Journal of Agriculture and Food Research 14 (2023) 100881

Contents lists available at ScienceDirect

Journal of Agriculture and Food Research

journal homepage: www.sciencedirect.com/journal/journal-of-agriculture-and-food-research

Drivers of food and nutrition security during the lean period in southeastern Madagascar

Sarah Tojo-Mandaharisoa [a,b,*], Narilala Randrianarison [a], Irmgard Jordan [c], Christoph Kubitza [d], Denis Randriamampionona [a], Harilala Andriamaniraka [a], Stefan Sieber [b,e], Christian Ulrichs [d], Jonathan Steinke [b,d]

[a] Department of Tropical Agriculture and Sustainable Development, Ecole Supérieure des Sciences Agronomiques Ankatso, University of Antananarivo, Antananarivo, Madagascar
[b] Sustainable Land Use in Developing Countries, Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany
[c] Alliance of Bioversity International and CIAT, Nairobi, Kenya
[d] Department of Crop and Animal Sciences, Albrecht Daniel Thaer Institute of Agricultural and Horticultural Sciences, Humboldt-Universität zu Berlin, Berlin, Germany
[e] Department of Agricultural Economics, Albrecht Daniel Thaer Institute of Agricultural and Horticultural Sciences, Humboldt-Universität zu Berlin, Berlin, Germany

ARTICLE INFO

Keywords:
Dietary diversity
FIES
Markets
On-farm diversity
Smallholder farmers
WDDS

ABSTRACT

The rural population in southeastern Madagascar faces widespread poverty and weak resilience to frequent climate shocks, both contributing to severe food and nutrition insecurity. For effective policy responses and tailored interventions, development stakeholders need to know which factors determine household food and nutrition security status. In particular, the relative contributions of on-farm production diversity versus cash income are of importance since they would suggest different intervention priorities. We collected survey data on household food security and women's diets during the lean season, where improvements are most needed, as well as on households' agricultural activities, market participation, and sources of cash income from 413 randomly sampled households. Regression results suggest that frequent market participation and cash income from non-farm self-employment improve food security, but on-farm diversity does not. Other determinants of household food security include livestock assets and maternal education. Women's dietary diversity, in contrast, is associated only with market participation. The importance of market participation for food and nutrition security reflects the situation in the lean period, when farm production is low and many households' food supply relies, in part, on market purchases enabled by non-agricultural income. Our findings imply that a focus on developing food markets and enabling opportunities for income generation are likely viable strategies for improving the rural food and nutrition security situation during the lean period in southeastern Madagascar. Relatively food- and nutrition-secure households are characterized by their ability to mobilize cash (e.g., from non-farm self-employment) to purchase food.

1. Introduction

Adequate access to healthy diets is a major challenge for human development in many places worldwide. Especially in low- and middle-income countries, widespread poverty contributes to elevated rates of undernourishment and under-diversified diets [1]. In Madagascar, hunger is widespread, as over a third of households lack access to adequate food at any given time of the year [2,3]. Frequent climate shocks, including tropical cyclones and droughts, as well as strong seasonal variation in food availability and affordability contribute to food insecurity [4–6]. With 61 % of the overall population considered food insecure, many people suffer from impaired health and physical development: 40 % of children under five years of age are stunted and 38 % of women in reproductive age are affected by anemia [1]. This situation is especially critical in southeastern Madagascar. Due to a high level of poverty and limited resilience to frequent climatic shocks, this rural smallholder region experiences serious food and nutrition insecurity [7].

* Corresponding author. Department of Tropical Agriculture and Sustainable Development, Ecole Supérieure des Sciences Agronomiques Ankatso, University of Antananarivo, Antananarivo, Madagascar.
E-mail address: tojmands@yahoo.fr (S. Tojo-Mandaharisoa).

https://doi.org/10.1016/j.jafr.2023.100881
Received 28 March 2023; Received in revised form 19 October 2023; Accepted 15 November 2023
Available online 18 November 2023

Food and nutrition insecurity may not only have long-term repercussions for human well-being, health, and cognitive development, but may also affect wider economic development [8,9]. Hence, national and international policies should prioritize reducing food and nutrition insecurity in the region. However, while there are many different policy and intervention options, ultimately, effective interventions depend strongly on local context [10,11]. In this context, one important discussion in the socioeconomic literature relates to the impacts of diversifying on-farm production of smallholder farmers versus enabling them to purchase food on markets. Positive links between on-farm species diversity and dietary diversity are well-documented, albeit specific and often weak [12–16]. Most meta-analyses suggest that the relative effects of on-farm diversification vary by location and context [17–19]. In places where farmers are able to generate cash income, investments into improved market access may generate stronger effects on food and nutrition security [14,20]. Where food markets are not easily accessible and income generating activities are rare, on-farm production diversity remains important for local food and nutrition security [21,22]. Another important discussion relates to the role of increased off-farm income generation for improving food and nutrition security. In smallholder farming households, access to cash income is associated with better outcomes, especially as non-agricultural income can help smooth food access across the year [23,24]. Notwithstanding, opportunities for income generation are not equally available to all farmers, and additional income may not translate into improved food and nutrition security for all households [25–28].

Considering the context-specific nature of effective food and nutrition security interventions, policy makers and development stakeholders need to understand local determinants. This is particularly true for vulnerable settings with high incidences of poverty, like southeastern Madagascar, where research findings from regions with higher income may not apply. To date, no such analysis is available for southeastern Madagascar. Exploring the drivers of existing local variation in food security and dietary outcomes can also help identify locally promising intervention opportunities [6,29,30]. Thus, to contribute to better-informed decision-making on effective policy and development interventions we intended to answer the question: what factors explain food and nutrition security of rural smallholders in southeastern Madagascar? In particular, we were interested in exploring the potentials of improving local diets by (a) enhancing self-supply from own farming vs. (b) enhancing market purchases by strengthening incomes. We thus specifically studied the roles of on-farm diversity and access to cash income sources. We explored data from 413 rural households on food security, women's diets, assets, on-farm production, market participation, and income sources. On this basis, we conducted a cross-sectional study to determine the drivers of food and nutrition security in rural southeastern Madagascar. Our analysis contributes an understanding of the context-specific interplay of on-farm production diversity, cash income, and market participation for food and nutrition security in the study region. From this evidence, we derive concrete recommendations for locally suitable interventions.

2. Methods

2.1. Background on food and nutrition security

Food security and nutrition security have underlying concepts that has evolved across the year. During World food summit in 1996, food security was defined as a state "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". This includes the four dimension of food availability, access, utilization and stability. In the other side, nutrition security has been evolved as multi-sectorial nutrition planning approach with the three determinants access to adequate food, care and feeding practices, and sanitation and health. More precisely, …"a person is considered nutrition secure when she or he has a nutritionally adequate diet and the food consumed is biologically utilized such that adequate performance is maintained in growth, resisting or recovering from disease, pregnancy, lactation and physical work" … [31]. Food and nutrition security has become a combination of both concepts linguistically and conceptually further to emphasize the achievement of both food security and nutrition security. In 2012, the Committee for World Food security set the benchmark as "when all people at all times have physical, social and economic access to food, which is safe and consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life" [32].

Apart of providing a comprehensive overview of key themes, this section also give an overview of previous findings on food and nutrition security in low-income countries, with a focus on determinants.

Household characteristics contribute to the food security status of the household. Larger households encounter greater challenges in providing an adequate food and balanced diet for family members [33,34]. Education level is also an important factors for food and nutrition security [6,35]. Indeed, knowledgeable women have skills and knowledge in hygiene, health, as well as more employment opportunities that will improve their family overall nutrition status and securing the household income [33,36,37].

In agrarian economies, productive assets such as farm size, livestock, investment capital play also a crucial role in food and nutrition security [38]. Larger farms and diversified agricultural practices increase food availability and dietary diversity, while livestock contribute essential nutrients and income diversification [26]. Investment capital enables food production capacity improvement. The impact of farm productivity on food and nutrition security is, however, influenced by contextual factors.

Seasonality figure among the factors influencing food production by creating fluctuations in the availability and accessibility of essential food [39]. Agricultural production often peaks during specific times of the year, leading to abundant harvests followed by periods of scarcity that influence the food consumption patterns [40]. During lean seasons, household is more vulnerable to hunger and malnutrition due to higher food prices, exacerbate food spoilage, reduced income [39,41].

