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Tropical Cyclones Exacerbate all Dimensions of Food Insecurity among Smallholder Farmers in Coastal Madagascar

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Abstract

Tropical cyclones are increasing in intensity and frequency due to climate change. In Madagascar, where food insecurity—a normative benchmark for food system resilience—is already widespread, rural farming communities are especially vulnerable to this growing threat. While food security is multidimensional, encompassing availability, access, utilization, stability, agency, and sustainability, existing research has largely focused on availability and access. Here, we examine how back-to-back cyclones affected multiple dimensions of food security among smallholder farmers. During the 2022 rice-growing season, Madagascar's southeastern coast was hit by two powerful cyclones, Batsirai and Emnati. Using panel data from 277 households collected before and after the cyclones, we find that food insecurity was significantly higher in the cyclone year (2022) than in the non-cyclone year (2021). In the immediate aftermath, food access strategies shifted: emergency food aid played an initial role, while mutual aid (support from neighbors and family) reduced the likelihood that households experienced worsened food security. Beyond access, the cyclones significantly disrupted other dimensions of food security, including agency and utilization. Access to clean water declined from 87.0% to 60.6% ($p < .001$), and nearly one-quarter of households reported waterborne illness. At the same time, 93.8% of respondents reported having no choice in the foods they consumed. One-third of respondents reported complete destruction of their rice fields, and damage to other food crops further compounded seasonal food insecurity. Contrary to expectations, crop diversification did not appear to be protective, likely because multiple crops were simultaneously affected by the cyclones. Furthermore, households that were already highly food insecure prior to the cyclones were less likely to undertake cyclone preparedness measures, underscoring the compounding effects of repeated shocks on resilience. These findings highlight the severe and multidimensional impacts of climate change-intensified cyclones on food security among vulnerable coastal populations. Strengthening social support systems, alongside efforts to enhance community resilience and farmer adaptive capacity, will be critical in the face of escalating climate shocks.

1. Introduction

Climate change poses multi-dimensional threats to many aspects of food security, including both its original four pillars (availability, access, utilization, and stability (FAO, 2008)), as well as two new proposed pillars of agency (ability to make choices about food) and sustainability (capacity of a food system to preserve and protect ecological functions while supporting equitable social structures for current and future generations, Clapp et al. 2022).

For example, climate change is impacting food availability, as rising temperatures, erratic rainfall patterns, and prolonged droughts lead to crop failures (Lobell et al., 2011; Rezaei et al., 2023) and livestock losses (Bekele, 2017; Cheng et al., 2022). Access to food is increasingly at risk, particularly for vulnerable populations, with climate-related shocks disrupting livelihoods and driving up food prices (Erdogan et al., 2024). Utilization, or the ability to safely and effectively consume food, is undermined by the increased prevalence of foodborne illnesses and water contamination caused by rising temperatures and flooding (Duchenne-Moutien & Neetoo, 2021). Additionally, higher carbon dioxide levels are reducing the nutritional quality of crops (Ebi et al., 2021; Ziska, 2022), including important staples like rice and wheat. Finally, although there is limited research, agency—or the ability of individuals and communities to make decisions

about the foods they eat—may be compromised when climate shocks limit food choice and increase dependence on emergency food aid that may not fit local needs (e.g., Wentworth, 2020).

Beyond these long-term climate-driven impacts, extreme weather events and sudden climate-related shocks, such as hurricanes and cyclones, pose additional threats to food security. While still an understudied topic, empirical studies have linked climate-related shocks to heightened food insecurity (Hadley et al., 2023; Niles & Salerno, 2018). Broadly, research has found that extreme weather events generate multiple challenges that affect food security (e.g., Clay et al., 2018; Chriest & Niles, 2018; Nozhati et al., 2019). Nonetheless, much of that research has been done in the Global North and has focused on non-farming populations (Clay, 2020; Rodríguez-Cruz, et al., 2022). For instance, a pilot study on post-disaster food insecurity in Puerto Rico found that more than half of respondents experienced food insecurity following Hurricane Maria, primarily due to disruptions in the food supply chain (Mark et al., 2025). Given that farmers are key agents in safeguarding food security, and that in the Global South many farmers are subsistence farmers, it is critical to expand our understanding on their food security in the context of climate-related shocks.

In this study, we examine how cyclones exacerbate multiple dimensions of food insecurity among vulnerable farmers in a heightened food insecure context, focusing specifically on the immediate impacts of these extreme weather events. Madagascar, a climate change "hotspot" (Harvey et al., 2014), exemplifies these challenges. As one of the world's most cyclone-prone countries (Rakotobe et al., 2016), situated at the western edge of the South-West Indian Ocean tropical cyclone zone or basin, the island nation routinely experiences multiple cyclones on an annual basis. Due to warming of the Indian Ocean, their intensity and frequency are increasing (Llopis, 2018; Weiskopf et al., 2021). Known as hurricanes in the Atlantic and typhoons in the Pacific, cyclones disproportionately impact low-lying coastal areas, compounding existing vulnerabilities.

Recent cyclone seasons in Madagascar, which typically span from December to April, have been both particularly severe and with above-average frequency (Fayad, 2023). During the 2021/2022 cyclonic season, Madagascar experienced five of these extreme weather events within a span of 45 days, following a rainfall deficit brought on by a prolonged period of drought since 2019. These storms brought heavy rains, strong winds, floods, and landslides, causing widespread destruction to road and housing infrastructure as well as agricultural land, and leaving nearly 900,000 people in the southeast acutely food insecure (Reliefweb, 2023).

In February 2022, the southeastern coast was struck by back-to-back Intense Tropical Cyclones Batsirai and Emnati (Fig. 1), flooding 60,000 hectares of rice fields *twice* and impacting over 420,000 people during the main rice-growing season (Reliefweb, 2023). These compound shocks highlight the acute food security challenges in a nation where most of the population relies on semi-subsistence farming. The destruction caused by such tropical cyclones disrupts primary agricultural production, leaving communities struggling to meet basic nutritional needs as both staple and cash crops are lost. Unlike food chain supply-related disruptions, which can also affect post-disaster food security, these challenges mainly stem from localized devastation of agricultural systems.

Furthermore, while humanitarian assistance organizations play a vital role in delivering emergency food aid throughout Madagascar (Zambiazzi et al., 2023), food aid programs can present multiple challenges - from

compromising self-sufficiency (e.g., Jackson, 2020) to posing nutritional or health concerns. The foods provided (often non-perishable foods such as rice, pulses and vegetable oil) may not always align with nutritional recommendations, local cultural preferences or dietary practices. For example, Wentworth (2020) and Colón-Ramos et al. (2019) found that food aid distributed in Vanuatu after Cyclone Pam and in Puerto Rico after Hurricane Maria, respectively, did not align with nutrition education efforts or established federal nutrition guidelines, while Gallanis et al. (1995) found that post-cyclone food aid accelerated an existing modernizing trend in the Samoan diet. In Madagascar, past field observations revealed that split peas, a common relief food, are culturally unfamiliar and local recipients have expressed their dissatisfaction (unpublished data).

