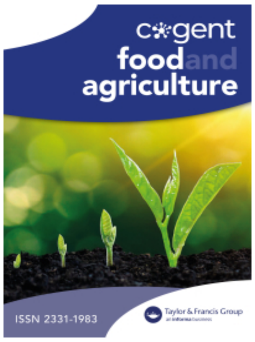

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An analysis of the adoption of the "system of rice intensification" (SRI): why a homegrown technique has yet to take seed among rice farmers in Madagascar

Maya Moore[a,b], Kimmerling Razafindrina[c], V. Ernesto Méndez[b,d,e] and Meredith T. Niles[a,b]

[a]Department of Nutrition and Food Sciences, University of Vermont, Burlington, VT, USA; [b]Gund Institute for Environment, Rubenstein School, University of Vermont, Burlington, VT, USA; [c]Kimmerling Consulting, Fianarantsoa, Madagascar; [d]Department of Plant and Soil Sciences, University of Vermont, Burlington, VT, USA; [e]Institute for Agroecology, University of Vermont, VT, USA

ABSTRACT
To combat food insecurity in Madagascar, organizations have promoted the *Système de Riziculture Intensifiée* (SRI), or System of Rice Intensification, an agroecological rice-growing technique. However, despite its many benefits, adoption remains low (and disadoption remains high) in Madagascar. To better understand these dynamics, we use data from two surveys of 328 rice farming households in southeastern Madagascar to conduct an analysis of decisions to adopt SRI, as well as look at the differences between adopters and non-adopters. Results show that despite strong intentions to adopt the technique, actual rates of adoption were lower than expected. Indeed, while 89.8% ($n=291$) of respondents stated intention to adopt SRI, only 21.6% ($n=60$) had trialed it one year later. Results also indicate that exposure to SRI trainings did not have spill-over effects to "untreated" farmers, as nearly all (95%, $n=57$) of the farmers adopting SRI had registered for the training, with the majority (89.5%, $n=51$) attending some days of training. Reasons given for not adopting SRI included lack of rice seeds deemed suitable by farmers, as well as insufficient labor, time and other resources. Furthermore, using an integrated Theory of Planned Behavior - Technology Acceptance Model framework and structural equation modeling (SEM), we find that perceived behavioral control, training participation and household assets are significant predictors of adoption. This research is important in efforts to better support uptake of improved agricultural practices among food insecure farming populations. It also fills a gap in the literature regarding SRI adoption among lowland coastal farming populations.

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1. Introduction

Rice (*Oryza sativa*) is the principle staple food in Madagascar and plays an extremely important socio-cultural role as well (Hume, 2009; Linton, 1927; Keller, 2008). Despite being grown by nearly 90 percent of Malagasy households and occupying an estimated 1,200,000 hectares of land (IFAD, n.d.; Senahoun & Nikoi, 2016), 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). This situation is expected to worsen as a result of climate change, with global rice production on the decline (Ringler, 2010).

While the underlying reasons for Madagascar's current rice "yield gap" are complex, 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. Indeed, largely bypassed by the Green Revolution, use of external inputs such as high-yielding seed varieties and fertilizers remains extremely low, terracing is rare outside of the central highlands, 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, 2020).

CONTACT Maya Moore mayamoore@iri.columbia.edu Department of Nutrition and Food Sciences, University of Vermont, Burlington, VT, USA
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Given the importance of rice agriculture in Madagascar (and around the world), as well as the urgency to mitigate the negative impacts of climate change, the general objective of this paper is to contribute to the literature on the underlying factors driving rice technology adoption dynamics among rural smallholder farmers, particularly in coastal regions. More specific research questions are presented in section 1.1. Research methods and results are covered in sections 2 and 3, respectively. Lastly, in sections 4 and 5, we discuss findings and present our conclusions.

1.1. 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, often for rice cultivation. However, Malagasy actions regarding land-use are frequently 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 agroecosystems (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 approach called *Système de Riziculture Intensifiée* or "System of Rice Intensification" (SRI) (Freudenberger & Freudenberger, 2009; Jones et al., 2021; Moser & Barrett, 2003; Tsujimoto et al., 2012; Whitman et al. 2020). SRI, originally developed in Madagascar by Henri de Laulanié, a French Jesuit priest working in conjunction with Malagasy farmers since the 1960s to co-create the technique, is a low-input intensification method consisting of a series of management principles. By 1990, a national organization, *Association Tefy Saina*, had formed in Madagascar with the mission of disseminating SRI. In the mid-90s, championed by American Professor Norman Uphoff, SRI began its spread to other parts of the world. Today, an estimated 10 million farmers in over 60 countries practice some combination of SRI steps (Prasad, 2020; Uphoff & Thakur, 2019).

Rooted in agroecological principles, SRI is a knowledge-intensive technology addressing the biophysical requirements of rice plants, both above and below ground (Uphoff, 2023; Stoop et al., 2002). Though some varieties may perform better than others (Uphoff, 2023), SRI can be practiced with any variety of rice. It differs from traditional paddy rice cultivation in a number of ways however (Table 1) - including defying the common misconception that rice requires permanently flooded conditions (Uphoff et al., 2011). Emphasizing low external-input agriculture, it involves a series of synergistic steps 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 and reduce competition between plants, as well as to facilitate weeding (Uphoff, 2023). While the core components of SRI can vary according to the context,[4] Noltze and colleagues (2012) identify the first four steps as the essential components for adoption, while SRI-Rice (n.d.-a) also 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.

Table 1. Comparison of SRI recommendations to traditional rice-growing practices observed in study area, with color coding to reflect gender roles (yellow for women's, blue for men's) associated with various steps in the Madagascar context (Achandi et al., 2018).

Observed practices	Recommended SRI steps
1. Transplant older rice seedlings (28 days on averages)	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	Transplant seedlings singly into level, unflooded field
3. Seedlings transplanted densely and 'scatteredly'	Spacing seedlings 25–40 cm apart (along line and in a square grid pattern)
4. Continuous flooding (CF) of rice paddy[a] to ensure water supply and suppress weeds	Intermittent irrigation or alternative wetting and drying (AWD) of paddy[b]
5. Little to no organic fertilizer added, no chemical fertilizer	Maintain soil fertility by adding organic compost
6. Control weeds by flooding and infrequent weeding by hand (1–2 times)	More frequent and earlier weeding (3–4 times), preferably with a *sarcleuse*

Note. Table adapted from Randriamiharisoa & Uphoff (2004), cited in Perera et al. (2007).
[a]Due to lack of irrigation infrastructure, Manombo area rice paddies are often situated in marshy lowlands which may remain flooded throughout the season.
[b]In marshy lowlands, AWD may be limited to deliberate draining of fields only, where possible.

