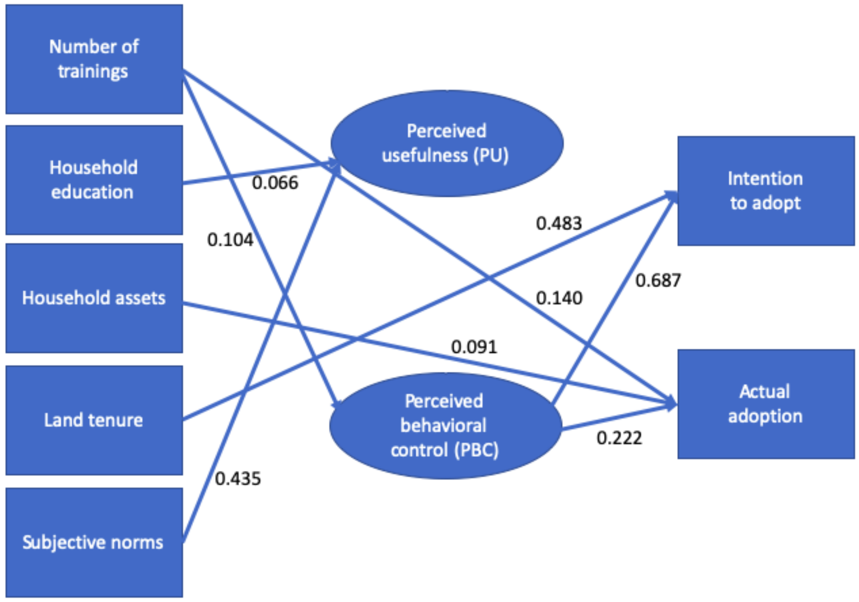
2. Supplementary Figures



Supplemental Figure 3-1. Bar graph of respondents least preferred steps in the rice growing process



Supplemental Figure 3-2. Bar graph of adopter (n=60) perceived benefits of SRI



Supplemental Figure 3-3. SEM Diagram with standardized coefficients. Circles indicate latent variables; squares indicate observed variables. Lines represent statistically significant relationships (*p* <.05)