In some cases, foods provided as aid raised health concerns among Manombo community members that we spoke with in 2017 (unpublished data). For instance, women reported experiencing mobility impairments and symptoms resembling konzo—a neglected neurological disease associated with improperly prepared cassava and malnutrition—after consuming large amounts of cassava flour distributed as food aid. While these symptoms were not clinically diagnosed, they align with documented cases of konzo which particularly affects young children, pregnant women, and lactating mothers (Banea et al., 2013; Nzwalo & Cliff, 2011; Kashala-Abotnes et al., 2019). These examples highlight the complexity of responding to food and nutrition security challenges during post-disaster settings, especially in a way that maintains food agency for the local population.

Literature on food insecurity in the context of shocks/ post-disaster settings

While it has been shown that social support networks, material assets, and levels of exposure to extreme weather events are linked to food insecurity in post-disaster settings, including the length in which it is affected (Clay et al., 2018; Nohzhati et al., 2019; Ross & Clay, 2020), household food security in post-disaster settings remains an underexplored area of research. There is also no commonly agreed upon definition for post-disaster food insecurity (Mark et al., 2025), though Clay et al. (2023) recently developed the Disaster Food Security Framework, measuring the four domains of availability, accessibility, acceptability, and agency; however, this framework was developed and validated using data from the United States.

In a systematic review of food security following climatic events, Hadley et al. (2023) identified only 18 studies that met their inclusion criteria. Among these studies, over one-quarter investigated food insecurity following hurricanes or cyclones, another quarter focused on droughts, and more than one-third examined the aftermath of floods. Notably, most studies prioritized availability (n = 17), access (n = 12), or utilization (n = 11), while agency and sustainability were largely overlooked. Another review by Firdaus et al. (2019) also found that studies mainly focused on food availability and not on the other dimensions of food security. Our study fills this gap by taking a multidimensional approach to examining food security impacts.

Furthermore, while studies have looked at food security following cyclones (e.g., Guill et al., 2001; Hossain et al., 2021; Mark et al., 2025) and other climate-related shocks, from floods in Nigeria (Ajaero, 2017) and Bangladesh (Parvez et al., 2021) to landslides in Uganda (Rukundo et al., 2016), relatively few have assessed the impacts of successive or compounding shocks on food security (e.g., Abasolo & Montefrio, 2025). Our study is among the first to assess food insecurity within the same population before and after successive

cyclones, without relying on retrospective recall. Several studies have examined cyclone impacts and coping strategies among rural populations in Madagascar (Mohan et al., 2020; Rakotobe et al., 2016; Raveloson et al., 2024), but besides the recent work of Keller and Mulungu (2025), ours is among the first to specifically analyze food insecurity outcomes using pre- and post-cyclone data following back-to-back storms.

Our research was guided by several hypotheses. We hypothesized that household food insecurity would be significantly higher post-cyclone compared to a non-cyclone year (H1), and that households taking cyclone preparedness measures would be less likely to experience heightened food insecurity post-cyclone (H2). We also hypothesized that both food agency (H3) and utilization (H4) dimensions of food security would be adversely affected by the cyclones.

2. Methods

Study Area

The Manombo area, situated in Faragangana District along Madagascar's southeast coast, is mainly comprised of communities of small-scale farmers and fisherfolk, with some households further diversifying their livelihoods through charcoal-making and other income generating activities. Rice, the main staple food in Madagascar, is the primary crop grown by all study participants.

Though both chronic and seasonal food insecurity is prevalent throughout Madagascar, this region is among the island's most food-insecure (Randrianarison et al., 2020), largely due to its exposure to frequent cyclones and limited resilience to these shocks (Tojo-Mandaharisoa et al., 2022). It experiences two annual hunger seasons, locally known as *sakave*. The primary hunger season typically occurs from February to April, while the secondary hunger season spans from September to November (Moore et al., 2022). The region also supports two rice-growing seasons: the primary season, *vary vatomandry*, is harvested in May-June, and the secondary season, *varihosy*, is harvested in December (Rousseau et al., 2023). Madagascar's cyclone season is from December to April, with the rainy season from November to April historically (ACAPS, 2024).

Sampling and Data Collection

This study employed a repeated measures design. In February 2021, 328 farmers from 15 coastal villages and sub-villages were surveyed at the onset of the region's main lean season. The survey was repeated the following year, in April 2022, with 277 of the same respondents (51 participants were lost to follow-up). The second survey followed the passage of two intense tropical cyclones: Batsirai (Category 4), which made landfall on February 5, 2022, and Emnati (Category 2), which made landfall on February 23, 2022.

Throughout this manuscript, the term "cyclone(s)" is used to refer to one or both of these cyclone events, reflecting both the consecutive nature of the events as well as the inherent ambiguity in the Malagasy language, which does not clearly distinguish singular from plural forms. Exemption for this study was granted by the University of Vermont's Institutional Review Board (IRB; study #00001290).

Measures

In both 2021 and 2022 surveys, household food security was measured using a five-item yes-no scale assessing experiences of food insecurity within the past 30 days (Supplemental Table 1). Affirmative responses were used to generate a food security score ranging from 0–5. As is standard in many food security assessments (e.g. USDA six-item food security module; Bickel et al., 2000), households were then categorized into three food (in)security categories based on the number of affirmative responses: food secure (answering 'yes' to zero or one of the five questions), moderately food insecure (answering 'yes' to two or three questions), and very food insecure (answering 'yes' to four or five questions).

Our 2022 survey also included items on both general and crop-specific damage from the two cyclones, changes in food sources before and after the cyclone(s), food agency and utilization (e.g., access to clean water and incidence of waterborne disease) after the cyclone(s), as well as cyclone preparedness.

Specifically, to examine changes in food access/availability, respondents were asked whether they experienced difficulty obtaining food in the 30 days prior to, as well as one week (seven days) and one month (30 days) following the cyclone(s). To assess their primary means of accessing food, respondents were also asked to indicate how they obtained food in the 30 days preceding the cyclone(s), with options such as self-provisioning, market purchases, or food aid. This approach allowed us to compare the prevalence of food access challenges and to identify the dominant food sourcing strategy before and after the cyclone(s).

In addition, to examine the agency dimension of food security, whether the food that they ate post-cyclone(s) was part of their normal diet, if they liked it, and whether they felt that they had a choice in their food selection. To assess the utilization dimension of food security, respondents provided information on their access to clean water prior to and following the cyclone(s). Lastly, respondents shared details about the preparations they typically undertake before a cyclone makes landfall.

Analysis

Statistical analyses were conducted using SPSS 31.0 (IBM) and R. To test H1, we used a paired samples t-test to compare food insecurity scores for the same households between 2021 (non-cyclone year) and 2022 (post-cyclone). To assess changes in food security status across categorical groups (food secure, moderately food insecure, very food insecure), we used the Stuart-Maxwell test for marginal homogeneity, which is appropriate for paired categorical data with more than two levels. McNemar's test (for paired binary data) was used to examine changes in food security categories in 2021 and 2022, as well as changes in difficulty obtaining food and changes in sources of food, before and after the cyclone(s).