1.2. Benefits and adoption of SRI methods

Notwithstanding early skepticism and criticism - dubbed the 'Rice Wars' (Ho, 2005), 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 (Takahashi & Barrett, 2014; Norman Uphoff, 2007). Average gains of over 84% compared to traditional methods have been reported in Madagascar (Barrett et al., 2004), with similar yield increases reported across countries in West Africa (Styger and Traoré, 2018). Though less research has been conducted in lowland coastal ecologies, a study in Sierra Leone demonstrated that SRI tripled yields in brackish mangrove swamps (salt-free for half of the year), even without systematic water control (Harding et al., 2017).

SRI has also been shown to enhance rice plant resilience to pests and diseases, as well as to abiotic stresses such as low moisture (Uphoff, 2007), especially useful for farmers in drought-prone regions (Taylor & Bhasme, 2019). Besides requiring less water, SRI also reduces the quantity of other inputs needed, such as seed and fertilizer (Berkhout & Glover, 2012; Win et al., 2020).

Furthermore, SRI has been shown to provide benefits at both farm/household and societal levels. In addition to alleviating poverty and lowering food prices (Minten & Barrett, 2008), there is also evidence that SRI rice has higher levels of micronutrients (Uphoff, 2023), with the potential to improve dietary diversity outcomes. For example, SRI techniques have facilitated conversion of rice paddies into fishponds, and freed up land for poultry raising, as well as fruit and vegetable production in Cambodia (Uphoff, 2007), as well as encouraged crop rotational methods and intercropping adoption in China and India (Uphoff, 2023). At the global scale, SRI is important for addressing the climate crisis.[5] As it promotes alternative wetting and drying (AWD) of rice paddies, fields are flooded for shorter periods of time, thereby reducing the presence of greenhouse gas-generating microbes (Thakur et al., 2022).[6]

However, despite the many potential advantages for farming households, SRI adoption rates remain low (and "disadoption" remains high) among farmers 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). While there are reports of up to 30% adoption in some areas of Madagascar (SRI-Rice, n.d.-a), the true percentage is likely less than 5% (N. Uphoff, *personal communication*, December 8, 2020). For example, researchers found that fewer than 2% of farmers in the Itasy region, about 90 km west of Madagascar's capital, were practicing SRI (Rakotovao et al., 2021). 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). 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), the underlying lack of take-up, especially among Malagasy farmers, remains an enigma.

It is also crucial to highlight 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, potentially leading to changes in responsibilities and workloads. For example, shifting from hand weeding to the use of *sarcleuse* (mechanical weeder) could transfer the role from women to men (Uphoff, 2023), as women are usually 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* can alleviate physical discomfort associated with hand weeding by allowing an upright position (Mrunalini & Ganesh, 2008).

1.3. Objectives of this study

Using a case study of smallholder farmers living along the southeastern coast of Madagascar, we examine how perceptions of SRI, registering for and attending SRI trainings, and other factors predict rice farming decisions among "adopters"[7] and non-adopters within the same population. This study also fills the gap in the understanding of SRI adoption dynamics among Malagasy farmers by taking a behavioral approach and applying Structural Equation Modeling (SEM) to evaluate 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 that examine who registers for and actually attends SRI rice-growing trainings, and the effectiveness of trainings on adoption.

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

Farmers' perceptions of SRI

1. How do farmers' perceptions of SRI (perceived usefulness, perceived approval by others, perceived ability to successfully implement) predict adoption?
2. Given distinct gender roles within the rice growing process, do perceptions differ between men and women?
3. Do these perceptions change after practicing the technique?

Factors predicting registering for and attending SRI trainings

4. What are the factors that make farmers more likely to sign up ("registrants") for SRI trainings?
5. What are the barriers for registrants to attend trainings?

Factors predicting SRI adoption

6. Does intention to adopt SRI predict actual adoption?
7. What are the characteristics of "adopters" vs. non-adopters?
8. What barriers to adoption exist?

Factors predicting depth of adoption

9. When farmers do implement SRI, which factors predict implementation of certain steps within the SRI package, and what are reasons given for not implementing other SRI steps?

1.4. Studies on SRI adoption

The global adoption studies literature is rich with research seeking to understand SRI adoption dynamics. Factors which have been found to influence 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 (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). 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).

While a study in India found that labor was reduced under SRI (Sinha & Talati, 2007), labor availability, especially during transplanting and weeding, has also 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; Waris, 2017). Indeed, labor scarcity during critical stages of rice development can harm yields due to the time-sensitive nature of SRI and careful attention required. For instance, transplanted rice seedlings older than 7–10 days may underperform, and uncleared weeds can impede rice plant growth (Loukes, 2015). Similar to labor-time constraints, 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.[9]

While a growing body of research on SRI adoption exists, particularly in South and Southeast Asia, SRI adoption research in Madagascar remains relatively slim and most has primarily looked at SRI among farming communities in the High Plateau (e.g. Berkhout & Glover, 2012; Moser & Barrett, 2003; Serpantié & Rakotondramanana, 2014; Tezer, 2012; 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 sandier soil types present different growing challenges. There are also distinct ethnic divisions between Madagascar's highland and coastal populations which can influence agricultural practices and land-use decision-making. Lastly, despite ample evidence that gender often plays a role in adoption of agricultural technologies (e.g. Achandi et al. 2018), most SRI adoption studies have not considered farmers' gender.

Of the SRI adoption studies 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[10] (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 in Madagascar. However, while long considered in the anthropological literature, the role of culture has not been thoroughly acknowledged within the agricultural technology adoption studies literature until more recently (Ruzzante et al., 2021).

Furthermore, when SRI is "adopted," it is often only partially adopted, either in terms of intensity of adoption, referring to 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), even when successful yields are achieved (Taylor & Bhasme, 2019). For example, in Madagascar, Moser and Barrett (2003) found that 40% of "early adopters," those who according to Rogers' (1983) Diffusion of Innovation Theory are the initial adopters of a technology when it is first introduced into a population, had abandoned SRI five years after having been promoted by extension agents in five communities.

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). Previous 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, 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).

Lastly, while there has been some limited research conducted on the social implications of adopting SRI, 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) which examined implications of SRI adoption on children, only a small number of studies have given specific attention to gender dimensions of SRI adoption (e.g. Resurreccion et al., 2008; Waris, 2017). While research has shown that agricultural decisions are typically made jointly within the husband-wife dyad in non-polygamous regions of Madagascar (Achandi et al., 2018), men and women may have different needs and attitudes due to the gendered division of labor within rice production.[11]These differentiated roles, in turn, may shape their willingness and perceived ability to adopt various components of SRI (Jost et al., 2016; Resurreccion et al., 2008). Thus, there is an urgent need for additional gender-disaggregated research to more thoroughly understand these dynamics.

