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Horticulture Helps: How Home Garden Interventions Alleviate Food Insecurity in Polycrises

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Highlights

- Home garden intervention (HGI) increased food security by 33% after two years in a crisis context.
- Key impact mechanisms are assets, nutritional knowledge and commercialization.
- HGIs support recovery, enhancing food production and economic capacities.
- HGIs can serve as a resilience-building policy tool.

Abstract

Natural disasters, violent conflict and other adverse shocks severely disrupt food systems, causing or exacerbating food insecurity among many communities worldwide. This study examines the impact and mechanisms of an integrated home garden intervention on food security in South Sudan, a context severely affected by conflict, forced displacement, recurrent severe flooding, the COVID-19 pandemic and institutional fragility, where, at baseline, only 29% of households had adequate food consumption. Using a quasi-experimental design with three waves of panel data from 772 households over two years, we find that the intervention increased food security as measured through the Food Consumption Score by 33% after two years (4.4 points, 90% CI [2.8, 6.1], $p < 0.01$) while significant impacts were absent after one year. Improved nutritional knowledge, increased market-oriented production and, most notably, asset ownership explain 56% of this impact. Our findings demonstrate that home garden interventions are an effective policy tool to improve food access as well as broader resilience-building, supporting economic stabilization and livelihood recovery for highly vulnerable communities in crisis-affected contexts. Given

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their relatively low cost and high adaptability, home garden interventions merit consideration as a scalable response to persistent food insecurity in crisis settings.

Keywords
Home garden intervention, food security, polycrisis, conflict, displacement, resilience, humanitarian assistance

JEL Classifications
O12, Q15, Q54, I31

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Glossary

ATT - Average treatment effect on the treated

DiD - Difference-in-differences

ESS - Effective sample size

FCS - Food Consumption Score

FIES - Food Insecurity Experience Scale

HGI - Home garden intervention

MDD-W - Minimum Dietary Diversity for Women

1 Introduction

Natural disasters, violent conflict and other adverse shocks can severely disrupt food systems, causing or exacerbating food insecurity (Ahmadzai & Morrissey, 2025; Brück & d'Errico, 2019; Islam & Al Mamun, 2020; Martin-Shields & Stojetz, 2019; Muriuki et al., 2023; Oskorouchi & Sousa-Poza, 2021). When multiple crises overlap, a polycrisis, their adverse effects can interact and intensify, resulting in even more severe food insecurity (Anderson et al., 2021; Vesco et al., 2021). In this study, we examine whether and how home garden interventions (HGIs) can improve food security in a polycrisis setting.

HGIs are widely used in crisis programming to respond food insecurity, typically combining capacity-building elements, the provision of key inputs and materials, and network-building activities (Baliki et al., 2023a). Operationally simple, relatively cheap and often culturally appropriate, HGI are a promising policy option - provided they are effective in the target context. In development contexts, practicing horticulture enhances the supply of and the demand for nutritious foods (Schreinemachers et al., 2018). Experimental and quasi-experimental studies demonstrate that HGIs increase vegetable consumption, diversify diets and reduce food insecurity in development contexts (Baliki et al., 2019, 2022, 2023b; Blakstad et al., 2021; Depenbusch et al., 2022; Schreinemachers et al., 2016). However, some research expresses skepticism regarding HGI effectiveness, reporting only weak effects on horticultural production and no significant impact on household vegetable consumption (Depenbusch et al., 2021) or indicating that initial benefits dissipate fast (Blakstad et al., 2022).

These diverging findings may reflect factors that the interventions influence and which, in turn, impact food security, such as gender roles or skills and practices (Depenbusch et al., 2021). Ruel et al. (2018) identified income generation and nutritional knowledge as key mechanisms through which agricultural interventions, closely related to HGIs, influence nutritional outcomes. However, linking diverse evidence from gardening and food security literature, additional pathways might play a crucial role in shaping the impact of HGIs on food security at the micro-level, such as the accumulation of assets. Despite the relevance of understanding these mechanisms for effective programming, empirical studies systematically analyzing the impact pathways of HGIs on food security remain absent.