To examine factors predicting changes in household food security between 2021 and 2022, we created a multinomial dependent variable indicating whether a household's food security improved, remained unchanged, or worsened (coded 0, 1, and 2, respectively). We then estimated a multinomial logistic regression model using the "no change" category as the reference, allowing us to compare the relative likelihood of improvement or decline. Predictor variables (Table 1) were chosen based on prior research and field experience, and continuous variables were standardized (z-scored).

Table 1
Descriptive results of explanatory variables included in the model

Variable	N	Units	Mean	SD	Min	Max
Village distance to road	328	Kilometers	2.31	1.34	0	4.31
Household (HH) size	327	Persons	6.17	2.64	1	20
Highest education level	324	Years of schooling	3.73	3.07	0	15
HH assets	322	Count of items (0–30)	4.83	2.86	1	23
Crop production diversity	328	Number of crops grown (including cash crops)	9.59	3.49	1	15
Received mutual aid (30 days post-cyclone)	277	Binary (Yes/No)	0.23	0.42	0	1

We also used crosstab analysis and a Pearson's chi-square test to assess whether households that were more food secure in 2022 were more likely to have taken disaster preparedness measures (H2).

To examine significant changes in the utilization dimension of food security (H4), we conducted a McNemar's test to determine whether there was a significant difference in access to clean water for drinking and cooking before versus after the cyclone(s), based on recall data collected in 2022.

Lastly, we used NVivo 15 to code open-ended responses to the question: *What do you feel would help you to reduce negative impacts from future cyclones?*

3. Results

3.1 Cyclone Damage

Crop damage was the most frequently reported impact of the cyclone(s), cited by 99.3% (*n* = 275) of respondents, followed by damage to houses (86.3%, *n* = 239) and community infrastructure (64.3%, *n* = 178), such as schools and churches, mostly caused by wind (60.4%, *n* = 165), or a combination of wind and rain (36.6%, *n* = 100).

Farmers, on average, grew 8.13 (s.d. 2.64) different food crops. Overall, 94.8% (*n* = 253) reported significant crop damage from the cyclone(s), and 3.4% (n = 9) said that their crops were completely destroyed. Respondents reported that cassava, banana and breadfruit were the crops most affected, whereas low-lying crops, such as *bodoa* (an endemic yam variety) and pineapple, were the crops reported to be the most resistant to cyclone damage.

Because they struck during the early stages of the main rice-growing season (*vatomandry*), the cyclones also had a devastating impact on rice, the most important food crop. Most respondents (91%, *n* = 144) reported

already having transplanted their rice seedlings. Among them, more than a third (36%, *n* = 52) reported complete destruction of their rice fields, and nearly two-thirds (61%, *n* = 88) were unable to replant. Of those who did replant, most used their own seed (41%, *n* = 23) or purchased seed (38%, *n* = 21). Very few (5%, *n* = 7) received seeds from friends, family, or neighbors, and no respondents reported receiving seed assistance from NGOs or the government.

Selected quotes from 2022 Focus Group Discussion participants regarding their lived experiences during and after cyclones:

"Sakave (hunger season) started since Batsirai…Jackfruit, breadfruit were totally destroyed, no more cassava to collect, so we ate the tuber of the via plant."

"Houses were destroyed by Emnati. We slept on the ground outside of the house, we did not eat breakfast and lunch."

"The cyclones brought the sakave; our cassava and breadfruit were destroyed. The rice paddies were flooded. We had already transplanted rice and it was fruiting when the cyclone arrived. So our vatomandry rice did not produce well."

3.2 Cyclone Preparedness

In the 2022 survey, over half of respondents (56.0%; *n* = 155) reported taking no preventative actions to minimize cyclone damage. The most common preparedness activity was reinforcing homes—such as securing the roof, windows, doors, or walls—reported by 36.1% (*n* = 100).

Furthermore, very few respondents reported taking food security-related precautions prior to the arrival of Batsirai and Emnati, such as ensuring sufficient household food reserves (6.5%; *n* = 18), storing food in a flood-safe location (4.7%; *n* = 13), storing clean water for use after the cyclone(s) (3.6%; n = 10), storing rice seeds in a dry location (1.8%; *n* = 5), or relocating livestock to a safe place (0.4%; *n* = 1).

Data from the 2021 survey show a similar pattern regarding preparedness. Despite the near annual threat of cyclones, over two-thirds of 2021 respondents (66.2%; *n* = 217) reported typically taking no action to protect their crops in the fields. Only 2.1% (*n* = 7) reported typically clearing trees around their homes and fields pre-cyclone, while 1.5% (*n* = 5) maintained or cleared canals in rice paddies. Lastly, only one respondent (0.3%) reported harvesting crops in advance of storms.

3.3 Food security levels and cyclone preparedness

A Pearson's chi-square test was conducted to examine the association between cyclone preparedness and household food security status following the cyclone(s). The relationship was statistically significant, $\chi^2(2, N = 271) = 24.33$, $p < .001$. A significantly higher proportion of unprepared households were very food insecure (74.3%, *n* = 113) post-cyclone, compared to 47.9% (*n* = 57) of prepared households. In contrast, among households that engaged in preparedness activities (*n* = 119), 43.7% (*n* = 52) were moderately food insecure and 8.4% (*n* = 10) were food secure—both higher than among those who took no action (see Table 4).

Table 2
Household Pre-Cyclone Preparedness by Post-Cyclone Food (In)security Status

Food (in)security category post-cyclone	Prepared pre-cyclone	Did not prepare pre-cyclone	Total
Food secure	10 (8.4%)	1 (0.7%)	11
Moderately food insecure	52 (43.7%)	38 (25.0%)	90
Very food insecure	57 (47.9%)	**113 (74.3%)**	170
Total	119	152	271

Note

Bolded values indicate the food (in)security category most strongly associated with lack of cyclone preparedness, based on significant differences observed in the chi-square analysis.

3.4 Changes in food security levels between 2021 and 2022

Using a paired samples t-test, household food insecurity scores increased significantly from 2021 (M = 3.19, SD = 1.54) to 2022 (M = 3.63, SD = 1.20), $t(273) = -4.36$, $p < .001$, indicating a worsening of food security during a cyclone year. The Stuart-Maxwell test confirmed a significant overall shift in food security categories between February 2021 and April 2022, $\chi^2(2) = 24.94$, $p < .001$. Of the households in the sample, 42 (15%) experienced improved food security, 140 (50%) experienced no change, and 92 (33%) experienced worsened food security.

As shown in Table 3, the proportion of food secure and moderately food insecure households decreased, while the proportion of very food insecure households increased. McNemar's tests of paired proportions indicated that the decline in food secure households was significant ($\chi^2(1, N = 50) = 14.58$, $p < .001$), as was the increase in very food insecure households ($\chi^2(1, N = 111) = 17.45$, $p < .001$). Change in the moderately food insecure group was not statistically significant ($\chi^2(1, N = 107) = 2.39$, $p = .122$). Figure 2 depicts individual household shifts in food security categories visually.

Table 3
Percentage of households across food (in)security categories in 2021 and 2022

Food secure	**February 2021 (n = 325)**	**April 2022 (n = 274)**
	15.1% (n = 49)	**5.5% (n = 15)**
Moderately food insecure	37.2% (n = 121)	33.3% (n = 91)
Very food insecure	47.7% (n = 155)	62.6% (n = 168)

Furthermore, from a behavioral standpoint, more than a third of respondents (38.3%, *n* = 106) reported cooking less rice, their main staple, than they had at the same time the previous year, further illustrating the decline in food security post-cyclone(s) and supporting both H1 and H3.