1.5. Theoretical frameworks

As the process of technology adoption is complex and multi-faceted, a range of theories, collectively known as adoption-diffusion theories, have been developed in order to better comprehend the factors that contribute to people's decisions on whether to accept or reject an innovation. Since the 1970s, these theories have been increasingly 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).

1.5.1 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. 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),[12] 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.

1.5.2 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). However, this framework has not previously been used to examine SRI adoption. 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 1).

2. Methods

2.1. Study area

The study was conducted among 15 predominantly Antaifasy (People of the Sand) communities around Manombo Special Reserve in the Farafangana District of southeastern Madagascar, a coastal area prone to cyclones[13] with high levels of both chronic and seasonal food insecurity (Randrianarison et al., 2020; Rousseau et al., 2023). The general food availability environment is poor, with rural weekly markets located in communities along the paved Route National 12 road only. Off-farm work opportunities are scarce, and community members spoke of migrating to as far away as Diego at Madagascar' northernmost tip to look for seasonal agricultural work. Additionally, the area has seen a recent rise in crime (e.g. theft and cattle banditry; one study village was burned to the ground), potentially

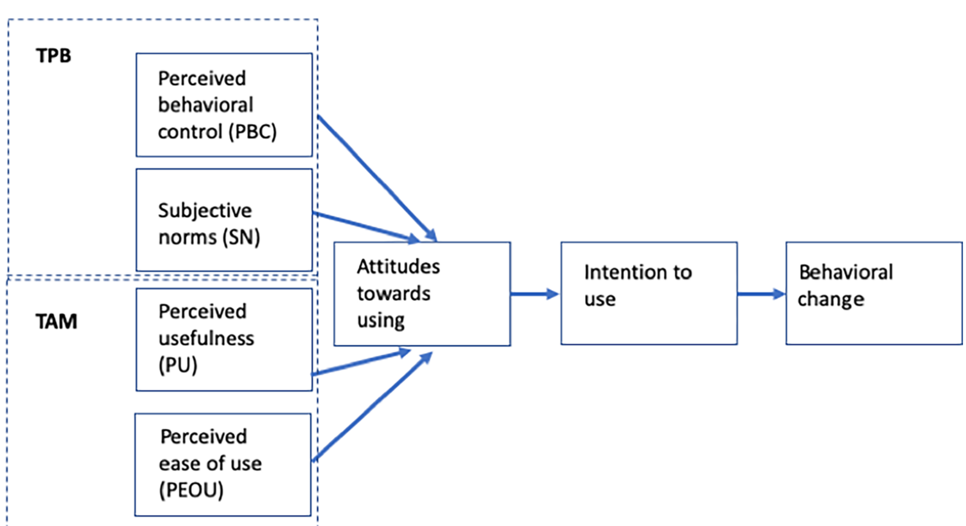

Figure 1. Integrated TPB-TAM framework.

driven by several years of drought conditions (De Berry, 2023).

The population consists primarily of small-scale farmers and fishers, who grow rice on rainfed uplands, as well as in marshy and rainfed lowlands, 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. Rice plots are often scattered and small, with the average distance (measured in minutes walking) from households to rice fields ranges from around 30 minutes for the nearest fields to almost 60 minutes for the farthest ones. Furthermore, households in this area are generally monogamous, consisting of a husband-wife pair who typically farm together on family parcels. Nonetheless, distinct gender roles in the rice-growing process may play a role in determining which SRI steps are implemented at the household level (e.g. women are typically responsible for transplanting and may therefore be more likely to make decisions regarding transplanting technique).

Farmers have limited access to extension services, credit, irrigation infrastructure, and inputs such as improved seeds and fertilizers, with degraded soils prevalent across the island (Berkhout & Glover, 2012). Furthermore, due to limited irrigation infrastructure, lowland paddies tend to be situated in marshy areas, which are often difficult to drain and may remain flooded throughout the entire growing season. Therefore, some SRI components may be less feasible to implement (e.g. alternate wetting and drying, organic fertilizer application), while others (e.g. transplanting modifications, frequent weeding) are feasible regardless of access to infrastructure and other locally available inputs.

Since 2019, the NGO Health in Harmony (HIH) has partnered with Manombo area communities to provide healthcare and support local conservation efforts. After using the "radical listening" method, HIH responded to community members' requests to augment their rice production through improved techniques by providing a free-of-charge training on organic SRI in lowland areas from October 2020 to January 2021. The training used a hybrid model of agricultural trainers and centrally located demonstration plots. A total of 213 subsistence rice farmers, of which an estimated 70% were women, registered for the SRI training across five demonstration sites (Figure 2). During the training period, one of two male agricultural agents visited each site once or twice per week. Participants were provided with fast growing rice seeds (three-month variety), and mechanical weeders (*sarcleuses*) were made available

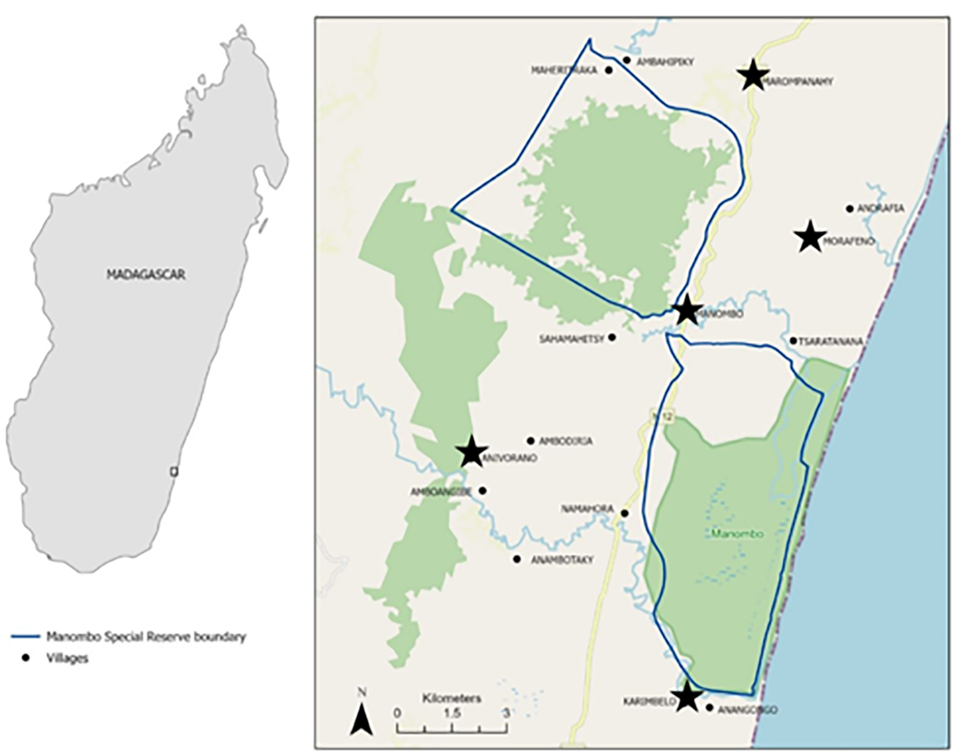

Figure 2. Map of study area. *Note:* Stars indicate SRI demonstration sites. Blue lines demarcate Manombo Special Reserve. Yellow line is RN12 (paved national road).

to borrow from each of the demonstration sites. Lunch was also offered to training participants.