Additionally, contextual factors are decisive for the effectiveness of HGIs, such as local stability (Fiorella et al., 2016). However, Baliki et al. (2023a) noted that no empirical study has yet evaluated the effectiveness of HGIs in (poly-)crisis settings using a robust counterfactual design. HGIs might be less effective in crisis settings because households lack the capacity to maintain and benefit from horticulture. Restricted markets, high production risks and other more pressing priorities may undermine the engagement and the return from gardening activities. At the same time, a garden enables households to grow diverse crops that might otherwise be unavailable, inaccessible or unaffordable, enhancing nutritional resilience and even generating income amid crises (Galhena et al., 2013; Lal, 2020; Maredia et al., 2023; Rahman et al., 2024). Evidence from related interventions in crisis settings suggests mainly positive impacts on food security. Al Daccache et al. (2024) identified three studies employing rigorous counterfactual methods in crisis settings, assessing impacts of multi-arm agricultural interventions. While two studies report positive effects on food security and dietary diversity in the Democratic Republic of Congo (Doocy et al., 2018) and South Sudan (Vallet et al., 2021), another study demonstrates no significant impact on food security in the Democratic Republic of Congo, even though the intervention enhanced the application of productive practices (Leuveld et al., 2018). Simpler agricultural interventions only providing inputs indicate improvements in food security in drought and conflict-affected settings (Baliki et al., 2024 and 2022 for Syria; Baliki et al., 2018 for North-East Nigeria). Still, these findings from broader agricultural interventions may not be transferable to HGIs as home gardens are typically less commercialized, operate on a smaller scale and are more accessible to households with limited initial endowments. This highlights the importance of explicitly generating rigorous evidence of HGIs from crisis settings.

To address these knowledge gaps, we investigate two research questions: (i) Do HGIs improve food security in (poly-)crisis settings?; (ii) Through which pathways do HGIs impact food security? To answer these questions, we examine an integrated HGIs targeting displaced former herders in the peri-urban areas of Juba, the capital of South Sudan. The intervention took place amid a polycrisis: right after the civil war, during severe floods and amid the COVID-19 pandemic, when institutions were fragile, food insecurity levels were high and large shares of the local population were displaced. We employ a quasi-experimental design to derive causal impacts, using three waves of panel data that we collected from 430 treatment and 342 comparable control households between 2019 and 2022. To estimate the overall program impact, we apply a difference-in-differences approach. To examine the underlying pathways through which HGIs impact food security, we conduct a mediation analysis testing the role of knowledge, practice, women's agency, income and asset endowment.

Our findings reveal that the HGIs significantly improved food security, increasing the Food Consumption Score by 33% (4.4 points, 90% CI [2.8, 6.1], $p < 0.01$), causing a graduation from poor to non-poor food security for 18% of the treatment households. These substantial positive impacts are consistent with other food security indicators and largely align with evidence from related studies in different contexts or intervention specifications. The key mechanisms driving these effects include improved nutritional knowledge, increased market-oriented production and, particularly, asset ownership. Together, these three mechanisms account for 56% of the treatment effect. The results demonstrate that HGIs can function as an effective resilience-building policy in contexts affected by conflict, natural disasters and other crises, by facilitating access to food and reducing reliance on unstable market availability. Moreover, we demonstrate the importance of holistic programming, integrating building capacity, marketing and accumulating productive assets beyond solely increasing the productivity of the gardens.

Our research design enables strong causal inference and contributes rare empirical evidence from an understudied context. It also makes several important contributions to the existing literature and offers broader policy implications. First, our findings expand the evidence base of agricultural and horticultural interventions as well as programming against food insecurity in (poly-)crisis settings by providing the first causal insights combining both strains of literature. Second, it is the first to systematically and empirically examine the pathways through which HGIs influence food security at the micro-level, offering a deeper understanding of how such interventions function under conditions of instability and stress. Finally, the impact and mediation analysis generate practical insights valuable for organizations and policymakers seeking to improve food security in (poly-)crisis contexts.

The remainder is structured as follows: Section 2 outlines the conceptual framework. Section 3 describes the study location and the intervention. Section 4 outlines our empirical approach. Section 5 presents the findings, followed by a discussion in Section 6. Section 7 presents contributions and policy implications.

2 Conceptual Framework

We posit that HGIs can influence food security through multiple, interrelated mechanisms. Although systematic empirical assessments of such pathways remain absent, the literature suggests many pathways of the treatment effects of HGIs and related interventions on food security.