In the 30 days prior to the cyclone(s), only 36.1% (*n* = 100) of respondents stated having difficulty obtaining food. However, this proportion rose to 83.4% (*n* = 231) in the 30 days following the cyclone(s). McNemar's test indicated that this increase was statistically significant, $\chi^2(1, N = 277) = 121.58$, $p < .001$, suggesting that the cyclone(s) had a substantial impact on food access and availability in the month following.

Given the cultural importance of rice as a staple food, respondents were also asked whether they felt they had sufficient rice to feed their families in the aftermath of the cyclone(s). In the first week following the cyclone(s), 80.9% (*n* = 224) said they did not, rising to 89.2% (*n* = 247) in the month afterward. Of note, this increase likely reflects not only cyclone-related disruptions but also the progression of the lean hunger season, which typically intensifies food scarcity over time.

3.5 Food sourcing

In the 30 days prior to the cyclone(s), respondents reported primarily accessing food through self-provisioning (46.9%, *n* = 130) and market purchases (71.8%, *n* = 199). Only 15.5% (*n* = 43) depended on emergency food aid during this period. However, in the immediate aftermath (seven and 30 days post-cyclone(s)), food access strategies shifted (Fig. 3).

In the seven days following the cyclone(s), the percentage of respondents harvesting their own crops or livestock dropped to 35.0% (*n* = 97), a statistically significant decrease according to McNemar's test, $\chi^2(1, N = 275) = 16.02$, $p < .001$. There was also a significant decline in respondents obtaining food from the market, $\chi^2(1, N = 275) = 22.12$, $p < .001$, likely due to disruptions in availability, reduced quality, and rising prices as transportation became more difficult. In contrast, over half of respondents (56.3%, *n* = 156) reported receiving emergency food aid, a statistically significant increase, $\chi^2(1, N = 275) = 69.22$, $p < .001$. While not statistically significant at the conventional 0.05 level, a notable proportion (25.3%, *n* = 70) also reported relying on mutual aid from friends and family, $\chi^2(1, N = 275) = 3.69$, $p = .055$.

In the 30 days following the cyclone(s), the percentage of respondents receiving food aid significantly dropped to 25.6% (n = 71), $\chi^2(1, N = 277) = 55.56$, $p < .001$. There were no statistically significant changes in the proportion of respondents harvesting their own crops or livestock, $\chi^2(1, N = 277) = 1.26$, $p = .263$, or receiving food from friends and family, $\chi^2(1, N = 277) = 1.09$, $p = .296$. However, the percentage of respondents obtaining food from the market showed a statistically significant rebound to nearly pre-cyclone levels, $\chi^2(1, N = 277) = 24.45$, $p < .001$.

Interestingly, both seven and 30 days after the cyclone(s), there was very minimal change in the proportion of respondents who reported collecting food from the forest compared to before the event. Although wild plant food procurement is often used as a coping strategy during the hunger season (Moore et al., 2022), respondents in this study did not report an increase in wild food collection following the cyclone(s).

3.6 Utilization - food safety: clean water for cooking/drinking

Before the cyclones, most respondents reported obtaining water for drinking and cooking from *ranoboky* springs (31.8%, *n* = 88) and rivers (30%, *n* = 83). Fewer reported using wells (15.5%, *n* = 43) or water pumps (8.3%, *n* = 23) as their primary sources.

The cyclones disrupted access to clean water, affecting both food preparation and overall health. Prior to the cyclones, the majority of respondents (87.0%, *n* = 241) reported having access to clean water for drinking and cooking. This proportion dropped to 60.6% (*n* = 168) in the aftermath. McNemar's test indicated that this decline was statistically significant, $\chi^2(1, N = 272) = 72.01$, $p < .001$, supporting H4 that the cyclone(s) had a substantial impact on the utilization dimension of food security. Furthermore, approximately one-quarter of respondents (24.5%, n = 68) reported experiencing waterborne illnesses after the cyclone(s), underscoring the need for improved water infrastructure and sanitation measures to safeguard both food safety and public health.

3.7 Agency

Following the cyclone(s), nearly a quarter of respondents (24.5%; *n* = 68) reported eating food that they do not normally eat, while 60.3% (*n* = 167) consumed food that they did not like to eat. Qualitative responses also indicated reliance on wild *via* tuber, a famine food commonly eaten during the main hunger season (Moore et al., 2022).

In addition, the vast majority of respondents (93.8%; *n* = 259) felt that they had no choice in the food that they ate following the cyclone(s). However, among those receiving food aid (*n* = 177), nearly all (97.7%; *n* = 173) reported that it was food that they normally eat, and 94.9% (*n* = 168) said that it was food they liked. These findings indicate that reductions in food agency post-cyclone(s) may not be due to reliance on food aid that fails to align with locally preferred and culturally appropriate diets. Rather, they likely reflect broader disruptions in food availability and access, limiting households' ability to obtain and choose the foods they typically consume.

3.8 Factors influencing change in food security status

To examine factors associated with changes in household food security between 2021 and 2022 (improved, no change, worsened), we estimated a multinomial logistic regression model. Likelihood ratio tests indicated

that receiving food from friends and family 30 days after the cyclones was the only significant predictor of change ($\chi^2 = 21.81$, df = 2, $p < 0.001$). Households receiving mutual aid were more likely to experience improvement and 67% less likely to experience worsened food security (OR = 0.33, 95% CI: 0.18–0.62, $p < 0.001$). Other variables—including household size, highest education, household assets, crop diversity, and village distance to the road—were not statistically significant. The model was modestly predictive, with a Nagelkerke pseudo R^2 of 0.131, indicating that it explained approximately 13% of the variation in changes in household food security (Table 4).

Table 4
Multinomial Logistic Regression Predicting Changes in Household Food Security

Predictor	***Improved vs. No Change***			***Worsened vs. No Change***		
	B	***SE***	***OR (95% CI)***	***B***	***SE***	***OR (95% CI)***
Intercept	*-1.89*	*0.66*	*-*	*-0.16*	*0.37*	*-*
Total household size	*-0.07*	*0.20*	*0.94 (0.64–1.38)*	*-0.25*	*0.16*	*0.78 (0.56–1.08)*
Highest education	*0.04*	*0.22*	*1.05 (0.68–1.60)*	*0.04*	*0.17*	*1.04 (0.75–1.45)*
Household assets	*-0.07*	*0.23*	*0.94 (0.60–1.46)*	*0.20*	*0.17*	*1.23 (0.88–1.70)*
Number of crops grown	*0.04*	*0.20*	*1.04 (0.71–1.53)*	*0.05*	*0.16*	*1.05 (0.78–1.42)*
Village distance to road	*-0.14*	*0.14*	*0.87 (0.66–1.15)*	*0.21*	*0.12*	*1.24 (0.99–1.55)*
Received food from friends/ family (mutual aid)	*1.14*	*0.64*	*3.12 (0.88–11.04)*	**-1.10**	*0.32*	**0.33 (0.18–0.62)**

Note: Values in bold indicate statistically significant predictors ($p < 0.05$). B = regression coefficient (log-odds); SE = standard error; OR = odds ratio; 95% CI = 95% confidence interval. Continuous predictors were standardized (z-scored) before inclusion in the model.