Market participation via food purchase and income from food sales [26,42] ensures the availability of diverse food products during seasonal food stress [39,43], as well as the fulfillment of nutrient intake during the harvest period [24]. Many researches highlight the importance of diverse off-farm cash income in the accessibility on safe and nutritious food throughout the year and the investment on family care [6,35]. In long term, income diversity improves household well-being, alleviate poverty and build household resilience to climate shocks and seasonality [44,45].

However, efforts to address food and nutrition security take into account the local social and cultural norms. Food consumption habits and taboos, in a given community, determine the household diets by their preferences, preparations and consumption period. This is also affected by social norms such as gender and social position within communities [46]. For Madagascar, there is social, cultural, and environmental variation of health conditions and nutritional status between region, community and even within community in Madagascar [46,47].

2.2. Research context

The Atsimo Atsinanana region of southeastern Madagascar is among the least developed regions of Madagascar. A high poverty rate contributes to food insecurity, with 51 % of households considered to be moderately food insecure and 7 % severely food insecure [48]. The region is characterized by a tropical and humid climate [49,50]. Of the adult population, 90 % is involved in agriculture, generally cultivating small farms focusing on rice and cassava, as well as on cash crops, such as cloves, coffee, and pepper [49]. Farming is often accompanied by

livestock rearing, including cattle and small livestock species (e.g., pig, poultry) as well as by sweet water or coastal fishing. However, agricultural production is challenging due to small farm sizes and limited access to modern inputs [49]. The region experiences frequent natural disasters that affect rural livelihoods, including both drought [51] and flooding due to tropical cyclones [50]. Strong seasonality in food supply leads to a marked lean period, which usually lasts from February to April [7,52]. During this period of limited agricultural activity, household's own rice production is increasingly depleted and there are few opportunities for generating cash through agricultural wage labor. This increases the prevalence of food and nutrition insecurity during the lean period.

The research was carried out within a food and nutrition security intervention project implemented by GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit; German Agency for International Cooperation). The project aimed at improving the food and nutrition security status of women in reproductive age (15–49 years) as well as their children and households. Data collection occurred as part of the baseline study and, thus, was not biased by the implementation of project interventions. The donor had no influence on study design, results interpretation, or the decision to publish these findings. Further, we declare no conflict of interest.

2.3. Data collection

2.3.1. Sampling

In February 2020, a quantitative household survey was carried out in three of the five districts of Atsimo Atsinanana: Vangaindrano, Farafangana, and Vondrozo (Fig. 1). Data were collected in 24 *communes* (municipalities), with the number of communes per district determined in proportion to each district's share of the region's overall population: eleven in Vangaindrano, nine in Farafangana, and four in Vondrozo. A multistage random sampling approach was used to select the 24 communes, 67 *fokontany* (rural municipalities in Madagascar), and 6 to 7 households within each fokontany. As the study took place in the context of a development project targeting maternal health, we exclusively interviewed women with a child aged 6–23 months at the time of the survey.

2.3.2. Indicators

We collected data on food security and dietary diversity, as well as information on household demographics, asset ownership, on-farm production, market participation, and cash income sources. To assess food and nutrition security drivers, most of the literature refer to food access at household level and diet diversity at individual level. For this purpose, food access is generally evaluated by using the Food Insecurity Experience Scale (FIES), while individual dimension is assessed with Women Dietary Diversity Score (WDDS) or Children Dietary Diversity Score (CDDS). In the context of our study, we use the indicators FIES and women's diet (WDDS-10) as the study is carrying out within a food and nutrition project intervention aiming women's diet improvement.

Food security: We assessed household food security by using the Food Insecurity Experience Scale [FIES; [53]. To focus on the lean season, we used a four-week recall period instead of a twelve-month recall period [27]. FIES comprises eight dichotomous questions about different experiences related to inadequate food supply. We defined households with 0–3 affirmative answers as 'food secure,' while households with 4–8 affirmative answers were defined as 'food insecure' [54,55].

Dietary diversity: To assess the dietary diversity of women, we elicited the WDDS-10, or Women's Dietary Diversity Score based on ten food groups [56,57]. The food groups were: starchy staples (including grains, white roots and tubers, and plantains); pulses (beans, peas and lentils); nuts and seeds; dairy; meat, poultry and fish; eggs; dark green leafy vegetables; vegetables and fruits rich in vitamin A; other vegetables; and other fruits [58,59]. An open 24-h recall period was used to capture information about women's food consumption at home and outside, within the last 24 h before the interview.

Socio-demographic variables: The socio-demographic variables included household characteristics that are known to influence the food and nutrition security situation [60–62]. These included household size, the child's age, maternal age, maternal education level, marital status, immigration from another region of Madagascar, and the access to farmland. We also enumerated whether the household has received any formal nutrition advice during the last 12 months, for example, from

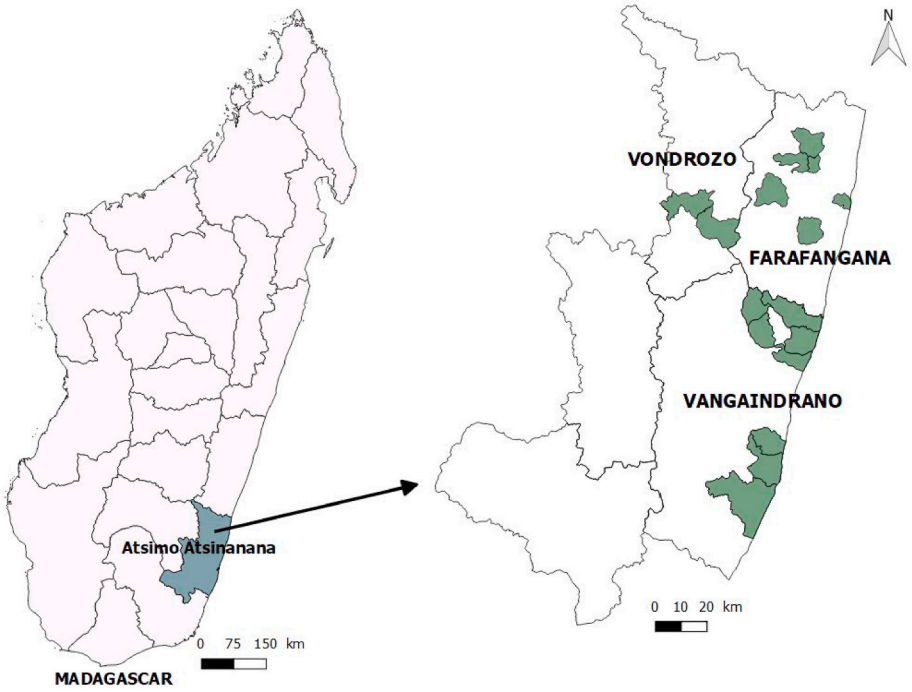

Fig. 1. Research sites in southeastern Madagascar (Atsimo Atsinanana region), with communes highlighted in green color. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

agricultural extension services, public nutrition agents, non-governmental organizations, or other sources.

Asset ownership: We collected information on certain assets owned by the household and on housing characteristics that may explain the food and nutrition security situation of the household. Domestic assets can represent household wealth, can be sold for cash in case of shocks, and may assist in informed decision making [63]. Thus, we enumerated whether households owned three assets: working TV, working radio, and a working mobile phone. We approach household assets as a count variable by adding the number of assets owned by the household. We also collected data on livestock assets (numbers of poultry, pigs, and cattle).

On-farm production: We measured on-farm production using the Production Diversity Score (PDS), defined as the number of food groups produced [21]. We enumerated whether or not, over the course of the 12 months preceding the survey, the household produced eight food groups: starchy staples, pulses, nuts and seeds, flesh foods, dark green leafy vegetables, Vitamin A-rich vegetables and fruit, other vegetables, and other fruits. We also enumerated the number of poultry, pigs, cattle, and eggs sold over the course of the 12 months preceding the survey.

Market participation: We assessed market participation by the estimated average frequency of market visits. There were three options: every day, at least weekly, at least monthly. Respondents provided the answer that best characterizes their overall market participation to the local market. In the context of the study, local market refers to the existing market at village or/and municipality level consisting of the sale of food and essential products for daily lives such as salt, oil. At these levels, markets are held independently of any project intervention.