Knowledge outcomes are likely mediators of HGIs on food security. Particularly targeted training sessions, often incorporated in HGI, are designed to enhance knowledge. Nutritional knowledge training typically covers topics related to healthy diets, as well as methods that preserve and unlock nutritive content. Empirical evidence suggests that HGIs can sustainably improve nutritional knowledge over several years (Baliki et al., 2022). In turn, better knowledge shapes attitudes and decision-making processes, leading to greater demand for healthier food (Hirvonen & Headey, 2018; Karanja et al., 2022;

Kumar et al., 2024; Schreinemachers et al., 2020). The literature confirms the mediating role of nutritional knowledge in shaping nutritional outcomes from agricultural and horticultural interventions in more stable settings (Baliki et al., 2019; Ruel et al., 2018; Sharma et al., 2021).

Similarly, we expect training to enhance agricultural knowledge, which may ultimately improve food security through higher horticultural productivity. The agricultural literature suggests that practical knowledge is critical for improving production and productivity (Asfaw et al., 2011; Nakano et al., 2018). In turn, agricultural knowledge can positively impact food security in developing settings (Larsen & Lilleør, 2014).

Relatedly, we posit that HGIs shape food security through changes in participants' adaptation of gardening practices. HGIs and related agricultural interventions raise awareness and foster the adoption of climate-smart practices and other innovative technologies (Amadu et al., 2020; Asfaw et al., 2011; Baliki et al., 2019; Depenbusch et al., 2022; Shah et al., 2023), which enhance agricultural productivity (Romero Antonio et al., 2025). However, research also indicates that while some related agricultural interventions successfully increased the use of climate-smart agricultural and other more effective practices, they did not always translate into significant improvements in nutritional outcomes (Doocy et al., 2017; Leuveld et al., 2018). Practice also includes diversifying horticultural systems, which is often promoted through HGIs. In turn, diverse production is associated with improved food security and dietary quality (Islam et al., 2018; Rahman et al., 2024). Additionally, garden diversity serves as an adaptation strategy to climatic risks, as different crops vary in their vulnerability to environmental stress and have distinct planting and harvesting cycles. This reduces the likelihood of total harvest failure, strengthening resilience (Castaneda-Navarrete, 2021).

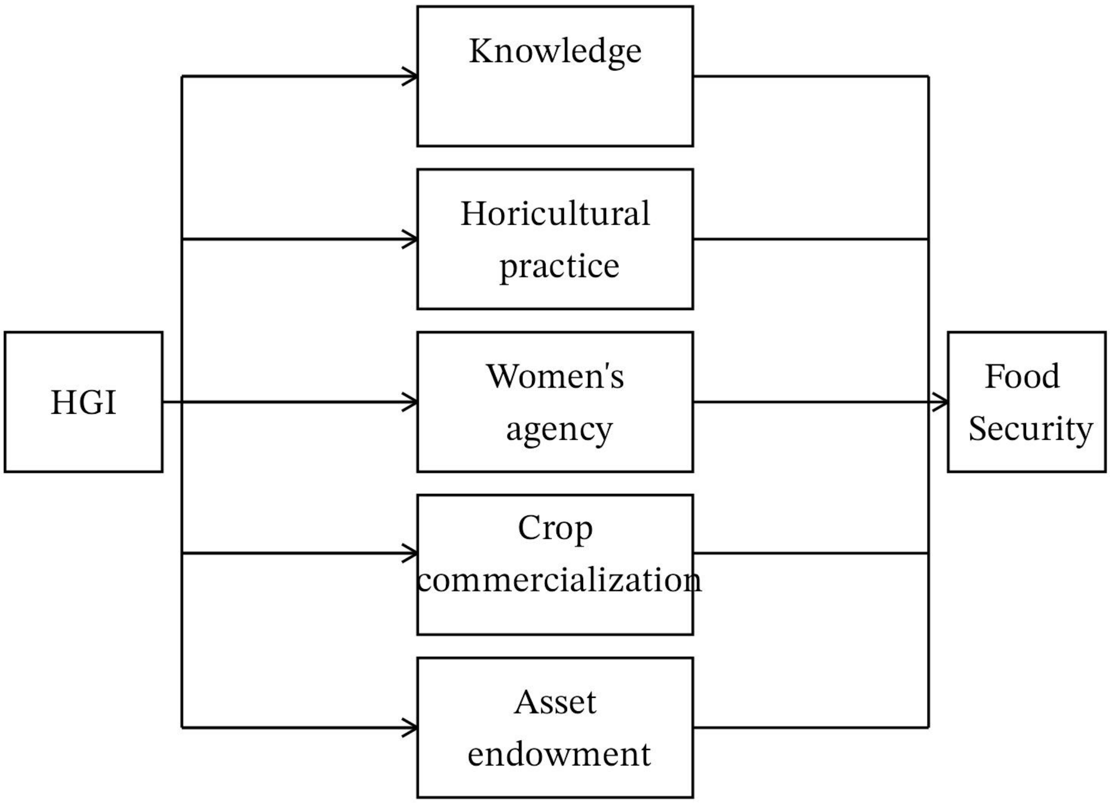
The literature also highlights women's agency as a critical pathway of HGIs and related agricultural interventions on nutritional outcomes (Ruel et al., 2018). In many contexts, women are primarily responsible for managing home gardens (Rybak et al., 2018). Training programs targeting gardening practices have been shown to strengthen women's agency, often by increasing the value of their contributions to household livelihoods (Baliki et al., 2019; Patalagsa et al., 2015). Women's roles in household food provision further amplify the potential impact of agency on food security, as they often make the decisions about dietary choices (Doss, 2014). Additionally, practicing horticulture has been linked to an increased demand for vegetables (Schreinemachers et al., 2018, 2020, 2021), suggesting that female gardeners may influence broader household consumption patterns. Empirical studies support the general association between greater women's decision-making power in agriculture and improved food security and dietary quality (Clement et al., 2019; Malapit & Quisumbing, 2015; Quisumbing et al., 2023).