2.2. Study design & data collection

A case-control design of treatment (SRI training registrants) and non-treatment (non-registrants) farmers from the same villages was conducted, and a pre-post design was used to measure the same individuals at two timepoints. To this end, two rounds of surveys were carried out; the first in February 2021 post-training/prior to farmers practicing SRI, and the second in April 2022. In 2021, we attempted to survey all training registrants (one registrant per household). Of the 328 total rice farmers surveyed, 199 had registered[14] for the HIH SRI training program (based on sign-up sheets provided by HIH), and 129 were non-registrants from households randomly selected from the 15 participating villages. The number of non-treatment respondents per village was determined using PPS (percentage proportional to sample) of remaining eligible farming households 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. demonstration site, number of trainings attended). While SRI adoption data was gender-disaggregated, respondents likely answered for the whole family unit (male and female household members have joint rice fields) regarding SRI steps adopted. Gender-disaggregated data was also collected on intention to adopt SRI, as well as on psychosocial (intrinsic) factors commonly used in the TPB and TAM frameworks, such as perceived behavioral control (PBC), perceived usefulness (PU) and perceived opinion of others (subjective norms), which 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 implemented certain SRI steps[15] 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 and "adopters" were carried out in August 2022 in six villages (one FG per village with the exception of Marompanahy in which two were conducted). Two villages from each of the three village types (coastal/east of road, "on road," and near lowland rainforest/west of road) were selected to counteract "roadside biases" (Chambers, 1983). 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.

2.3. Data analysis

2.3.1. Qualitative data

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 bi-lingual Malagasy and English-speakers to ensure its accuracy.

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. 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.

Following Noltze et al. (2012), a continuous variable model looking at the predictors of depth of adoption was also run using total number of SRI 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 (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, 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), highest household education level, as well as land ownership/tenure. As Tezer (2012) found 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. Results

3.1. Descriptive statistics

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 registered for the SRI trainings provided by Health in Harmony, respectively, while 39.3% ($n = 129$) and 41.5% ($n = 115$) had not.

3.1.2. Farmer 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 following *fomban-drazana* (the way of the ancestors) – a method which entails transplanting rice seedlings after about four weeks and in a haphazard fashion (not in a line or grid). Importantly, they do not broadcast seeds as has been documented in some lowland rice production systems (e.g. Graf & Oya, 2021).

In terms of identity and cultural beliefs, most respondents agreed that Malagasy farmers must grow rice (88.4%, $n = 289$), while slightly more than half believed they should follow traditional methods (56.3%, $n = 184$). However, only 14.4% ($n = 47$) worried that the ancestors would disapprove if they did not grow rice in the same way as they once did.

3.2. Perceptions related to SRI in the blended TAM-TPB framework

3.2.1. Perceptions of SRI attributes

In general, 2021 respondents perceived SRI to be extremely useful (Figure 3(a)). 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

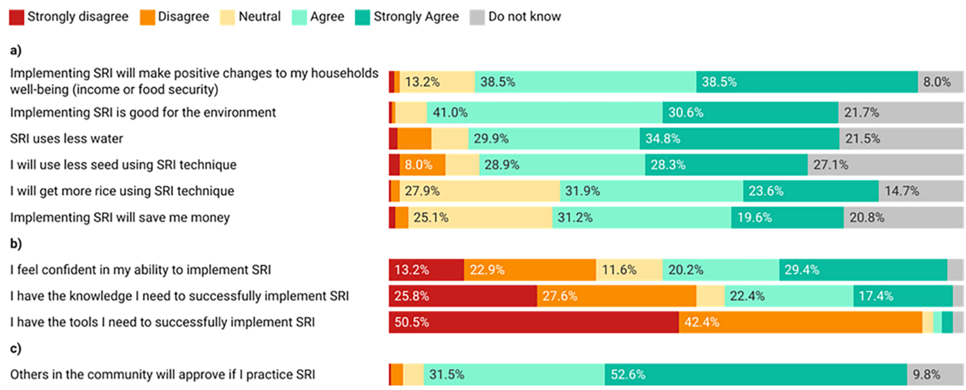

Figure 3. Agreement with statements to measure a) Perceived Usefulness (PU) of SRI, b) Perceived Behavior Control (PBC), and c) subjective norms.

conducted to determine if perceived ease of understanding differed by gender. The results indicated that there was no significant difference between men and women ($z=-0.01$, $p = .990$).

3.2.2. 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(b)). 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 ($z=-2.03$, $p = .042$).

3.2.3. Subjective norms

Figure 3(c) 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 ($z=-1.85$, $p = .064$).

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.

3.3.2. 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 reported as an obstacle. For example, one survey respondent said, "I took care of my ill spouse so I could not attend the training." We also heard during focus groups that families with younger children struggled to attend trainings because of needing to prepare food for those at home. One participant explained that, since her children are older, she was able to attend the training. 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, as the number of training days attended and household assets (wealth) were not correlated (–.031, 95% CI [–.173,.112]). However, despite household care-taking responsibilities, gender was not found to inhibit training participation, as women did not attend significantly less training days than men ($t = .781$, p =.436).