Income sources: Cash income, both from farm product sales and off-farm labor, is considered to be an important driver of food security [20,26,44]. Because greater income diversity is expected to enhance resilience, particularly during the lean season, we counted the number of different income sources contributing to the household income during the last 12 months. For this, we considered ten types of income: on-farm income from sale of food crops, on-farm income from sale of cash crops, non-farm self-employment, income from charcoal manufacturing, temporary wage labor, permanent salary, sale of wild (gathered or hunted) products, income from public transfers, income from family remittances or donations, and any other income sources.

2.4. Data analysis

We aimed at identifying determinants of food and nutrition security at the household and individual levels by using regression models. For household food security, measured by a dichotomous variable, we employed logistic regressions. For women's dietary diversity, measured by food group counts, we employed negative binomial regressions, given over-dispersed data. For both outcome variables, regression models take the following form:

$$p(FNS_i) = \alpha + \beta X_i + \gamma PDS_i + \varepsilon_i \quad (1)$$

In equation (1), FNS_i represents the food and nutrition security indicator for household i. This is either a binary indicator of household food security, based on FIES, or the WDDS-10 score for the interviewed woman. X_i represents a vector of observable variables: all models control for variations in local biophysical conditions by including the commune as a covariate. We also included a set of control variables, including demographic variables, domestic asset index, market participation, access to nutrition advice, livestock head counts, as well as the number of livestock and eggs sold. Models also considered whether the woman had immigrated from another region, as differences in regional culinary cultures can influence food and nutrition security outcomes [64]. An error term, ε_i, represents unobserved characteristics.

For both outcome variables (household food security and WDDS-10), we specified four alternative models. In model (1), we included Production Diversity Score (PDS) to test for the effect of on-farm production diversity. In model (2), for a better understanding of the role of different farm outputs, we disaggregated PDS and included each produced food group as an individual dummy variable.

$$p(FNS_i) = \alpha + \beta X_i + \gamma_1 foodgroup1_i + \gamma_2 foodgroup2_i + \ldots + \gamma_{10} foodgroup10_i + \varepsilon_i \quad (2)$$

In addition, to study the role of cash income versus the role of on-farm production diversity, we fit two more models: in model (3), we included PDS, but also added the diversity of income sources of the household, a count variable ranging from zero to eleven.

$$p(FNS_i) = \alpha + \beta X_i + \gamma PDS_i + \delta(\text{number of income sources})_i + \varepsilon_i \quad (3)$$

In model (4), we included PDS and added separate dummy variables representing eleven alternative sources of cash income. The individual income sources are listed in Table 1.

$$p(FNS_i) = \alpha + \beta X_i + \gamma PDS_i + \delta_1 incomesource1_i + \delta_2 incomesource2_i + \ldots + \delta_{11} incomesource11_i + \varepsilon_i \quad (4)$$

Thus, we specified a total of eight regression models. Due to missing values on outcome variables, the initial 413 sample size was reduced to 410 for household food security models and 400 for WDDS-10 models.

To control for family-wise error rate of multiple testing, we performed Holm-Bonferroni correction by adjusting p-values of model

Table 1
Characteristics of sampled households (n = 410). Values in parentheses are standard deviations (SD). Percentages refer to the share of all households. Food group self-supply refers to a twelve-month recall period.

	Variable definition	Mean (SD)
Food secure household	Binary variable	0.26
WDDS-10	Food groups	2.64 (1.09)
Household size	Persons	6.90 (3.10)
Maternal age	Years	26.39 (7.25)
Maternal education	Years spent in education	4.25 (3.85)
Female household head	Binary variable	0.20
Mother not married	Binary variable	0.27
Child's age	Months	12.87 (5.09)
Household receiving nutrition advice	Binary variable	0.23
Mother immigrated from another region	Binary variable	0.02
Domestic assets	Number of TV, radio, phone	0.71 (1.05)
Market visit: every day	Binary variable	0.27
Market visit: at least weekly	Binary variable	0.65
Market visit: at least monthly	Binary variable	0.08
Number of poultry owned	Animal heads	8.93 (12.38)
Number of pigs owned	Animal heads	0.50 (1.21)
Number of cattle owned	Animal heads	0.79 (1.93)
Production Diversity Score	Food groups	3.29 (1.87)
Number of poultry sold	Animal heads	19.16 (22.33)
Number of pigs sold	Animal heads	4.57 (3.10)
Number of cattle sold	Animal heads	2.5 (1.29)
Number of eggs sold	Number of eggs	32.78 (46.18)
Income diversity	Number of income sources	1.87 (0.91)
Income from sale of food crops	Binary variable	0.33
Income from sale of cash crops	Binary variable	0.26
Income from non-farm self-employment	Binary variable	0.16
Income from charcoal manufacturing	Binary variable	0.04
Income from temporary wage labor	Binary variable	0.60
Income from permanent salary	Binary variable	0.05
Income from wild products	Binary variable	0.22
Income from donations	Binary variable	0.09
Income from parental or NGO support	Binary variable	0.01
Income from public transfers	Binary variable	0.00
Income from other source	Binary variable	0.11
No cash income	Binary variable	0.09

covariates [65]. We assessed goodness-of-fit of the probit models with McFadden's Pseudo-R^2 [66]. All empirical analyses were carried out using R software [67]. The negative binomial regressions were estimated using package "AER" [68], and average marginal effects were estimated with package "margins" [69]. We checked for the absence of collinearity in all models with R package "performance" [70].

3. Results

3.1. Data exploration and descriptive statistics

Table 1 provides an overview of the survey population's socio-economic characteristics. Among all households, 26 % were food secure during the lean period and mean WDDS-10 was relatively low with an average of 2.6 food groups. Households produced on average 3.3 food groups across the twelve months preceding the survey. Starchy staples were the most commonly produced and self-consumed food group. Further, 92 % of all households received some cash income and 58 % of all households received income from two or more sources. Temporary wage labor was the most widespread source of income.

Fig. 2 provides an overview of the consumption of food groups by the sample population during a 24-h period in the lean period. This is put in perspective with an overview of self-provision of these food groups over the last twelve months, i.e., which food groups have generally been produced and consumed by the farming households. These are the data used to construct the PDS. The consumption of the household throughout the year was collected during the individual interview as the food groups produced on farm that is dedicated for the household own consumption within the last twelve months. Women's diets were generally based on starchy staples (consumed by almost all respondents) and dark green leafy vegetables (76 %). The next most-common food group added was meat, poultry, and fish (31 %). Further, 5 % of women reported having eaten only starchy staples (data not shown). Another 37 % ate only starchy staples and green leafy vegetables. All in all, the diets of 54 % of women were limited to some combination of the three basic food groups (starchy staples/dark green leafy vegetables/meat, poultry, and fish). Interestingly, there was a negative correlation between consumption of green leafy vegetables, and consumption of meat, poultry and fish ($r = -0.34$, $p < 0.001$). This observation likely points to regionally different diets, with more greens in remote highlands, and more animal protein near the coast. Beyond these basic diets, low shares of women reported consumption of legumes, fruit, or vegetables (less than 25 % for each) and only few respondents reported having eaten nuts and seeds, dairy products, or eggs (less than 5 % for each).

3.2. Regression results

3.2.1. Household food security

Results from the regressions fit to FIES data suggest that household food security is positively associated with maternal education, the child's age, the household's pigs and cattle assets, as well as the frequency of market visits. However, the numbers of sold pigs is negatively associated with the food security status of the household. These findings are robust across alternative model specifications (Table 2).

We do not find evidence that production diversity explains household food security status in general. The number of income sources does not seem to influence household food security (Table 2, model 3). However, our results show that having income from non-farm self-employment is positively associated with household food security. In contrast, having income from selling hunted or gathered wild products is negatively associated with household food security (Table 2, model 4).

3.2.2. Women's dietary diversity

We find that women's dietary diversity during the lean season is positively associated only with the frequency of visiting markets (Table 3). Like for food security, we do not find evidence for an influence of on-farm production diversity on women's dietary diversity. In contrast to food security, though, we do not find significant associations with any income source.