We also expect that home gardening will contribute to food security through economic benefits. Empirical evidence shows that the commercialization of home gardens and small-scale farms is positively associated with food security outcomes and greater dietary diversity (Abdoellah et al., 2020; Issahaku et al., 2023; Ruel et al., 2018; Tojo-Mandaharisoa et al., 2023). In particular, higher incomes allow households to purchase food that might otherwise be unaffordable. Moreover, market-oriented garden produce diversifies income sources, enhancing the resilience of household food security to shocks (d'Errico et al., 2023). This is especially beneficial in volatile or crisis-affected settings.

We posit that HGIs can influence household food security through asset endowment. HGIs often provide essential agricultural tools directly, while increased household income resulting from HGIs participation may also enable the purchase of additional assets. In general, asset endowment contributes to greater farm and garden productivity as well as to the accumulation of durable wealth (Asfaw et al., 2011; Gabrysch et al., 2024). In turn, cultivation asset, land and livestock ownership is strongly associated with improved food security (d'Errico et al., 2023; Kayaoglu et al., 2024; Tojo-Mandaharisoa et al., 2023). Moreover, accumulating durable assets can support the sustainability of intervention effects beyond the program period (Blakstad et al., 2022), making assets a plausible and promising pathway through which HGIs can generate lasting improvements in household food security.

Finally, while the broader literature suggests additional potential pathways, we consider some to be less relevant in our context. For instance, market or environmental conditions impact food security at a macro- or meso-level and these conditions can be influenced by large-scale interventions (Depenbusch et al., 2021; Fiorella et al., 2016; Ruel et al., 2018). However, we restrict this study to the micro-level as we do not expect HGIs to meaningfully impact community-level outcomes unless implemented at a large scale. Additionally, HGIs have been found to contribute to psychosocial well-being (Spano et al., 2020), which is strongly associated with food security (Ejiohuo et al., 2024). Nonetheless, we conceptualize psychosocial well-being more as a consequence of food security rather than a driver of it (Beck et al., 2024) and therefore exclude this mechanism from our framework.

Figure 1: Theorized Mechanisms of Increases in Food Security



Notes. This conceptual framework serves as a visualization of the theorized mechanisms moderating the impact of HGIs on Food Security.

Taken together, the literature suggests several pathways through which HGI can influence food security. We derive five key mechanisms that are both theoretically grounded and contextually plausible for HGIs to influence food security in crisis settings, namely (i) knowledge, (ii) horticultural practices, (iii) women's agency, (iv) crop commercialization and (v) asset endowment. Figure 1 visualizes our conceptual framework.