3.4. Intended and actual adoption of SRI

3.4.1. Intention

Of the farmers interviewed, a majority (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

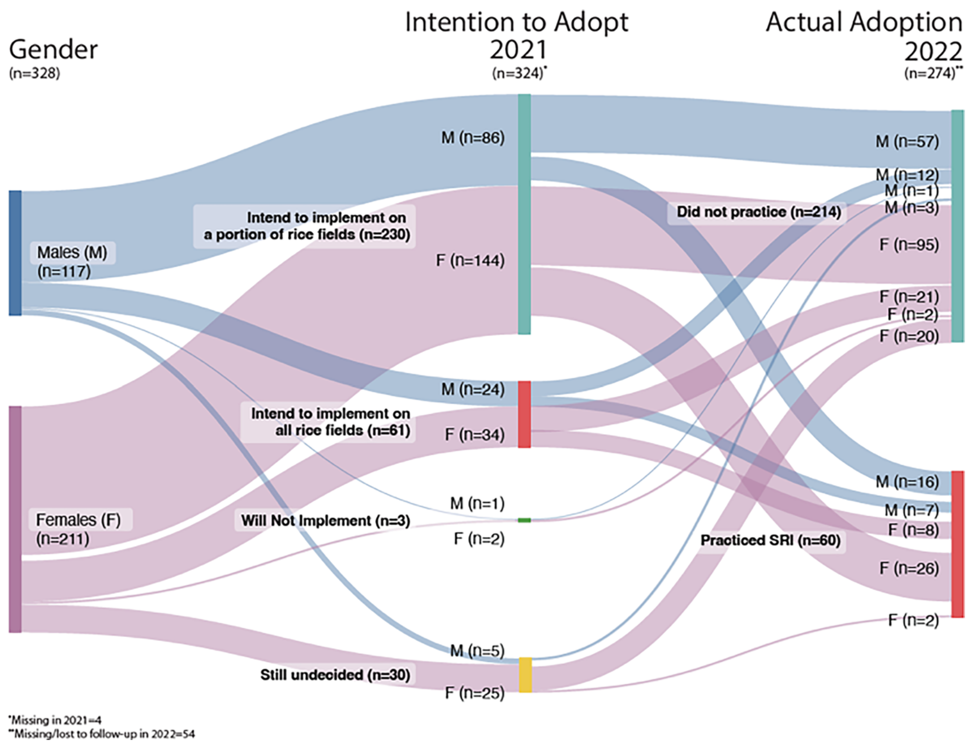

Figure 4. Number of farmers (gender-disaggregated) that stated intention to practice in 2021 compared with those that responded affirmatively to practicing SRI in 2022.

Table 2. Percentage of respondents belonging to SRI adopting and non-adopting households in 2022.

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

Note. Total $n=274$.

implement the technique on all of their fields, while 79% ($n=230$) planned to implement it on a portion of their fields (Figure 4). 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 ($\chi^2= 4.96$, $p =.026$).

3.4.2. SRI adoption

After one year, 21.9% ($n=60$)[16] of farmers self-identified as belonging to households who tried SRI on family rice paddies in the past year (henceforth referred to as "adopters"), compared to 89.7% ($n=291$) who had 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 ($\chi^2= 3.98$, p =.137).

3.4.3. Future intended adoption

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

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. Furthermore, while only 35.4% ($n=57$) of registrants trialed SRI on a portion or all of their fields (Table 2), nearly all (95%, $n=57$) of the 60 adopters were training registrants (less than 3% of non-treatment group trialed SRI).

3.6. Depth and intensity of adoption

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 5). One practitioner reported

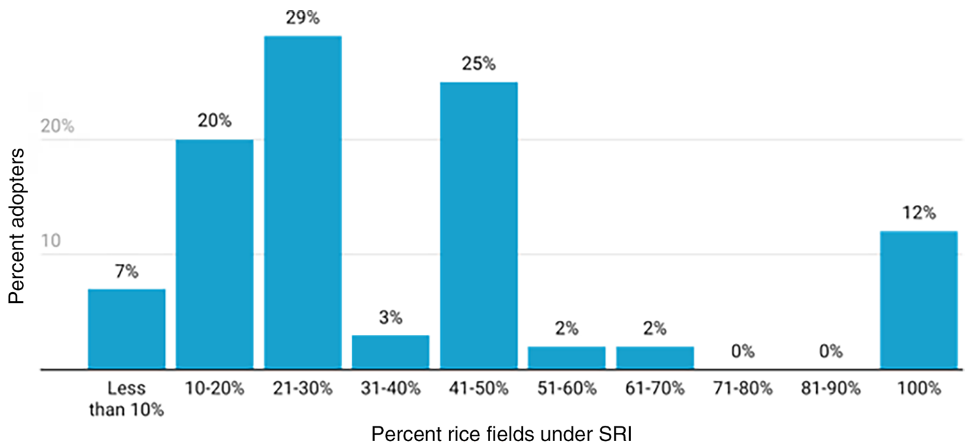

Figure 5. Percentage of rice fields on which SRI adopters trialed the technique.

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.

3.6.2. Depth of adoption

Table 3 presents the percentage of adopting households ($n=60$) implementing each of the SRI steps. Among adopters, an average of 6.7 SRI steps (SD = 1.5) out of eight measured were practiced. However, very few adopters (6.7%; $n=4$) were able to follow all of the steps. Soil preparation, water management, selection and care of seeds and transplanting seedlings in a line were among the steps more commonly practiced. Transplanting young seedlings (7–10 days) was the least implemented practice, with median days of transplanting for all adopters of 30 days (SD = 17.2). While many adopters (78.3%; $n=47$) weeded frequently, it was mainly done by hand. Weeding with a *sarcleuse* was only implemented by about one-third (35%; $n=21$) of practitioners. Of those that used organic fertilizer (85%; $n=51$), most used zebu manure; very few made compost.

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, $F(7,255) = 13.84$, $p < .001$, $R^2 = .28$. 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).

3.6.3. Reasons for not adopting certain steps

Of the steps least practiced, the most common explanation given for not transplanting early/singly in both the survey and focus groups (FG) was that transplants were too small, and therefore seemingly too vulnerable (Table 4). Many survey respondents also said that they did not weed often, or with a *sarcleuse*. From the FGs, we learned that some farmers found the *sarcleuse* challenging to use, and while they were available to borrow at the demonstration sites, supply was

Table 3. Summary table of SRI steps implemented among respondents from SRI adopting households.

Steps measured	Percent adopters ($n=60$)
Transplant young seedlings (7–10 days)	15.0
Transplant singly	75.0
Weed often	78.3
Use organic compost	85.0
Transplant in a line	95.0
Selection and care of seeds	95.0
Water management	95.0
Soil preparation	96.7

Table 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."

limited. Furthermore, while many respondents (28.2%, $n = 92$) said that there was nothing that they did not like about the rice-growing process, the most disliked task was weeding (Supplemental Figure 1). Transplanting, though less disliked than weeding, also ranked among respondents' top four least preferred 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.

3.7. Non-adoption

3.7.1. Adopters vs. non-adopters

"Non-adopters" account for 78.1% of surveyed farmers. Results from independent sample t-tests showed adopting households having significantly greater mean education levels, mean household assets (and therefore, greater ability to hire labor), and attending a greater average number of trainings 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. There was no significant difference between landowners and non-landowners in terms of SRI adoption ($\chi^2 = .75$, $p = .387$). However, respondents living in remote (off road) villages were significantly less likely to adopt SRI than respondents living in less remote (along road) villages ($\chi^2 = 8.25$, $p = .004$).