4. Discussion

Role of markets. In the Atsimo Atsinanana region of southeastern Madagascar, frequent market participation is associated with greater food security and women's increased dietary diversity. This finding is in line with other studies on the relationship between market participation, food security, and diet diversification [13,18,21]. Markets may not just increase the local availability of diverse food items, but also provide opportunities for farmers to generate income by selling their produce [71,72]. During the lean period, however, farmers have only limited

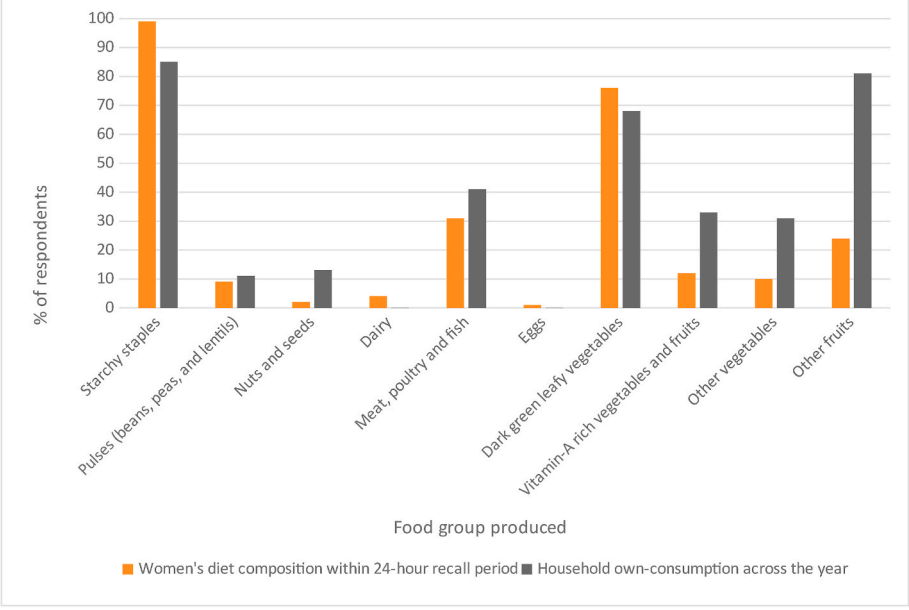

Fig. 2. Prevalence of individual food groups in women's diets within the 24-h recall period, compared to household-level self-provision of individual food groups across the last twelve months. Dairy and eggs were not elicited for the twelve –month recall.

Table 2
Model results from logistic regressions for household food security. Average marginal effects are shown with standard errors (SE). n = 410 households.

Model	(1) With PDS		(2) With food groups		(3) With PDS and income diversity		(4)With PDS and income types	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Household size	−0.012	0.007	−0.012	0.007	−0.012	0.007	−0.011	0.007
Maternal age	−0.004	0.003	−0.004	0.003	−0.004	0.003	−0.003	0.002
Maternal education	0.012*	0.006	0.012*	0.006	0.012*	0.006	0.009*	0.006
Female household head	−0.098	0.073	−0.104	0.073	−0.101	0.073	−0.079	0.075
Mother not married	0.002	0.066	−0.003	0.067	−0.002	0.067	0.014	0.068
Child's age	0.009*	0.004	0.009*	0.004	0.008*	0.004	0.009*	0.003
Household received nutrition advice	0.065	0.049	0.071	0.051	0.066	0.049	0.080	0.050
Mother has immigrated	−0.096	0.097	−0.099	0.097	−0.099	0.095	−0.139	0.081
Domestic asset ownership	0.017	0.021	0.019	0.022	0.017	0.021	0.010	0.022
Frequency of visiting market	0.258***	0.079	0.259***	0.080	0.259***	0.079	0.248***	0.085
Number of poultry	0.003	0.002	0.003	0.002	0.003	0.002	0.003	0.002
Number of pigs	0.074***	0.023	0.074***	0.023	0.075***	0.023	0.068***	0.022
Number of cattle	0.029*	0.013	0.029*	0.013	0.031*	0.013	0.031*	0.013
Number of poultry sold	−0.012	0.002	−0.012	0.002	−0.013	0.002	−0.018	0.002
Number of pigs sold	−0.075*	0.032	−0.078*	0.032	−0.077*	0.032	−0.071*	0.032
Number of cattle sold	0.083	0.054	0.082	0.054	0.083	0.054	0.080	0.053
Number of eggs sold	0.012	0.006	0.012	0.006	0.012	0.006	0.011	0.006
Production Diversity Score	−0.009	0.014			−0.009	0.014	−0.011	0.014
Starchy staples: consumed from own production		0.021	0.063					
Legumes: consumed from own production		−0.026	0.067					
Nuts and seeds: consumed from own production	0.015	0.072						
Meat, poultry and fish: consumed from own production	0.006	0.075						
Dark green leafy vegetables: consumed from own production	0.005	0.064						
Vitamin-A rich vegetables and fruits: consumed from own production	0.010	0.065						
Other vegetables: consumed from own production		−0.009	0.065					
Other fruit consumed from own production		−0.072	0.075					
Number of income sources					0.029	0.029		
Income from sale of wild products							−0.099	0.053 **
Income from sale of food crops							−0.014	0.062
Income from sale of cash crops							0.012	0.062
Income from temporary wage labor							−0.216	0.424
Income from non-farm self-employment						0.085	0.055 *	
Income from charcoal manufacturing							0.088	0.103
Income from permanent salary							0.125	0.094
Income from parental or NGO support							0.062	0.180
Income from public transfers							0.635	0.161
(Intercept)	0.997	1.349	1.043	1.397	0.800	1.370	0.493	1.429
McFadden's pseudo R^2		0.311		0.301		0.294		0.325

*p < 0.10, **p < 0.05, ***p < 0.01.

farm produce to sell. Moreover, our results show that more frequent market visits are linked positively with food and nutrition security, but on-farm income generation is not. Taken together, this suggests that, during the lean period, markets primarily serve as sources of food, rather than sources of income. Relatively food- and nutrition-secure households are characterized by their ability to mobilize cash (e.g., from non-farm self-employment) to purchase food, which in many cases is imported from other regions. Thus, efficient inter-regional food markets are critical for mitigating the strong seasonality of agricultural production and resulting fluctuating local food availability in Madagascar [73]. Food markets contribute to greater availability and affordability of food during the lean period, when little food is locally produced.

Role of on-farm production diversity. Positive associations between on-farm species diversity and food and nutrition security are commonly reported [13]. This association is highly context-specific, with positive links often weak, as well as often limited to the abundance period, when farmers are able to immediately consume their own farm production [40,57]. In our study setting, where production diversity across the year was relatively low, we find no evidence for a role of on-farm diversity for food security or dietary diversity during the lean period. Given low levels of farm productivity and the general absence of proper storage and processing facilities for farm produce in Atsimo Atsinanana, diets in the lean period are, to a large extent, composed of purchased food [7, 52].

Role of livestock. Our results show that larger livestock herds, especially pigs, are associated with greater food security in Atsimo Atsinanana. Similar findings are found in other low- and middle-income countries [74]. This is not surprising, as livestock assets may reflect wealth and social status levels of rural households [75]. In our study region, rural households typically maintain cattle as a social sign of wealth. Cattle are typically sold only on occasion of social events, such as circumcisions or funerals, thus contributing little to household food security. Pigs, however, are important commercial assets that can help households buffer shocks. Pigs are generally sold in case of emergencies (e.g., to rebuild the house after a natural disaster) or urgent cash needs (e.g., when staple stocks are depleted). Therefore, larger pig herds provide resilience against fluctuating food availability, as selling pigs allows farmers to purchase food from local markets, contributing to food security during the lean period. Interestingly, livestock assets do not seem to influence women's diets. As the local, extensive livestock systems generate only little income, selling pigs may help to reduce the gap in staple supply, but does not allow farmers to address dietary diversification. Further, given generally low levels of food security in the study region, many households give low priority to dietary diversity, instead prioritizing the purchase of starchy staples [76].

Surprisingly, households that have *sold* pigs are more likely to be food insecure, which seems to conflict with the evidence on livestock *assets*. The wider context of farmers' decisions to sell livestock or

Table 3
Model results from Negative Binomial regression for Women's dietary diversity. Average marginal effects are shown with standard errors (SE). n = 400 households.