3 Case Study

3.1 The Study Location

We conducted the study between 2019 and 2022 in the peri-urban area of Juba, the capital of South Sudan. South Sudan has endured a polycrisis for decades, including war, displacement, climatic extremes, food and health crises, contributing to its status as one of the least developed and most corrupt nations. This is reflected in global indices such as the Human Development Index, where South Sudan ranks second to last worldwide in 2022 (UNDP, 2024b) and the Corruption Perceptions Index, where it holds the lowest position in 2025 (Transparency International, 2025). After the civil war with almost 400 thousand direct and indirect fatalities (Checchi et al., 2022), South Sudan was officially peaceful during the study period following the 2018 peace agreement that also established the transitional administration without formal elections during our study period. Still, the country continued to experience high levels of violence and clashes, often fueled by political and ethnic tensions (UNDP, 2024a). The COVID-19 pandemic coincided with our study, restricting households through curfews and market restrictions and exposing the population to risk due to the low-developed healthcare system (Dinyo et al., 2020). Additionally, climate change exacerbates the severity of seasonal floods in river delta regions, posing significant threats to lives and livelihoods. In July 2020, a severe flood affected our study area (UNOCHA, 2020).

The ongoing polycrisis in South Sudan resulted in approximately 2.3 million refugees in neighboring countries at the end of our study period, while 2 million people were internally displaced (UNHCR, 2022). The crises have had a significant impact on the population, particularly on vulnerable groups. For instance, the United Nations documented the recruitment of children by armed groups in 2021 (UNSG, 2022). Additionally, 35% of displaced youth reported alcohol abuse as a coping mechanism (Makoha & Denov, 2024). The deep patriarchal structures systematically undermine women in South Sudan, for example, in terms of market participation (von der Goltz et al., 2020) or women's ability to claim and enforce land ownership rights (World Bank, 2020). On top of that, women face high levels of violence. Ellsberg et al. (2020) report that 50% of women interviewed in displacement camps in Juba have experienced physical or sexual violence at least once in their lifetime, while 35% have been subjected to rape.

Additionally, these crises severely deteriorated agrifood systems. Despite agriculture being the dominant livelihood and favorable climatic conditions, South Sudan remains a net importer of staple foods, primarily due to critically low agricultural productivity, which constrains the local food supply (Kuol et al., 2020). Another important cause is limited access to affordable seeds, as high domestic production costs, exceeding those of neighboring countries, leave farmers reliant on expensive imported hybrid seeds (AGRA, 2022). At the end of our study in 2022, 63% of the population was facing acute food insecurity (IPC Global Partners, 2022).

3.2 The Intervention

To address the multiple crises affecting peri-urban communities of Juba, Malteser International implemented an HGI aimed at strengthening the beneficiaries' resilience to food crises caused by conflict, natural disasters and price volatility. More specifically, by increasing homestead food production and its productivity, the objective was to strengthen and increase food availability and accessibility, ultimately contributing to enhanced and stabilized food security. The intervention should complement traditional farming practices by integrating modern cultivation techniques while providing essential inputs that are difficult to access, such as seeds and farming tools. Additionally, the program should improve participants' nutritional knowledge to promote healthier dietary practices. Without explicit activities, women's empowerment was another key component of the program: the intervention should encourage women indirectly to take on leadership roles and actively participate in decision-making processes related to garden production and food security. Hence, the HGIs was based on a holistic approach, integrating a comprehensive set of activities.

Table 1: Timeline of Interventions and Data Collection

	2019		2020				2021				2022
	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
Rainy season											
Harvest season											
Registration											
Expansion of agr. land											
Tools distribution											
Seeds distribution											
Training & demo. gardens											
Cash transfer											
Data collection											

Notes. Shaded cells indicate the approximate months of seasons, interventions implementation and data collection.

The implementation started in mid-2019 and continued until the end of 2022, providing annual, repetitive support to participating households. In 2019, the implementer registered beneficiaries and identified existing farmer groups among them or established new ones where none previously existed in collaboration with local authorities. Most support activities were delivered through the 35 farmer groups, ensuring efficient distribution and knowledge-sharing among participants. The provision of assistance started in early 2020. Table 1 presents the key elements of support relevant to this study in a timeline.