3.9 Community-Identified Needs for Reducing Negative Impacts from Cyclones

Lastly, using an open-ended survey question, we asked respondents what they felt they needed in order to reduce negative impacts from future cyclones. Figure 4. shows the relative frequency of the most frequently coded responses in NVivo.

The most frequent response was that there was nothing to be done or that the respondent had no idea, including responses like “waiting for God,” and indicating a fatalist outlook (a finding which we have previously reported on; Moore & Niles, 2025). The second most frequent response was to plant cyclone-resistent root and tuber crops (RTCs) like sweet potato, *bodoa* yam, and cassava. Planting short-duration

(three month) varieties of rice and sweet potato, which would allow farmers to harvest crops before the cyclone season, was the third most common response.

Other responses included reinforcing the house, making money by selling rice or looking for off farm work, including day labor as well as weaving handicrafts to sell, increasing agricultural productivity by following new practices, getting assistance such as seed and tool distribution, general capacity building, and “help from God,” and making preparations such as collecting food, cutting trees around home and storing water.

4. Discussion

The findings presented here confirm that the 2022 Madagascar cyclones that struck the southeastern portion of the island exacerbated food insecurity across multiple dimensions. The timing and consecutive nature of the storms, striking during the critical rice transplanting period, played a major role in worsening food insecurity during the height of the lean season and beyond (e.g., when rice should have been ready to be harvested). In addition, the loss of key secondary food crops such as cassava, banana, and breadfruit—important sources of food during the lean season (Moore et al., 2022)—further exacerbated pre-existing household vulnerabilities. This is consistent with earlier research documenting substantial agricultural losses following cyclones in Madagascar. For example, Rakotobe et al. (2016) reported that 81% of farmers experienced crop losses during Cyclone Giovanna, which struck the east coast of Madagascar in 2012. This also aligns with the work of Keller and Mulungu (2025) who found that food insecurity rose between 2020 and 2022 across 19,000 households in cyclone-affected and unaffected regions, with a decrease of more than 200 calories per person per day.

In our study, crop losses reduced self-provisioning as well as supplies to local markets, limiting both food availability and access. Food agency was also affected, with most respondents reporting a lack of choice in their food sources in the immediate aftermath of the storms (though nearly all respondents found the emergency food aid received to be acceptable). Additionally, food adequacy and utilization were compromised due to cyclone-related damage to water sources, which reduced access to clean water and raised concerns about food safety and general health.

The multidimensional effects observed here suggest that responses to cyclones must go beyond protecting crop yields alone. To reduce production losses, respondents emphasized the importance of planting cyclone-resistant crops, as well as early-maturing varieties that can be harvested before the cyclone season; such strategies are widely reported forms of adaptation among smallholder farmers (e.g., Addaney et al., 2021; Ali & Erenstein, 2017; Eludoyin et al., 2017; Hoang & Trinh, 2024). However, because the cyclones also affected food agency, adequacy and utilization, strengthening household preparedness will also require attention to food and water storage, access to clean water, sanitation, and timely, acceptable emergency assistance, especially for more remote and food-insecure households.

Shifting food access pathways

In the immediate aftermath of the storm(s), respondents obtained less food from markets, and widespread crop losses reduced self-provisioning, forcing households to initially rely more heavily on emergency food aid. Unlike Rakotobe et al. (2016), who reported increased wild food collection following Cyclone Giovanna in

2012, we did not observe this behavior. Results also suggest that market access was largely restored and that receipt of formal food aid diminished in the month following the storms, underscoring the critical role of emergency assistance in the immediate aftermath of storms when food is unavailable or inaccessible.

Strengthening resilience and adaptive capacity

Food system resilience refers to the ability of food systems to absorb, adapt to, and recover from shocks, while adaptive capacity reflects the ability of households and systems to adjust practices in response to changing conditions. While emergency food aid is critical immediately following extreme weather events, strengthening both system- and household-level responses is essential to reduce vulnerability and accelerate recovery.

Promoting wind- and flood-tolerant cultivars that mature early and offer high nutritional value, such as three-month sweet potato varieties, can enhance food system resilience (Hadley et al., 2023; Raveloson et al., 2024). Jayarajan and Gangadharan (2022) report how farmers in Kerala, India shifted to short-term crops after devastating floods, with hopes of being able to harvest before the monsoons.

Given households' increased reliance on tubers following cyclones and farmer recommendations to plant cyclone-resistant crops, interventions should prioritize resilient starchy root and tuber crops (RTCs) such as cassava, sweet potato, and endemic yams, which respondents reported were more likely to survive cyclone impacts than aboveground crops. Evidence from other cyclone-prone contexts highlight the role of RTCs in buffering the impacts of tropical storms. For example, following Super Typhoon Ompong in the Philippines, planting short-cycle sweet potato and cassava helped to replenish food supplies more quickly (Gatto et al., 2021). Similarly, in Fijian agroforests affected by a Category 5 cyclone, farmers planted many new starch crop cultivars, especially of sweet potatoes, to stabilize food availability (McGuigan et al., 2022). Thus, improving the productivity of these crops is a recommended strategy for addressing seasonal food insecurity in Madagascar (Dostie et al., 2002).

Additionally, bolstering farmers' ability to replant after disasters is essential for rapid recovery (Hadley et al., 2023). A recent study among farming households in Malawi found seed security to be a significant predictor of climate resilience (Amoak et al., 2024). In our study, respondents specifically requested seeds as a strategy to reduce future cyclone impacts, but reported not receiving any, highlighting the need for aid programs to include the provision of seeds and seedlings for post-disaster replanting.

Contrary to recommendations that crop diversification can reduce vulnerability (e.g., Endalew & Sen, 2021; Fernandez & Mendez, 2019; Hadley et al., 2023; Magesa et al., 2023), we do not find diversification to be protective in our study population. In situations where all crops are severely damaged, diversification may offer limited protection.

To strengthen food agency, a cash transfer system could be implemented as an alternative or complement to in-kind food aid. Such approaches can empower households to purchase preferred foods and livestock, offering greater flexibility in meeting their needs. Evidence suggests that cash-based interventions can support food security and recovery following shocks. For example, financial services have been associated with reduced food insecurity in drought years (Niles & Brown, 2017), and households receiving government-

provided cash transfers following Tropical Cyclone Winston were significantly more likely to recover than those that did not (Ivaschenko et al., 2020). Similar effects have been observed in other contexts, including among artisanal fishing communities in Indonesia (Nasrudin et al., 2020). However, as noted by Barrett (2006), increased local food demand from cash transfers may contribute to price inflation in constrained markets, underscoring the importance of pairing such interventions with efforts to stabilize supply. In Madagascar, programs such as the FIAVOTA initiative operated by UNICEF demonstrate the feasibility of cash-based approaches in addressing climate-related food insecurity.