Models	(1) With PDS		(2) With food groups		(3) With PDS and income diversity		(4) With PDS and income types	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Household size	−0.017	0.031	−0.016	0.032	−0.018	0.031	−0.015	0.032
Maternal age	−0.003	0.013	−0.0013	0.013	−0.002	0.013	0.0000	0.013
Maternal education	0.034	0.026	0.031	0.026	0.036	0.026	0.028	0.027
Female household head	0.209	0.363	0.155	0.361	0.207	0.363	0.163	0.365
Mother not married	0.352	0.306	0.319	0.310	0.352	0.306	0.299	0.314
Child's age	0.029	0.018	0.028	0.018	0.029	0.018	0.032	0.018
Household received nutrition advice	0.242	0.210	0.237	0.214	0.245	0.210	0.264	0.212
Mother has immigrated	0.141	0.676	0.166	0.688	0.128	0.674	0.028	0.672
Domestic asset ownership	0.118	0.097	0.129	0.098	0.118	0.097	0.104	0.098
Frequency of visiting market	0.729*	0.391	0.688*	0.401	0.723*	0.392	0.720*	0.398
Number of poultry owned	0.014	0.009	0.014	0.009	0.014	0.009	0.013	0.009
Number of pigs owned	0.032	0.081	0.026	0.082	0.033	0.081	0.029	0.082
Number of cattle owned	0.015	0.055	0.018	0.055	0.019	0.056	0.016	0.058
Number of poultry sold	−0.007	0.012	−0.006	0.012	−0.008	0.012	−0.007	0.012
Number of pigs sold	0.011	0.103	0.002	0.104	0.008	0.103	0.014	0.104
Number of cattle sold	0.159	0.220	0.157	0.221	0.159	0.220	0.175	0.222
Number of eggs sold	−0.014	0.015	−0.013	0.015	−0.013	0.015	−0.013	0.015
Production Diversity Score (PDS)	−0.023	0.063			−0.026	0.066	−0.031	0.065
Starchy staples: consumed from own production			−0.120	0.327				
Pulses: consumed from own production			−0.159	0.317				
Nuts and seeds: consumed from own production			−0.009	0.303				
Meat, poultry and fish: consumed from own production			0.203	0.302				
Dark green leafy vegetables: consumed from own production			−0.130	0.297				
Vitamin-A rich vegetables and fruits: consumed from own production		0.254	0.303					
Other vegetables: consumed from own production			0.076	0.306				
Other fruit consumed from own production			−0.183	0.354				
Number of income sources					0.049	0.128		
Income from sale of wild products							−0.033	0.255
Income from sale of food crops							0.026	0.314
Income from sale of cash crops							0.221	0.294
Income from temporary wage labor							−0.098	0.243
Income from non-farm self-employment							0.092	0.269
Income from charcoal manufacturing							0.354	0.554
Income from permanent salary							0.304	0.434
Income from parental or NGO support							0.631	1.068
Income from public transfers							−1.376	1.381
(Intercept)	0.483	0.264	0.544	0.275	0.468	0.267	0.498	0.269
McFadden's pseudo R^2	0.034		0.035		0.033		0.036	

*p < 0.10.

livestock products may help explain this apparent contradiction. Pigs are not sold on a general basis, but only in case of emergency. Thus, our interpretation is that livestock assets contribute to mitigating shocks that may affect food security, such as natural disasters or urgent health-related expenditures. Consequently, households that report sales of livestock products face lower food security because they have recently experienced such shocks, which were only partly mitigated by their livestock sales [75].

Role of income sources. Households with income from non-farm self-employment, for example carpentry or handcrafting, experience a better food security situation overall. The key role of off-farm income for promoting the food security of smallholder households is well known [26,44,77,78]. Generating revenue from non-agricultural activities allows for a steadier income, even during the lean period, when farming activities are mostly idle [24]. Off-farm income was, however, not associated with better dietary diversity. This suggests that, in our study setting, where food security levels are generally low, off-farm income is mainly used to purchase staple food (i.e., rice) and safeguard the family's calorie intake. Thus, promoting non-farm income generation could be a viable strategy to promote household food security. The poorest households, however, often possess limited skills and resources to generate income with, so food and cash transfers are likely to remain important strategies [28].

In contrast to non-farm self-employment, we find that households generating income from selling hunted or gathered products are relatively *less* food secure, even compared with households with no source of cash income. This is likely due to the fact that the sale of hunted or gathered products is a fallback option practiced predominantly by the most precarious, resource-restricted households [52].

Role of selected household characteristics. In Atsimo Atsinanana, maternal education is an important determinant of household food security. This finding reflects research linking household food security with educational attainment [40,54,79]. Surprisingly, nutrition counseling is not significantly associated with food security and dietary diversity, thus contrasting with findings from the literature [80,81]. One possible explanation is that widespread seasonal poverty, during the lean period, does not allow the study population to implement knowledge acquired through nutrition advice. In the study region, dietary diversity generally requires market purchases during the lean period and, thus, is likely limited by low purchasing power despite potentially increased nutrition awareness.

Our results also highlight a positive link between the child's age (range 6–23 months) and household food security. This finding possibly points to a trade-off in time allocation between reproductive work, including childcare, and productive work, including farming and income generation [82,83]. As children grow older and become less dependent on their biological mothers, these women farmers can dedicate more time to productive labor, contributing to better food security

and nutrition outcomes.

Methodological considerations. For household food security, our models have acceptable explanatory power (pseudo R^2 between 0.293 and 0.325). This implies that the identified explanatory variables are relevant determinants of household food security status in southeastern Madagascar. For WDDS-10, in contrast, pseudo R^2 values are relatively low (between 0.033 and 0.035). The relatively low explanatory power of the WDDS models may be due to unobserved variables that may explain dietary diversity, but were not elicited due to their sensitivity or difficulty of data collection. Examples include the level of household income, farm size, or access to agricultural inputs [6,26,54]. Potential bias affecting model fit may also be associated with the use of 12 months recall periods for some variables, such as reception of nutrition advice or the number of poultry sold. Survey question recall length is associated with measurement error in agricultural surveys [84]. In future research, focusing on shorter recall periods may increase the explanatory power of analyses.

5. Conclusions

This study identifies determinants of rural household food security and women's dietary diversity in southeastern Madagascar during the lean period. One main insight relates to the importance of market access: during this time of limited agricultural production, food and nutrition security is driven by access to market supply, with off-farm income playing a role in enabling food purchases. In contrast, on-farm production diversity does not play a significant role. For local policy makers and development stakeholders, these findings suggest that rural development strategies should emphasize improved affordability of purchased food. One important lever consists in increasing opportunities for off-farm income generation, for example, through building practical skills (e.g., carpentry, handcrafts) or providing direct public transfers through cash-for-work programs [85]. Currently, livestock assets are primarily sold in emergencies, but investments into extension and local veterinary services may allow farmers to increase outputs, thus generating income more regularly; for example, through the sale of chickens or pigs [86]. Frequent market participation is found to be associated with food and nutrition security during the lean season. Therefore, in addition to increased incomes or cash reserves, relevant policy interventions may relate to improving market access by reducing transaction costs associated with buying food. This can be achieved by establishing local village markets or through infrastructural development related to major district markets [21].

Future research by academics and practitioners in southeastern Madagascar should explore the selection and adaptation of the suggested interventions to each local context, as different sub-districts differ in market access, potential for livestock rearing, and opportunities for off-farm income generation, *inter alia*. Moreover, interventions should be accompanied by case-specific analyses of trade-offs between benefits and risks associated with recommended interventions. For example, our findings suggest that increased off-farm income and livestock production may translate into improved food security. These strategies might, however, also increase household vulnerability to food price shocks or cattle theft, which is common in rural Madagascar [75,87]. Lastly, any interventions should emphasize sustained, long-term improvements that survive the end of development projects or fluctuating public spendings. Community-based, participatory approaches in development planning and practice are crucial for achieving sustainable change [76,88].

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Sarah Tojo Mandaharisoa reports administrative support and equipment, drugs, or supplies were provided by Deutsche Gesellschaft für INTERNATIONALE ZUSAMMENARBEIT. Sarah Tojo Mandaharisoa reports financial support and article publishing charges were provided by Humboldt-Universität zu Berlin.

Data availability

The authors do not have permission to share data.

Acknowledgments

We are immensely grateful to the local community and the interview respondents for their time and exchange during the data collection. We truly appreciate the logistic support of GIZ during the fieldwork.

We also thank Adam Lederer for the editorial support, as well as two anonymous reviewers whose comments have helped us improve the manuscript.

This research was supported by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) via a grant to Humboldt-Universität zu Berlin. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] I.F.A.D. FAO, W.F.P. UNICEF, WHO, The State of Food Security and Nutrition in the World 2022. Repurposing Food and Agricultural Policies to Make Healthy Diets More Affordable, Food and Agriculture Organization of the United Nations, Rome, 2022, https://doi.org/10.4060/cc0639en.

[2] E. Mathys, Z. Maalouf-Manasseh, USAID Office of Food for Peace, Food Security Country Framework for Madagascar (FY 2014–FY 2019), 2013. Washington, D.C.: FHI 360/FANTA. Available online at: https://www.fantaproject.org/sites/default/files/resources/FSCF-Madagascar-2013-web.pdf.