3.7.2. Main reasons given by respondents for non-adoption

3.7.2.1. Perceived lack of inputs. Responses to the April 2022 survey indicated that the predominant reason that farmers did not practice SRI was due to a perceived lack of special "SRI seeds."[17] In both the survey and focus groups (FG), many farmers complained of either not receiving this particular variety of fast-growing "SRI" seeds from HIH, or having them damaged/lost due to pests, fire, or theft. Others stated that the seeds distributed by HIH did not germinate. One survey respondent shared that, as a result of household food insecurity, they had resorted to eating the seeds that they received from HIH. Indeed, FG participants repeatedly requested the provision of fast-growing rice seeds to alleviate food insecurity. Thus, a desire for additional seed distribution could have been a motivating factor in respondents' expressing lack of seed as the main reason for not implementing SRI.

Through FGs, we further learned that, in addition to respondents' perceived lack of access to seeds deemed appropriate for SRI, access to fertilizer and water (irrigation) were also major obstacles for farmers. Furthermore, as those that did not adopt SRI indicated challenges with controlling water levels in their fields (or coordinating water management with neighbors in irrigation perimeters), a commonly documented issue (Berkhout & Glover, 2012; Minten & Barrett, 2008; Stifel et al., 2003), "adopters" were mainly from households with the ability to manage their fields' water levels.

3.7.2.2. Labor and other seasonal considerations. Other explanations provided for lack of adoption included limited financial capital (especially to hire labor to transplant) and perceived time/labor-intensiveness of the new technique. More specifically, FG participants shared that the significant amount of additional labor required for SRI was a major factor hindering its implementation during the primary rice cultivation period (*vatomandry*), which also coincides with the region's main hunger season (Moore et al., 2022). Thus, many participants stated preference for practicing SRI during *varihosy* rather than during *vatomandry* (the reverse was true for farmers in more southern communities, because, as they explained, their rice paddies do not drain well and therefore have too much standing water to transplant small SRI seedlings during *varihosy*).

As FG participants further clarified, they view SRI as a supplemental practice meant to augment, not replace, traditional rice growing methods. To that end, some expressed not having the time or physical energy needed to work both SRI rice (three-month variety) and traditional rice (5–6 month variety) fields simultaneously, in addition to cultivating other important staple crops such as cassava and sweet potato, during *vatomandry*.

3.7.2.3. Perceptions of vulnerability. While most farmers expressed preference for trialing SRI during the off-season (*varihosy*), they also shared their hesitations regarding practicing it during this time of year. 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 voiced concern that their rice fields would be more vulnerable to pests, such as rats and birds, as well as at increased risk of theft, if they were among just a handful of farmers growing rice in the off-season. Because of risk of theft, some FG participants also stated preferring that the SRI training be held on their individual plots rather than in collective demonstration sites (indeed, farmers reported that their harvest had been stolen from one of these sites).

3.7.2.4. Climatic and geographical factors. While 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, the ongoing drought plaguing the region does appear to have affected some farmers' decision-making regarding SRI adoption. One farmer pointed out, "We should change to SRI, but due to lack of water, we just change the [variety] of sweet potatoes."

In addition to climatic considerations, geographical location/distance of rice fields also influenced farmers' decisions. As one respondent explained, "[Other farmers practiced SRI] because these people have paddies with water around the village, but we do not have rice paddies with water, and our rice paddies are very far away."

3.7.2.5. Human capital ("know how"). Another common explanation provided by FG participants was their hesitation in trialing SRI because they were not "*zatra*," or accustomed, to the new technique. This is likely related to the increased level of precision required to transplant according to SRI prescription, as well as specific instructions on water management and additional weeding effort recommended. Indeed, the learning curve associated with SRI led farmers to request more individualized support from trainers beyond that received at the demonstration sites. Overall, a desire for field-specific and continued training support was expressed: "We need monitoring in the practice to check what we have done…the trainer should monitor the practice."

3.8. Changes in perceptions among adopters

A Wilcoxon signed-ranks test was used to determine the change in perceptions of all adopters 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 6). Indeed, one focus group respondent and "early adopter" shared her experience of being mocked by others because her SRI rice seedlings appeared too sparse and weak.

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

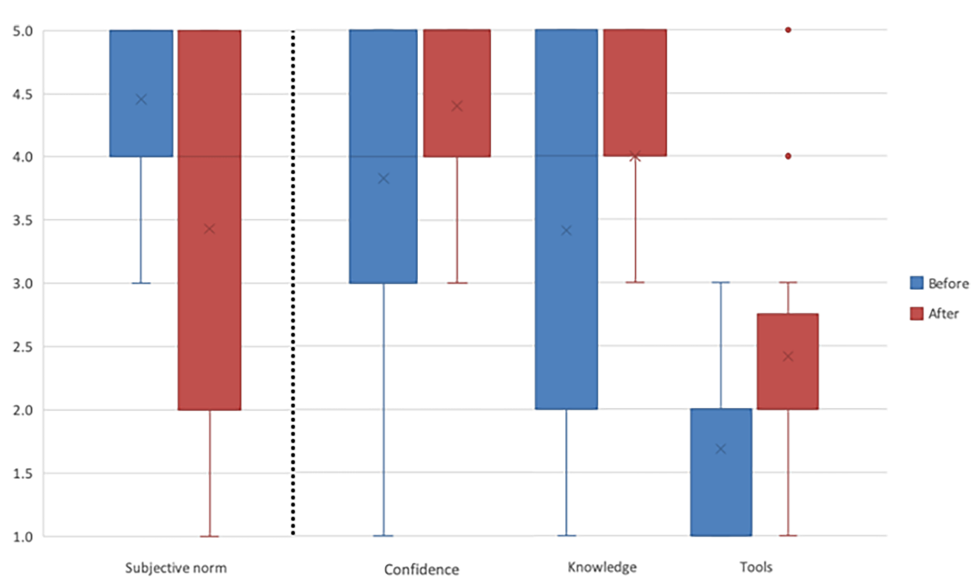

Figure 6. Median scores on a five-point Likert scale (1 = strongly disagree; 5 = strongly agree) for subjective norm and perceived behavioral control (confidence, tools, knowledge) among adopters before (2021) and after (2022) practicing SRI.

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 ($z = -3.35$, $p = .101$).

3.9. Perceptions of SRI after adoption

Among the 60 respondents from SRI adopting households, the majority (68.3%; $n = 41$) did not find SRI difficult to implement. For those that did find 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.