Strengthening household preparedness

Beyond post-disaster recovery, our findings highlight preparedness as a critical gap. Many of the most food insecure households reported taking no protective measures before the cyclone(s), suggesting constraints in resources and access to risk-reduction strategies. More food-insecure households were less likely to implement preparedness measures, potentially due not only to material limitations but also to more fatalistic outlooks, which have been linked to lower uptake of climate adaptation measures elsewhere (e.g., Mahmood et al., 2020).

These results also reinforce the need for aid programs to specifically target the most vulnerable households, as has been recommended in other contexts; for example, following 2017 flash floods in northeastern Bangladesh, emergency food assistance programs were advised to prioritize the most food-insecure households rather than using poverty alone as the selection criterion (Parvez et al., 2021).

Specifically, strengthening the adaptive capacity of the most vulnerable households is critical. Consistent with this, Thompson et al. (2023) found that farmers in the Dominican Republic with access to flood preparedness training recovered more quickly following hurricanes, while Pienaah et al. (2025) show that preparedness significantly reduced water insecurity risk at individual, household, and community levels in rural Ghana. Similarly, Keller and Mulungu (2025) argue that the Government of Madagascar should expand social safety nets and improve cyclone preparedness to support recovery and resilience.

Limited food and water storage capacity within these communities also constrains households' ability to stockpile essential supplies before a storm. As access to clean water for cooking and food preparation is central to food security, actions such as distributing water filters and improving sanitation can help protect overall food safety. Additionally, improving food storage systems could help households preserve food supplies and reduce post-harvest losses. Alongside early warning systems and disaster preparedness education, such material support may help reduce cyclone-related losses and speed recovery.

Social resilience

Lastly, community cohesiveness has been shown to influence resilience to food insecurity in other post-disaster contexts (e.g., earthquakes; Amaya, 2014). In our study, households that received food assistance from friends or family (mutual aid) in the 30 days following cyclones were less likely to experience worsened food security, highlighting the protective role of informal social networks in the immediate aftermath of disaster events. These findings underscore the importance of kinship and reciprocity within Malagasy society (Douglass & Rasolondrainy, 2021) and align with prior research highlighting the role of community support

networks in post-cyclone recovery in Madagascar (Mohan et al., 2020; Raveloson et al., 2024). Strengthening both formal cooperative structures, such as agricultural cooperatives, and informal ones, like kinship networks and village labor exchange systems, can facilitate knowledge-sharing, improve resource access, and foster collective action in times of crisis.

Study limitations and further research

Our study had several limitations. While consistent survey timing was intended, unavoidable delays occurred due to COVID-19 and the passage of the two cyclones. As a result, the 2021 surveys were conducted in February at the onset of the lean season, whereas the 2022 surveys took place in April. This discrepancy in timing could potentially influence the measured levels of food insecurity, as typically, food insecurity tends to escalate as the lean season progresses due to dwindling household food stocks and lack of fresh harvests, and food security is at its worst in April (Rousseau et al., 2023). Consequently, the 2022 surveys occurring later in the lean period may have captured more acute food shortages compared to the slightly earlier 2021 time point.

Future research should assess the long-term impacts of cyclones on food security, particularly whether the lean season was extended due to cyclone-related disruptions. Conducting follow-up surveys in the months following the cyclone season leading up to the June rice harvest and beyond can provide valuable insights into recovery trajectories and whether households regain stability or remain trapped in prolonged vulnerability. Additionally, examining how household-level decisions on disaster preparedness are shaped by resource constraints, past experiences, and access to information will be essential. To support this, developing and validating scales that capture all dimensions of food security—availability, access, agency, utilization, sustainability and stability—can improve measurement and inform more targeted policies and programs to strengthen cyclone resilience and household food security under increasing climate variability.

Furthermore, as many respondents—particularly in coastal villages—engage in both farming and small-scale fishing, our survey, which primarily focused on cyclone impacts to agricultural production, did not capture detailed information on fishing activities. As fisherfolk are known to be negatively affected by tropical storms in other island contexts (e.g., Abasolo & Montefrio, 2025; Turner et al., 2020), we acknowledge that these storms likely reduced their food security and dietary diversity both directly and indirectly, for example through lost fishing days and income reducing households' ability to purchase other foods.

5. Conclusion

As tropical storms such as cyclones increase in frequency and strength, more research is needed on their effects across all dimensions of food security, not just availability and access. While emergency food aid plays an essential role in providing immediate relief, it should be complemented by longer-term strategies that strengthen household and community resilience, particularly for the most food-insecure households that often have the least capacity to prepare for storms. Our findings point to the value of supporting community-based coping mechanisms, alongside formal aid, as households reported increased reliance on friends and family for food after the cyclones. Promoting cyclone-resistant crops and early maturing cultivars, improving food storage, and safeguarding access to clean water through water and sanitation infrastructure

investments can all help reduce vulnerability to future shocks. Continued research on long-term recovery pathways is also needed to understand whether households regain stability or remain trapped in prolonged vulnerability. These insights can inform policies that connect disaster response with sustainable agricultural and community development, helping communities build resilience to increasingly frequent climate shocks.

Declarations

Ethics approval and consent to participate

This study was approved by the University of Vermont's Institutional Review Board (IRB; study #00001290). Informed consent was obtained from all participants prior to data collection. Due to low literacy levels, consent was obtained verbally

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Authors Contribution Statement

M.M., L.A.R.C., and M.T.N. conceived the study. M.M. wrote the main manuscript and prepared the figures. M.M. performed the analysis, and M.T.N. verified the analytical methods. All authors reviewed and approved the final manuscript.

Author Contribution

M.M., L.A.R.C., and M.T.N. conceived the study. M.M. wrote the main manuscript and prepared the figures. M.M. performed the analysis, and M.T.N. verified the analytical methods. All authors reviewed and approved the final manuscript.

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Data Availability

The datasets generated during the current study are available from the corresponding author on reasonable request.