[3] Southern African Development Community (SADC), Synthesis Report on the state of food and nutrition security and vulnerability in Southern Africa, Available online at: https://www.sadc.int/sites/default/files/2022-08/SADC_RVAA_Synthesis_Report_2022-ENG.pdf, 2022.

[4] B. Dostie, S. Haggblade, J. Randriamamonjy, Seasonal poverty in Madagascar: magnitude and solutions, Food Pol. 27 (5–6) (2002) 493–518, https://doi.org/10.1016/S0306-9192(02)00063-5.

[5] C.A. Harvey, Z.L. Rakotobe, N.S. Rao, R. Dave, H. Razafimahatratra, R. H. Rabarijohn, H. Rajaofara, J.L. MacKinnon, Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar, Philos. Trans. R. Soc. B 369 (1639) (2014), 20130089, https://doi.org/10.1098/rstb.2013.0089.

[6] J.N. Andriamparany, H. Hänke, E. Schlecht, Food security and food quality among vanilla farmers in Madagascar: the role of contract farming and livestock keeping, Food Secur. 13 (4) (2021) 981–1012, https://doi.org/10.1007/s12571-021-01153-z.

[7] Rousseau, S., Steinke, J., Vincent, M., Andriatseheno, H., & Pontarollo, J. Strong Seasonality in Diets and Alarming Levels of Food Insecurity and Child Malnutrition in South-Eastern Madagascar. *Under Review*.

[8] S. Wieser, B. Brunner, C. Tzogiou, R. Plessow, M.B. Zimmermann, J. Farebrother, S. Soofi, Z. Bhatti, I. Ahmed, Z.A. Bhutta, Societal costs of micronutrient deficiencies in 6- to 59-month-old children in Pakistan, Food Nutr. Bull. 38 (4) (2017) 485–500, https://doi.org/10.1177/0379572117720012.

[9] A.M. DiGirolamo, L. Ochaeta, R.M. Mejía Flores, Early childhood nutrition and cognitive functioning in childhood and adolescence, Food Nutr. Bull. 41 (S1) (2020) 31–40, https://doi.org/10.1177/0379572120907763.

[10] M.T. Ruel, H. Alderman, the Maternal and Child Nutrition Study Group, Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? Lancet 382 (9891) (2013) 536–551, https://doi.org/10.1016/S0140-6736(13)60843-0.

[11] P. Pingali, N. Sunder, Transitioning toward nutrition-sensitive food systems in developing countries, Annu. Rev. Resour Economics 9 (1) (2017) 439–459, https://doi.org/10.1146/annurev-resource-100516-053552.

[12] A.D. Jones, A. Shrinivas, R. Bezner-Kerr, Farm production diversity is associated with greater household dietary diversity in Malawi: findings from nationally representative data, Food Pol. 46 (2014) 1–12, https://doi.org/10.1016/j.foodpol.2014.02.001.

[13] K.T. Sibhatu, M. Qaim, Review: meta-analysis of the association between production diversity, diets, and nutrition in smallholder farm households, Food Pol. 77 (2018) 1–18, https://doi.org/10.1016/j.foodpol.2018.04.013.

[14] M.J. Chegere, J. Stage, Agricultural production diversity, dietary diversity and nutritional status: panel data evidence from Tanzania, World Dev. 129 (2020), 104856, https://doi.org/10.1016/j.worlddev.2019.104856.

[15] D. Muthini, J. Nzuma, R. Nyikal, Farm production diversity and its association with dietary diversity in Kenya, Food Secur. 12 (2020) 1107–1120, https://doi.org/10.1007/s12571-020-01030-1.

[16] L.T. Habtemariam, C. Gornott, H. Hoffmann, S. Sieber, Farm production diversity and household dietary diversity: panel data evidence from rural households in Tanzania, Front. Sustain. Food Syst. 5 (2021), 612341, https://doi.org/10.3389/fsufs.2021.612341.