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 benefits. Only three respondents noted that SRI decreases the amount of rice seeds needed, and only one participant recognized that it saves money. There was no mention of environmental benefits – such as reduced water usage.

3.10. Structural equation model (SEM)

A SEM was implemented to predict the factors supporting intention and adoption of SRI (Table 5). According to the final model (lowest AIC), household education level ($\beta = .066$, $p = .013$) and subjective norms ($\beta = .428$, $p < .001$) were significant predictors of perceived usefulness (PU) of SRI, while the number of training days attended ($\beta = .105$, $p < .001$) was a significant predictor of perceived behavior control (PBC) (Supplemental Figure 3). PBC ($\beta = .669$, $p < .001$) and land tenure ($\beta = .450$, $p = .038$) emerged as significant predictors of intention to adopt SRI, while PBC ($\beta = .222$, $p = .028$), the number of training days attended ($\beta = .140$, $p < .001$), and household assets ($\beta = .091$, $p = .001$) were significant predictors of adoption. According to the model, PU, household education level and size, geographical isolation/remoteness of villages, land tenure and subjective norms did not have any significant effects on SRI adoption.

Table 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			
• Village remoteness	−0.117	0.180	.516
• Number of trainings	0.017	0.022	.448
• Education	0.066	0.027	.013
• HH assets	−0.013	0.027	.642
• HH size	−0.033	0.030	.265
• Land tenure	0.445	0.233	.056
• Subjective norm	0.428	0.100	.000
Perceived Behavioral Control (PBC) on			
• Village remoteness	0.093	0.175	.594
• Number of trainings	0.105	0.020	.000
• Education	0.020	0.027	.454
• HH assets	0.041	0.026	.113
• HH size	−0.027	0.028	.338
• Land tenure	0.257	0.222	.247
• Subjective norm	0.135	0.095	.157
Intention to practice SRI on			
• PU	0.126	0.121	.296
• PBC	0.669	0.137	.000
• Village remoteness	−0.063	0.273	.818
• Number of trainings	0.079	0.052	.125
• Education	0.021	0.040	.601
• HH assets	0.031	0.050	.539
• HH size	0.036	0.042	.397
• Land tenure	0.450	0.216	.038
• Subjective norm	0.089	0.116	.441
Actual adoption of SRI on			
• PU	0.014	0.100	.885
• PBC	0.222	0.101	.028
• Village remoteness	0.172	0.181	.341
• Number of trainings	0.140	0.025	.000
• Education	0.042	0.027	.125
• HH assets	0.091	0.027	.001
• HH size	−0.053	0.033	.104
• Land tenure	−0.455	0.238	.056
• Subjective norm	−0.119	0.112	.286

4. Discussion

Our study reveals that Manombo area farmers perceive SRI as relatively easy to implement and understand, and that they are keenly aware of its potential benefits at the household level, especially in terms of increased food supply. This positive perception is evidenced by the large percentage of respondents expressing intentions to practice it. However, we find that farmers face a range of constraints that hinder their adoption efforts and/or decision-making ability. These include extreme vulnerability to food 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 (e.g. *vatomandry*), 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.

In line with a large body of evidence from the adoption literature, we find that farmers tend to exhibit selective adoption of specific aspects of SRI that align with their existing farming systems, and that they are more inclined to reject elements perceived as less feasible. For example, similar to SRI studies in other lowland areas (e.g. Graf & Oya, 2021), Manombo area farmers prefer transplanting in clumps of two or more because young seedlings are considered too delicate to be planted singly, especially in poorly drained fields or fields with standing water. Also, as Lee and Kobayashi (2018) report among rainfed lowland rice farmers in Cambodia, differential access to water supply is an important determinant of SRI adoption decisions. Furthermore, although SRI can decrease water-use in irrigated rice farming systems, in the context of this study, alternate wetting and drying (AWD) could mean simply draining standing water away, rather than conserving irrigation water.

While we did not find farm characteristics, such as household education level and size, to play significant roles in adoption decisions, households with greater household wealth were more likely to register for trainings (they could be prominent members in the community more easily sought out by extension agents), as well as more significantly likely to adopt SRI, and to a greater depth. These findings are likely due to wealthier households having greater means to hire labor, particularly for more labor-intensive SRI steps such as transplanting and weeding, which also allows them more "free time" to attend trainings. Wealthier households may also have greater food security and may therefore be more willing and capable of taking agricultural production risks. In addition, as households in more remote villages were significantly less likely to adopt SRI than those in roadside villages, access to trainings, either physically or because of financial and human capital, emerged as critical.

Furthermore, SEM results underlined the importance of training participation and attendance. Attending trainings, as well as having higher perceived behavioral control (PBC) and household wealth, were significant predictors of SRI adoption. Experience implementing SRI on one's own land for one season also increased farmer PBC (confidence, know-how, tools) to successfully implement SRI – particularly for women. Increased confidence among women as a result of attending trainings and implementing SRI for one season could also indicate increased agricultural decision-making power within the household.

However, while our results show that trainings are important, it is still necessary to consider what may be lacking in the trainings, and areas for improvement to foster higher take-up of the technique. For example, in households with multiple decision-makers, family inclusion in trainings is essential in contexts where the transfer of knowledge between family members cannot be assumed.

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 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, few actually practiced, especially among those that did not register or attend trainings. While it is possible that some respondents who expressed intentions to practice SRI did not have the ultimate decision-making power required to do so, there are many other factors which could 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 for SRI was the most commonly cited reason for not adopting the technique.[18] Soil infertility and limited access to fertilizers and irrigation infrastructure were also reported as major obstacles. Farmers also expressed perceived inability to implement SRI successfully due to insufficient tools, providing further evidence that farmers simply do not have the resources to adopt all aspects of SRI (Freudenberger & Freudenberger, 2009). Thus, in resource-limited settings such as rural Madagascar, it is crucial to support community seed networks, with access to farmers' preferred seed varieties[19] (Hume, 2006), provide basic tools in an equitable manner, while also bolstering farmers' capacity to rebuild healthy soils and construct improved water systems. Furthermore, as research has shown female farmers to be less likely to purchase, for example, fertilizer and drought-resistant seeds (Carranza & Niles, 2019; Voss et al., 2021), additional supports should be oriented towards them.

Additionally, we find that, similar to conclusions of multiple authors (e.g. Kamara et al., 2023; Loukes, 2015; Moser & Barrett, 2003), SRI's additional labor requirements during an already labor-intensive period are a main deterrent for farmers. To lessen labor demands, a flexible pedagogical approach is recommended, whereby farmers are encouraged to experiment[20] with suitable adaptations through participatory processes. 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).