The intervention supported households in establishing home gardens and expanding their productive land annually between April and May 2020 and 2021, before the start of the rainy season. At the beginning of each new agricultural cycle in March and April, the beneficiaries received essential farming tools such as hoes, watering cans and rakes for land preparation. Additionally, households received crop seeds in April or May and vegetable seeds during the dry season, between November and March, along with specific training on crop and vegetable cultivation. Other training sessions covered essential home garden practices, including soil management and post-harvest handling and were conducted throughout the year. These applied sessions should encourage participants to apply new skills directly in their farming activities. Additionally, the hands-on demonstration gardens should promote peer learning and knowledge exchange. The participants also benefited from regular monitoring visits and technical assistance to support their ongoing home garden activities. In addition to home garden assistance, an emergency cash transfer was introduced in August 2020 in response to the economic shock caused by the COVID-19 pandemic and severe flooding. Depending on household size, the transfer amount ranged between 103 EUR and 307 EUR.

The intervention targeted formally herding households displaced during the civil war, ultimately benefiting 1,000 households (approximately 7,000 individuals). Beneficiary households had access to all horticultural support components; however, detailed records are not available to us. The only intervention not offered to all beneficiaries was the cash transfer, which the implementer directed towards beneficiary households severely affected by flooding. This group comprised approximately 88% of all beneficiary households.

The intervention prioritized (widowed) women, internally displaced households, people with disabilities, elderly individuals and other vulnerable groups in coordination with local authorities. The original targeting plan aimed for 55% of the beneficiary households to be female-headed and at least 60% to have fertile land with river access for year-round cultivation. The research team received information on the characteristics of all beneficiary households, which closely reflected these targets: 54% of households were female-headed and 60% had land with water access.

4 Empirical Approach

To address our research questions (i) Do HGIs improve food security in (poly-)crisis settings?; (ii) Through which pathways do HGIs impact food security?, we apply a quasi-experimental design with three waves of household panel data ("Baseline", "Follow-up 1" and "Follow-up 2") comparing households that received the HGI, the treatment group, with similar households that did not receive the HGI, the control group. This design enables us to attribute the impacts of the HGI on food security causally and to examine the mechanisms through which the intervention influences food security outcomes.

4.1 Study Design

We conducted a survey with the same households across the three waves to track the changes within each household. As shown in Table 1, we collected Baseline data in November 2019, coinciding with the harvest season and before the treatment group received any HGI assistance. Follow-up 1 took place in November 2020, also during the harvest season, after the severe 2020 floods and following the first cycle of support, including the cash transfer. Follow-up 2 was conducted in January 2022, after the second cycle of support and at the end of the harvest season. Conducting the surveys at the same time of the year accounts for any seasonal variations, for example, in climatic conditions, food security or livelihood activity. Additionally, conducting the surveys during the harvest season minimizes recall biases in production questions.

We use a stratified sampling strategy to ensure that our sample is representative of the entire beneficiary population while avoiding overly stretching resources. Rather than interviewing all 1,000 beneficiary households, we randomly selected a sample of 500 treatment households. We use stratification to reflect key characteristics of the overall beneficiary group, thereby enhancing the validity of our findings. Specifically, we stratified the sample by farmer group membership, the share of female-headed households (54%) and access to land with water (60%), ensuring proportional representation across these dimensions. This approach allows us to capture the overall impact of the intervention more accurately.

Second, we compiled a list of replacement households to compensate for potential non-responses during the Baseline survey. If a selected treatment household was unavailable for the Baseline interview, the enumerators replaced it with a pre-identified household from the replacement list. To maintain the integrity of the stratified sampling strategy, replacement households matched the original households in terms of their farmer group, their land water access and the gender of their household head.

Third, in collaboration with local community representatives, we identified and selected

500 control households in the field during the Baseline, as no reliable census or alternative data of non-beneficiaries were available for sampling. To ensure comparability, enumerators were provided with aggregate information on the target control sample on access to water and the household head's gender. The control households were selected from the same neighborhoods as the treatment households to minimize contextual differences.

The enumerators conducted interviews in the local language, translating the questionnaire in real-time. To maintain consistency and quality of the data, all enumerators underwent intensive training before each data collection round. This training covered ethical research principles, practical advice on data collection and standardized translation practices. Before participating in the interviews, all respondents provided verbal informed consent, following ethical guidelines for research with human subjects. The informed consent form provided a comprehensive explanation of the study's purpose and the participants' rights in clear and understandable language, ensuring that they fully understood the nature of their involvement.