[17] A.D. Jones, Critical review of the emerging research evidence on agricultural biodiversity, diet diversity, and nutritional status in low-and middle-income countries, Nutr. Rev. 75 (10) (2017) 769–782, https://doi.org/10.1093/nutrit/nux040.
[18] R. Nandi, S. Nedumaran, P. Ravula, The interplay between food market access and farm household dietary diversity in low and middle income countries: a systematic review of literature, Glob.Food Sec. 28 (2021), 100484, https://doi.org/10.1016/j.gfs.2020.100484.
[19] D. Milner, L. Wolf, M. van Wijk, J. Hammond, Market access and dietary diversity: a spatially explicit multi-level analysis in Southern and Western Kenya, Front. Sustain. Food Syst. 6 (2022), 740485, https://doi.org/10.3389/fsufs.2022.740485.
[20] K.T. Sibhatu, V.V. Krishna, M. Qaim, Production diversity and dietary diversity in smallholder farm households, Proc. Natl. Acad. Sci. USA 112 (34) (2015) 10657–10662, https://doi.org/10.1073/pnas.1510982112.
[21] S. Koppmair, M. Kassie, M. Qaim, Farm production, market access and dietary diversity in Malawi, Publ. Health Nutr. 20 (2) (2017) 325–335, https://doi.org/10.1017/S1368980016002135.
[22] O. Ecker, Agricultural transformation and food and nutrition security in Ghana: does farm production diversity (still) matter for household dietary diversity? Food Pol. 79 (2018) 271–282, https://doi.org/10.1016/j.foodpol.2018.08.002.
[23] R. Ritzema, R. Frelat, S. Douxchamps, S. Silvestri, M. Rufino, M. Herrero, K. Giller, S. López-Ridaura, N. Teufel, B. Paul, M. van Wijk, Is production intensification likely to make farm households food-adequate? A simple food availability analysis across smallholder farming systems from East and West Africa, Food Secur. 9 (1) (2017) 115–131, https://doi.org/10.1007/s12571-016-0638-y.
[24] K.T. Sibhatu, M. Qaim, Rural food security, subsistence agriculture, and seasonality, PLoS One 12 (10) (2017), e0186406, https://doi.org/10.1371/journal.pone.0186406.
[25] K. Otsuka, T. Yamano, Introduction to the special issue on the role of nonfarm income in poverty reduction: evidence from Asia and East Africa, J. Agric. Econ. 35 (2006) 393–397, https://doi.org/10.1111/j.1574-0862.2006.00185.x.
[26] R. Frelat, S. Lopez-Ridaura, K.E. Giller, M. Herrero, S. Douxchamps, A. Andersson Djurfeldt, O. Erenstein, B. Henderson, M. Kassie, B.K. Paul, C. Rigolot, R. S. Ritzema, D. Rodriguez, P.J.A. van Asten, M.T. van Wijk, Drivers of household food availability in sub-Saharan Africa based on big data from small farms, Proc. Natl. Acad. Sci. USA 113 (2) (2016) 458–463, https://doi.org/10.1073/pnas.1518384112.
[27] S. Fraval, J. Hammond, J.R. Bogard, M. Ng'endo, J. van Etten, M. Herrero, S. J. Oosting, I.J.M. de Boer, M. Lannerstad, N. Teufel, C. Lamanna, T.S. Rosenstock, T. Pagella, B. Vanlauwe, P.M. Dontsop-Nguezet, D. Baines, P. Carpena, P. Njingulula, C. Okafor, M.T. van Wijk, Food access deficiencies in sub-Saharan Africa : prevalence and implications for agricultural interventions, Front. Sustain. Food Syst. 3 (104) (2019) 1–13, https://doi.org/10.3389/fsufs.2019.00104.
[28] J. Hammond, T. Pagella, M.E. Caulfield, S. Fraval, N. Teufel, J. Wichern, M.T. van Wijk, Poverty dynamics and the determining factors among East African smallholder farmers, Agric. Syst. 206 (2023), 103611, https://doi.org/10.1016/j.agsy.2023.103611.
[29] S. Lopez-Ridaura, L. Barba-Escoto, C. Reyna, J. Hellin, B. Gerard, M. van Wijk, Food security and agriculture in the Western highlands of Guatemala, Food Secur. 11 (2019) 817–833, https://doi.org/10.1007/s12571-019-00940-z.
[30] F. Alpízar, M. Saborío-Rodríguez, M.R. Martínez-Rodríguez, B. Viguera, R. Vignola, T. Capitán, C.A. Harvey, Determinants of food insecurity among smallholder farmer households in Central America: recurrent versus extreme weather-driven events, Reg. Environ. Change 20 (1) (2020) 1–16, https://doi.org/10.1007/s10113-020-01592-y.
[31] T.R. Frankenberger, A. Oshaug, L.C. Smith, A Definition of Nutrition Security, CARE Mimeo, 1997.
[32] Food and Agriculture Organization, Committee on World Food Security. CFS 2012/39 Final Report, FAO, Rome, 2012 available at: http://www.fao.org/3/a-mf115e.pdf.
[33] L. Ravaoarisoa, L. Randriamanantsaina, J. Rakotonirina, J.D.M. Rakotomanga, P. Donnen, M.W. Dramaix, Socioeconomic determinants of malnutrition among mothers in the Amoron'i Mania region of Madagascar: a cross-sectional study, Feb, BMC Nutr 17 (2018) 4–6, https://doi.org/10.1186/s40795-018-0212-4. PMID: 32153870; PMCID: PMC7050867.
[34] D. Thompson, N.-A. Etim, N. Etim, Modelling the factors influencing urban households food and nutrition security status, Journal La Lifesci 1 (4) (2020) 9–19, https://doi.org/10.37899/journallalifesci.v1i4.201.
[35] L. Ravaoarisoa, H. Raherimandimby, J. Rakotonirina, J.D.M. Rakotomanga, M. W. Dramaix, P. Donnen, Mothers' dietary practices in the Amoron'i Mania region Madagascar, May 29, Pan Afr Med J 30 (2018) 76, https://doi.org/10.11604/pamj.2018.30.76.15140. PMID: 30344860; PMCID: PMC6191245.
[36] C.E. Levin, M.T. Ruel, S.S. Morris, D.G. Maxwell, M. Armar-Klemesu, C. Ahiadek, Working women in an urban setting: traders, vendors and food security in accra, World Dev. 27 (11) (1999) 1977–1991, https://doi.org/10.1016/S0305-750X(99)00096-0.
[37] S. Sharaunga, M. Mudhara, A. Bogale, Effects of women empowerment on household food security in rural KwaZulu-Natal province, Dev. Pol. Rev. 34 (2) (2016) 223–252.
[38] M. d'Errico, J. Pinay, E. Jumbe, et al., Drivers and stressors of resilience to food insecurity: evidence from 35 countries, Food Secur. 15 (2023) 1161–1183, https://doi.org/10.1007/s12571-023-01373-5.
[39] I. Bonuedi, L. Kornher, N. Gerber, Agricultural seasonality, market access, and food security in Sierra Leone, Food Secur. 14 (2022) 471–494, https://doi.org/10.1007/s12571-021-01242-z.
[40] L.M. Waswa, I. Jordan, M.B. Krawinkel, G.B. Keding, Seasonal variations in dietary diversity and nutrient intakes of women and their children (6-23 Months) in Western Kenya, Front. Nutr. 8 (2021), 636872, https://doi.org/10.3389/fnut.2021.636872.
[41] C. Hillbruner, R. Egan, Seasonality, household food security, and nutritional status in Dinajpur, Bangladesh, Food Nutr. Bull. 29 (3) (2008) 221–231.
[42] K. Waha, M.T. van Wijk, S. Fritz, et al., Agricultural diversification as an important strategy for achieving food security in Africa, Global Change Biol. 24 (2018) 3390–3400, https://doi.org/10.1111/gcb.14158.
[43] S.R. Khandker, M.A. Baqui Khalily, H.A. Samad, Seasonal hunger and its mitigation in north-west Bangladesh, J. Dev. Stud. 48 (12) (2012) 1750–1764, https://doi.org/10.1080/00220388.2012.720369.
[44] R.O. Babatunde, M. Qaim, Impact of off-farm income on food security and nutrition in Nigeria, Food Pol. 35 (4) (2010) 303–311, https://doi.org/10.1016/j.foodpol.2010.01.006.
[45] Pham Bao Duong, Pham Tien Thanh, Tihomir Ancev, Impacts of off-farm employment on welfare, food security and poverty: evidence from rural Vietnam, Int. J. Soc. Welfare 30 (1) (2021) 84–96.
[46] E.A. Briones, L. Cockx, Swinnen Johan, Culture and food security, Global Food Secur. 17 (2018) 113–127, https://doi.org/10.1016/j.gfs.2018.02.002.
[47] C.D. Golden, B.L. Rice, H.J. Randriamady, A.M. Vonona, J.F. Randrianasolo, A. N. Tafangy, M.Y. Andrianantenaina, N.J. Arisco, G.N. Emile, F. Lainandrasana, R. Mahonjolaza, F. Fenoarison, H.P. Raelson, V.R. Rakotoarilalao, A. A. Rakotomalala, A.D. Rasamison, R. Mahery, M.L. Tantely, R. Girod, A. Annapragada, A. Wesolowski, A. Winter, D.L. Hartl, J. Hazen, C.J.E. Metcalf, Study protocol: a cross-sectional examination of socio-demographic and ecological determinants of nutrition and disease across Madagascar, Front. Public Health 8 (2020). https://www.frontiersin.org/articles/10.3389/fpubh.2020.00500.
[48] FAO & WFP, Special report: crop and food security assessment mission to Madagascar, Available online at: https://www.fao.org/3/CA2925EN/ca2925en.pdf, 2018.
[49] Centre de Recherches, d'Etudes et d'Appui à l'Analyse Economique à Madagascar (CREAM), Monographie Région Atsimo Atsinanana. Centre de Recherches, d'Études, de d'Appui à l'Analyse Économique de Madagascar, Antananarivo, Available online at: https://www.pseau.org/outils/ouvrages/mg_mef_monographie-region-atsimo-atsinanana_2014.pdf, 2013, p. 223.
[50] N. Rakotoarison, N. Raholijao, L.M. Razafindramavo, Z.A. Rakotomavo, A. Rakotoarisoa, J.S. Guillemot, Z.J. Randriamialisoa, V. Mafilaza, V. A. Ramiandrisoa, R. Rajaonarivony, S. Andrianjafinirina, V. Tata, M. C. Vololoniaina, F. Rakotomanana, V.M. Raminosoa, Assessment of risk, vulnerability and adaptation to climate change by the health sector in Madagascar, Int. J. Environ. Res. Publ. Health 15 (12) (2018) 26–43, https://doi.org/10.3390/ijerph15122643.
[51] M.F.R. Tanteliniaina, J. Chen, T.M. Adyel, J. Zhai, Elevation dependence of the impact of global warming on rainfall variations in a tropical island, Water 12 (12) (2020) 3582, https://doi.org/10.3390/w12123582.
[52] M. Moore, M. Alpaugh, K. Razafindrina, A.B. Trubek, M.T. Niles, Finding food in the hunger season: a mixed methods approach to understanding wild plant foods in relation to food security and dietary diversity in southeastern Madagascar, Front. Sustain. Food Syst. 6 (2022), 929308, https://doi.org/10.3389/fsufs.2022.929308.
[53] C. Cafiero, S. Viviani, M. Nord, Food security measurement in a global context: the food insecurity experience scale, Meas 116 (2018) 146–152, https://doi.org/10.1016/j.measurement.2017.10.065.
[54] M.D. Smith, M.P. Rabbitt, A. Coleman-Jensen, Who are the world's food insecure? New evidence from the food and agriculture organization's food insecurity experience scale, World Dev. 93 (2017) 402–412, https://doi.org/10.1016/j.worlddev.2017.01.006.
[55] E.A. Wambogo, H. Ghattas, K.L. Leonard, N.R. Sahyoun, Validity of the food insecurity experience scale for use in sub-saharan africa and characteristics of food-insecure individuals, Curr. Dev. Nutr. 2 (9) (2018) nzy062, https://doi.org/10.1093/cdn/nzy062.
[56] FAO and FHI 360, Minimum Dietary Diversity for Women: A Guide for Measurement. Rome: Food and Agricultural Organisation of the United Nations, 2016. https://www.fao.org/3/i5486e/i5486e.pdf.
[57] A. Lourme-Ruiz, S. Dury, Y. Martin-Prével, Linkages between dietary diversity and indicators of agricultural biodiversity in Burkina Faso, Food Secur. 13 (2) (2021) 329–349, https://doi.org/10.1007/s12571-020-01137-5.
[58] Y. Martin-Prével, P. Allemand, D. Wiesmann, M. Arimond, T. Ballard, M. Deitchler, M.-C. Dop, G. Kennedy, W.T.K. Lee, M. Moursi, Moving Forward on Choosing a Standard Operational Indicator of Women's Dietary Diversity, Food and Agriculture Organisation of the United Nations, Rome, 2015, p. 226. https://hdl.handle.net/10568/72450.
[59] Y. Martin-Prevel, M. Arimond, P. Allemand, D. Wiesmann, T.J. Ballard, M. Deitchler, M. Moursi, Development of a dichotomous indicator for population-level assessment of dietary diversity in women of reproductive age, Curr. Dev. Nutr. 1 (12) (2017), e001701, https://doi.org/10.3945/cdn.117.001701.
[60] S.A. Oni, L.L. Maliwichi, O.S. Obadire, Socio-economic factors affecting smallholder farming and household food security: a case of Thulamela local municipality in Vhembe District of Limpopo Province, South Africa, Afr. J. Agric. Res. 5 (17) (2010) 2289–2296. Available online at: http://www.academicjournals.org/AJAR.
[61] L.M. Waswa, I. Jordan, J. Herrmann, M.B. Krawinkel, G.B. Keding, Community-based educational intervention improved the diversity of complementary diets in western Kenya: results from a randomized controlled trial, Publ. Health Nutr. 18 (18) (2015) 3406–3419.