Similarly, women's reluctance in adopting new practices, in particular, can be reduced through labor saving technologies (Mujawamariya et al., 2022). For example, direct seeding or broadcasting rice seeds, rather than transplanting seedlings,[21] has been found to reduce 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). There is also ongoing research being conducted in China on a perennial rice variety (PR23), which would reduce labor, but not without potential drawbacks (Stokstad, 2022).

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 (and real) risks. Similar risk-related reluctancies have been reported among farmers in multiple contexts, from the central highlands of Madagascar (Berkhout & Glover, 2012) to south India (Taylor & Bhasme, 2019), as well as in Java where farmers discontinued SRI 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.

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), at least at this early stage of diffusion.

As women were significantly less confident than men 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. Given the importance of family labor dynamics within the rice-growing process and the understanding that farmer-to-farmer knowledge transmission of information tends to be low in Madagascar (Hume, 2006, 2020), even within households, trainings could be more effective if they were multigenerational and family-inclusive, with a focus on empowering youth leaders.

Additionally, 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, reasons for not attending trainings among registered farmers were often 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 of 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 recommendations made in previous studies of Malagasy farmers for more frequent, continuous and individualized technical support for farmers (Achandi et al., 2018; Moser & Barrett, 2003; Tezer, 2012). As farmers living in remote villages were significantly less likely to adopt SRI, providing additional support and oversight, 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.

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).

As the Diffusion of Innovation (DOI) theory states, perceived attributes of an innovation, such as compatibility with existing worldviews and systems, are also important 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, 2012), they align with findings from studies in Asia (Arsil et al., 2019; Palanisami et al., 2013) and in other lowland rice farming systems where water cannot be easily controlled (Graf & Oya, 2021). Furthermore, while the lower rate of transplanting single seedlings could be partially attributed to the training approach used (some participants reported being taught to plant seedlings in clumps of two), older, sturdier seedlings may be necessary for survival in certain paddy locations experiencing strong waterflows after rain events.

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 introducing steps and teaching them 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 can more fully comprehend the significance of each step and the advantages of incorporating them.

4.5. Critique of sociopsychological models

While underscoring the significance of trainings and farmers' perceived behavioral control (PBC) 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 demonstrates that intentions do not drive behavior change in this context, casting doubt on the applicability of Western-developed frameworks in certain settings. Furthermore, the role of subjective norms on farmer decision-making is more complex than the theoretical models allow for – i.e. while neighbors may seemingly approve of others practicing SRI, there is real vulnerability to crop loss from theft, as demonstrated in our FG 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 plot 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, analyses 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 consistent presence in communities, would help to further elucidate the best way for farmers to adopt SRI, given its flexibility and emphasis on working together with farmer communities to resolve challenges (Castellanet & Jordan, 2002; Kindon et al., 2007; Méndez et al., 2017).

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). 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." It is also critical to examine the social implications that arise after adoption, as highlighted by Theis et al. (2018).

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 incentives are discontinued (Andersson & D'Souza, 2013; Moser & Barrett, 2003). It is therefore crucial to move beyond the 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. Thus, 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).

While the gender variable was ultimately removed from the SEM, a further limitation in our study is that the model is based on the assumption that the respondent was involved in the decision to practice SRI (even in households were the family unit makes joint decisions, power imbalances almost always exist). Since smallholder farms are typically family-operated with the potential for multiple decision-makers within the same household, it is crucial for research to more deeply consider the role of family power dynamics in the innovation adoption process (Perret & Stevens, 2006). Thus, more studies examining intra-household decision-making at various steps is required. To tease out the role of gender on SRI adoption decisions, future research should include questions designed to elicit additional information on the following topics: 1) rice parcel ownership (e.g. are all "owned" by the family unit, or are there instances in which either the male or female counterpart is considered the owner, perhaps through inheritance) and 2) which members of the household make decisions related to rice-growing more generally, as well as within each step in the rice-growing process (with the understanding that respondent type can affect perceptions regarding who has agricultural decision-making power; Alwang et al, 2017).

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 closer examination of plot-level factors affecting SRI adoption, such as biophysical constraints (e.g. types and 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 SRI and non-SRI 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 households with members 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 social desirability bias, in which respondents may have over-indicated their intention to adopt SRI practices because they did not want to give an answer that they felt might be undesirable to interviewers.

5. Conclusion

This study highlights the importance of understanding farmers' perceptions regarding new agricultural techniques (e.g. even if the SRI technique does not prescribe special "SRI" seeds, farmers perceived lack of these seeds as one of their main limitations), as well as their lived realities (e.g. some had to eat their "SRI" seeds). It also provides evidence of the importance of bolstering farmers' perceived behavioral control (PBC) in promoting the adoption of sustainable intensification practices, such as SRI, over other factors such as perceived usefulness and perceived ease of use. Thus, 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. Furthermore, it is important to provide targeted support to women, whose PBC can be enhanced through practical experience with the technique. At the same time, increasing incentives offered and employing methods to reduce both actual and perceived risks associated with trialing a new agricultural practice, as well as considering the structural barriers to adoption, such as infrastructure and institutions, are critical. Not only does this work add to the academic conversation in adoption studies on SRI as well as agricultural technology adoption more generally, but from an applied standpoint, it can also inform policies and interventions to achieve better outcomes for smallholder farmer food security and livelihoods.

Notes

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).
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).
4. SRI has progressed more into a set of agronomic principles than simply a list of practices (Uphoff, 2023), which can be adapted and customized to fit local contexts (Beumer et al., 2022; Uphoff et al., 2011).
5. SRI has 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).
6. Rice paddies account for an estimated 19% of global methane gas and 11% of global nitrous oxide emissions (Win et al., 2020).
7. As various steps within the SRI package may be adopted, it can be challenging to determine what constitutes an "adopter" (Tezer, 2012). In this study, farmers were asked to self-identify as to whether they consider having practiced SRI or not.
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).
9. 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.
10. The Malagasy term for traditional rice growing practices is "fomban-drazana" [ways of the ancestors].
11. 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).
12. 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).
13. The area was hit by two consecutive cyclones in early 2022.
14. 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.
15. 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.
16. Although they did not consider themselves "adopters," 101 respondents indicated practicing at least one of the steps in SRI.
17. It is important to note that SRI itself does not require a specific type of seed (Barrett et al., 2021).
18. 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.
19. 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.
20. Though Noltze et al. (2012) caution against expecting excessive experimentation from farmers.
21. Despite some 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.

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Data availability statement

The data that support the findings of this study are openly available in Figshare at http://doi.org/10.6084/m9.figshare.23732466

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