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Figures

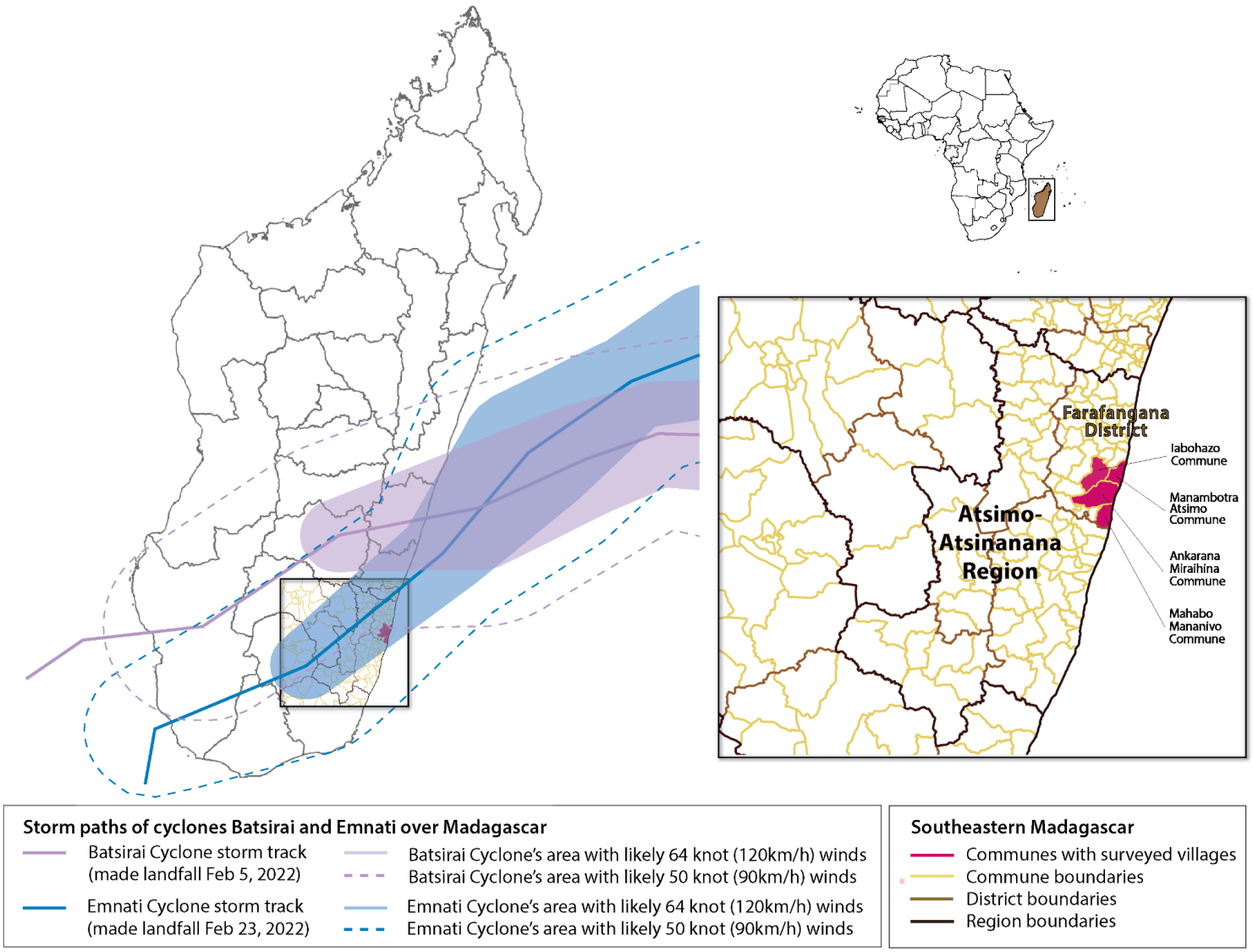


Figure 1

Storm Paths of Batsirai and Emnati over Madagascar (February 2022)

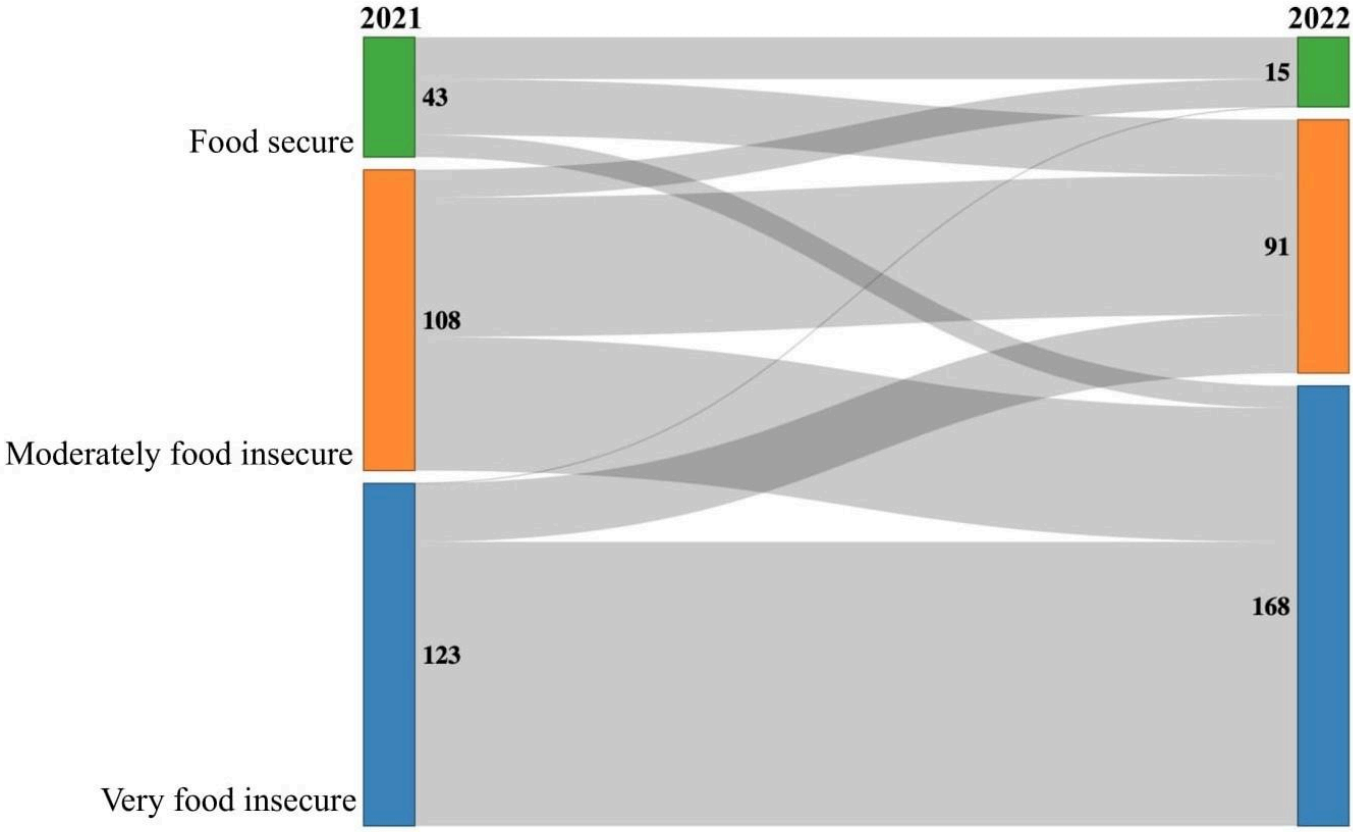


Figure 2

Individual Household Shifts in Food (In)security Category from 2021 to 2022 (n=274)