[62] T. Assefa, E.B. Abide, Determinants of food insecurity in rural households: a case of lemo district, southern Ethiopia, Heliyon 9 (1) (2023), e12764, https://doi.org/10.1016/j.heliyon.2022.e12764.
[63] S. Silvestri, D. Sabine, K. Patti, F. Wiebke, R. Maren, M. Ianetta, R.M. Cristina, Households and food security: lessons from food secure households in East Africa, Agric. Food Secur. 4 (1) (2015) 1–15, https://doi.org/10.1186/s40066-015-0042-4.
[64] A.S. Rafanomezantsoa, C. Coral, N. Randrianarison, C. Kubitza, D. Randriamampionona, H. Andriamaniraka, S. Sieber, S. Tojo-Mandaharisoa, J. Steinke, Identifying nutrition-sensitive development options in Madagascar through a positive deviance approach, Food Secur. (2022) 1–16, https://doi.org/10.1007/s12571-022-01339-z.
[65] S. Holm, A simple sequentially rejective multiple test procedure, Scand. J. Stat. 6 (2) (1979) 65–70. https://www.jstor.org/stable/4615733.
[66] D. McFadden, Conditional logit analysis of qualitative choice behavior, in: P. Zarembka (Ed.), Front. Econ, Academic Press, 1974, pp. 105–142.
[67] R Core Team, R: A Language and Environment for Statistical Computing, 2020. Vienna, Austria, http://www.R-project.org/.
[68] C. Kleiber, A. Zeileis, Applied Econometrics with R, Springer-Verlag, New York, 2008. URL: https://CRAN.R-project.org/package=AER.
[69] T.J. Leeper, Margins: marginal effects for model objects, R package version 0.3.26, https://github.com/leeper/margins, 2021.
[70] D. Lüdecke, M.S. Ben-Shachar, I. Patil, P. Waggoner, D. Makowski, performance: an R package for assessment, comparison and testing of statistical models, J J. Open Source Softw. 6 (60) (2021) 3139. https://github.com/easystats/performance.
[71] M.R. Bellon, G.D. Ntandou-Bouzitou, F. Caracciolo, On-farm diversity and market participation are positively associated with dietary diversity of rural mothers in Southern Benin, West Africa, PLoS One 11 (9) (2016), e0162535, https://doi.org/10.1371/journal.pone.0162535.
[72] L. Kissoly, A. Fasse, U. Grote, Implications of smallholder farm production diversity for household food consumption diversity: insights from diverse agro- ecological and market access contexts in rural Tanzania, Horticulturae 4 (3) (2018) 14, https://doi.org/10.3390/horticulturae4030014.
[73] D.C. Stifel, J.C. Randrianarisoa, Agricultural policy in Madagascar: a seasonal multi-market model, J. Pol. Model. 28 (9) (2006) 1023–1027, https://doi.org/10.1016/j.jpolmod.2006.06.018.
[74] A. Ali, M. Khan, Livestock ownership in ensuring rural household food security in Pakistan, J. anim. plant sci. 23 (1) (2013) 313–318. http://thejaps.org.pk/docs/v-23-1/48.pdf. ISSN: 1018-7081.
[75] H. Hänke, J. Barkmann, Insurance function of livestock, Farmers coping capacity with crop failure in southwestern Madagascar, World Dev. 96 (2017) 264–275, https://doi.org/10.1016/j.worlddev.2017.03.011.
[76] S. Tojo-Mandaharisoa, J. Steinke, N. Randrianarison, C. Kubitza, A. Konzack, A. Rafanomezantsoa, D. Randriamampionona, S. Sieber, H. Andriamaniraka, Assessing farmers' diverse preferences and expectations for tailoring food and nutrition security interventions in southeastern Madagascar, Curr. Dev. Nutr. 6 (10) (2022) nzac142, https://doi.org/10.1093/cdn/nzac142.
[77] V. Owusu, A. Abdulai, S. Abdul-Rahman, Non-farm work and food security among farm households in Northern Ghana, Food Pol. 36 (2) (2011) 108–118, https://doi.org/10.1016/j.foodpol.2010.09.002.
[78] F.M. Dzanku, Food security in rural sub-Saharan Africa: exploring the nexus between gender, geography and off-farm employment, World Dev. 113 (2019) 26–43, https://doi.org/10.1016/j.worlddev.2018.08.017.
[79] M. Mutisya, M.W. Ngware, C.W. Kabiru, N. Kandala, The effect of education on household food security in two informal urban settlements in Kenya: a longitudinal analysis, Food Secur. 8 (4) (2016) 743–756, https://doi.org/10.1007/s12571-016-0589-3.
[80] L.Z. Katenga-Kaunda, P.R. Kamudoni, G. Holmboe-Ottesen, H.E. Fjeld, I. Mdala, Z. Shi, P.O. Iversen, Enhancing nutrition knowledge and dietary diversity among rural pregnant women in Malawi: a randomized controlled trial, BMC Pregnancy Childbirth 21 (1) (2021) 1–11, https://doi.org/10.1186/s12884-021-04117-5.
[81] E. Ezekekwu, S.S. Salunkhe, J.A.C. Jennings, B.N. Kelly Pryor, Community-based and system-level interventions for improving food security and nutritious food consumption: a systematic review, J. Hunger Environ. Nutr. 17 (2) (2022) 149–169, https://doi.org/10.1080/19320248.2021.2021120.
[82] D. Rowland, G. Zanello, E. Waliyo, A. Ickowitz, Oil palm and gendered time use: a mixed-methods case study from West Kalimantan, Indonesia, For. Policy Econ 137 (2022), 102682, https://doi.org/10.1016/j.forpol.2021.102682.
[83] M. Shandal, S. Mohapatra, P.C. Veettiàl, Pareto efficiency in intrahousehold allocations: evidence from rice farming households in India, Oxf. Dev. Stud. 50 (2) (2022) 158–176, https://doi.org/10.1080/13600818.2021.2020741.
[84] P. Wollburg, M. Tiberti, A. Zezza, Recall length and measurement error in agricultural surveys, Food Pol. 100 (2021), 102003, https://doi.org/10.1016/j.foodpol.2020.102003.
[85] B.L. Debela, G.E. Shively, S.T. Holden, Implications of food-for-work programs for consumption and production diversity: evidence from the Tigray Region of Ethiopia, Agric. Food Econ. 9 (2021) 1–24, https://doi.org/10.1186/s40100-021-00189-1.
[86] B. Kurz, J. Steinke, S. Sieber, Intervention options for small-scale family poultry development in south-eastern Madagascar: an expert survey, J. Agric. Rural Dev. Tropics Subtropics 124 (1) (2023) 23–36, https://doi.org/10.17170/kobra-202302217526.
[87] K.B. Amolegbe, J. Upton, E. Bageant, S. Blom, Food price volatility and household food security: evidence from Nigeria, Food Pol. 102 (2021), 102061.
[88] J. Boedecker, F. Odour, C. Lachat, P. Van Damme, G. Kennedy, C. Termote, Participatory farm diversification and nutrition education increase dietary diversity in Western Kenya, Matern. Child Nutr. 15 (2019), e12803, https://doi.org/10.1111/mcn.12803.