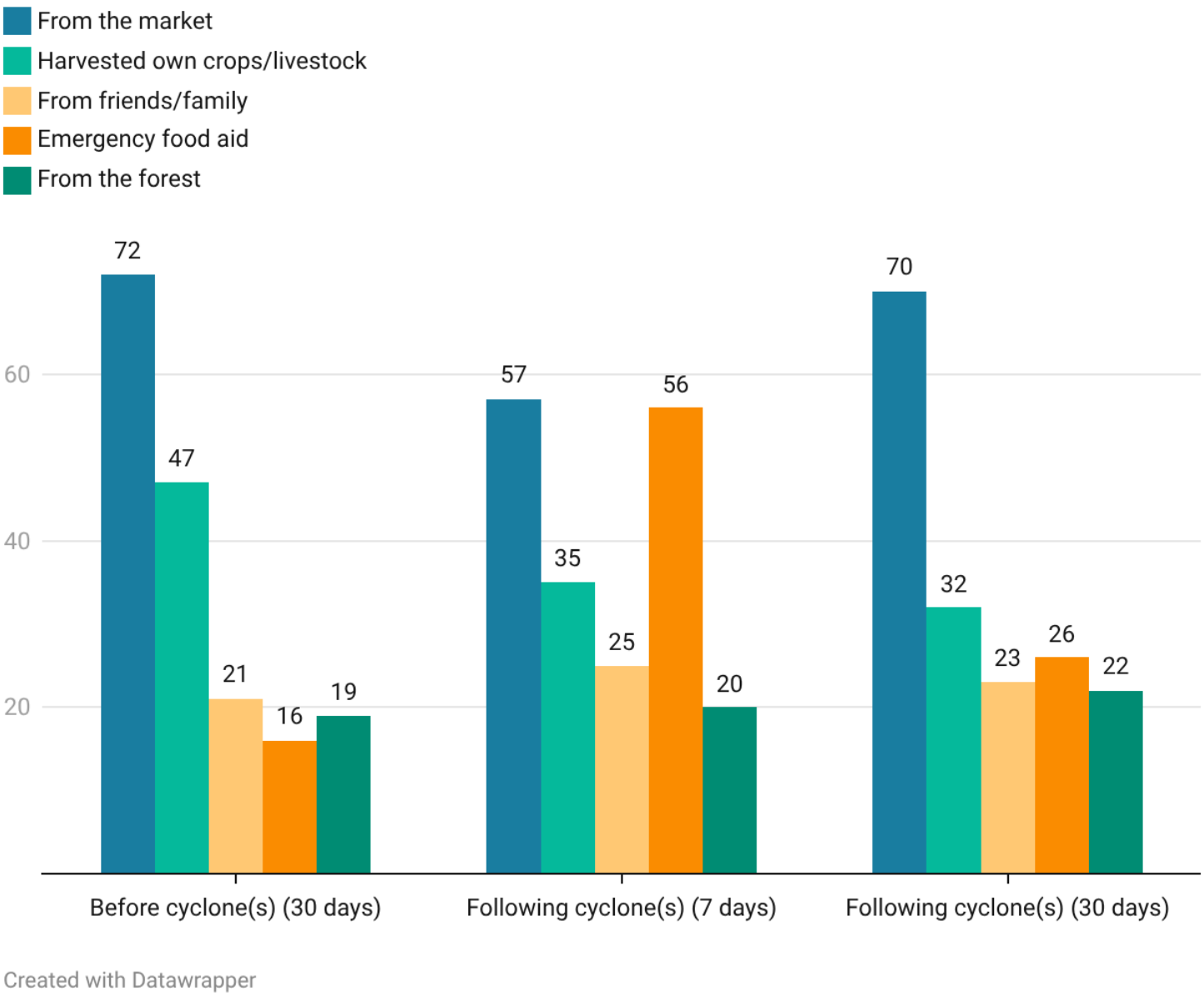


Figure 3

Percentage of 2022 respondents obtaining food from sources before and after cyclones (n=277)

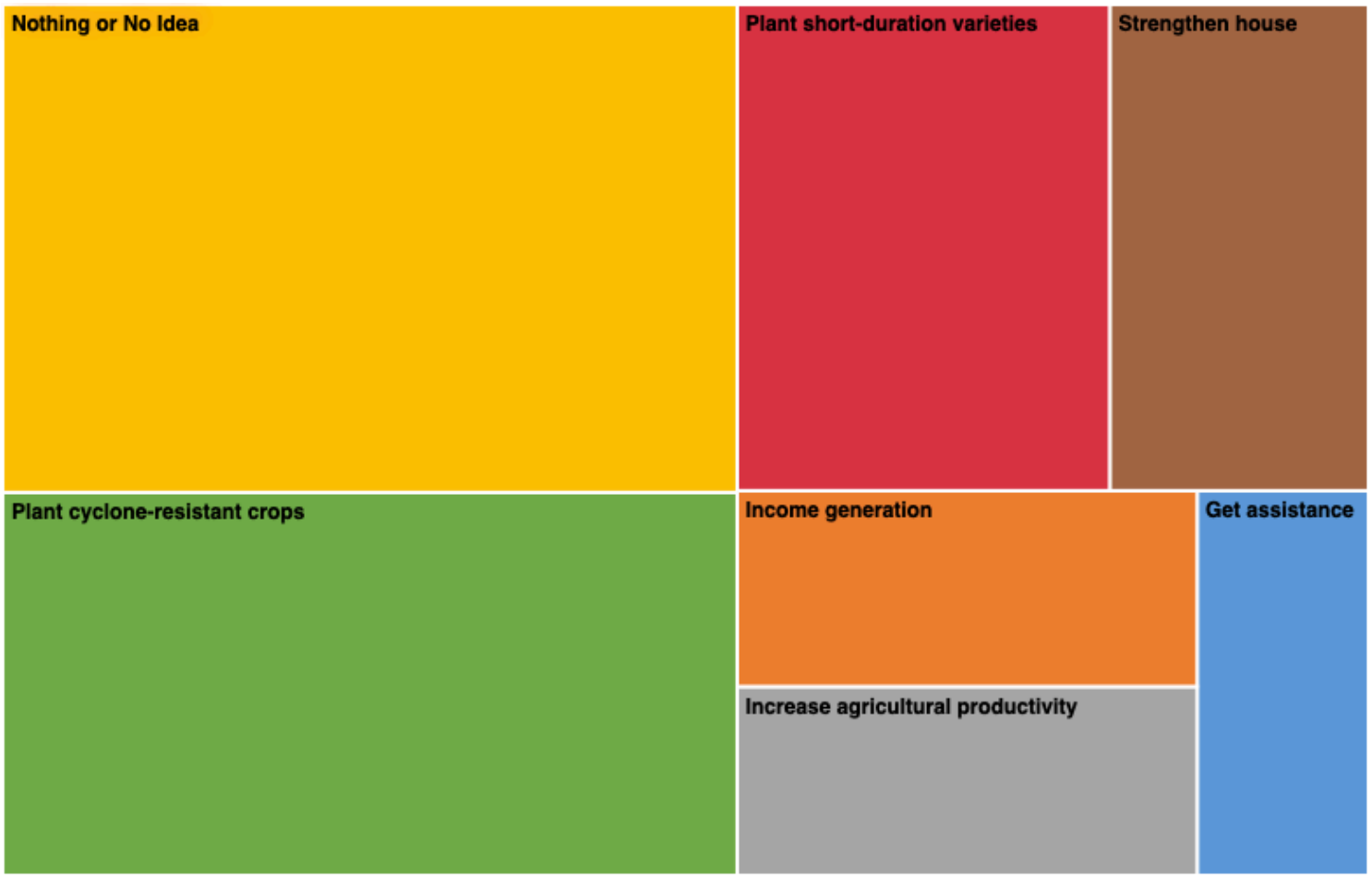


Figure 4

Hierarchical representation of proportionally coded responses to the question: “What do you need to reduce negative impacts from future cyclones?”