4.2 Data

In total, the enumerator team interviewed 1,002 households at Baseline, 859 households at Follow-up 1 and 864 households at Follow-up 2. The balanced panel dataset consists of 772 households that we successfully tracked across all three waves, comprising 342 control and 430 treatment households. Table 2 presents the sample composition by stratification criteria. Regarding the stratification criteria, 63.6% of control households and 60.2% of treatment households reported land access to water, meeting closely the minimum target. In the control group, 50.6% of the interviewed households are female-headed [1], while in the treatment group, this proportion is 48.4%. This slightly deviates from the planned 55% of female-headed households. Possible reasons for a lower ratio of female-headed households than planned initially may be attributed to female-headed households being less willing to participate or being less available. Another possible reason might be

[1] In this study, gender refers to the perception of the respondent or, where applicable, the gender attributed by the respondent to another household member (e.g., household head).

strategic misreporting of the household head's gender during registration for assistance (Martinelli & Parker, 2009), which still does not explain the lower ratio among the control group.

Table 2: Sampling Rollout

	Control	Treatment
Plan		
N	500	500
Female household heads	55%	55%
Land access to water	60%	60%
Baseline rollout		
N	502	500
Female household heads	50.8%	47.2%
Land access to water	64.3%	60.8%
Panel		
N	342	430
Female household heads	50.6%	48.4%
Land access to water	63.6%	60.2%

Notes. The table reports the sampling plan, the Baseline rollout and the panel households that could be interviewed all three times in number of observations and the shares of female-headed households and households with land access to water, disaggregated by treatment and control groups.

Attrition is not unexpected in a challenging study environment, including displacement, weak institutions, extreme poverty, conflict and a severe flood. From the 1,002 households in the initial sample, 230 households could not be interviewed in Follow-up 1 or Follow-up 2 for the following reasons: 31% of the households moved away, 34% refused the interview, 28% of the households could not be found or the interviews could not be matched and 7% stated other reasons. Refusing the interview was particularly high in the control group, where 47% of the attrited households refused the interview (not displayed). Appendix A.1 provides a detailed attrition analysis. Some differential dynamics in attrition are seemingly linked to the attractiveness of engaging with home garden support. While this may constrain the representativeness of our sample, it does not compromise the internal validity of our findings as long as the final sample remains sufficiently powered and the treatment and control group continue to be comparable. We show a detailed balance analysis in Section 5.1.

4.3 Variables

We designed a questionnaire that captures all relevant variables for our study, carefully contextualized to the setting. In light of low literacy levels, we deliberately refrained from including complex variables such as expenditure or productivity data in our analysis, given the limited reliability of such information in this context.

Our primary outcome variable is the Food Consumption Score (FCS), a widely used food security indicator developed by the World Food Programme. The FCS measures the frequency and diversity of food consumption over the past seven days, with a weighted score reflecting the relative nutritional importance of different food groups. The food groups and their respective weights are as follows: main staples (2), pulses (3), vegetables (1), fruits (1), meat/fish (4), milk products (4), sugar (0.5), oil (0.5). The score is computed as the sum of the days each food group was consumed, multiplied by its corresponding weight, resulting in a score ranging from 0 to 112. In the context of South Sudan, an FCS above 21 points is considered borderline food security, while a score above 35 points is classified as acceptable (WFP, 2008). The FCS has been validated as a proxy for adequate caloric intake (Wiesmann et al., 2009) and is widely used in humanitarian settings to assess household-level food security (for example, Baliki et al., 2024; Castaneda-Navarrete, 2021; Issahaku et al., 2023). Hence, we adopt the FCS as our primary proxy for food security in this study.

As a robustness check, we test the sensitivity of our findings against two additional food security indicators. We provide a more detailed description of the computation of the alternative food security outcomes in Appendix A.2. First, we test sensitivity regarding access to food using a food insecurity classification based on the Food Insecurity Experience Scale (FIES) (Cafiero et al., 2018) following Balana et al. (2023). Hence, we classify a household as severely food insecure if the respondent reports experiencing at least one of the three most severe FIES items in the past year, namely (i) running out of food, (ii) going hungry but not eating or (iii) going an entire day without food. We primarily use the dummy variable because it allows us to assess the lower-bound classification and capture graduation from extreme food insecurity. We also test for the gradual classification into four groups: Food secure, mildly, moderately and severely food insecure. The recall period is one year. Second, we test sensitivity in dietary diversity using the Minimum Dietary Diversity for Women (MDD-W) indicator (FAO & FHI, 2016), which measures the number of food groups consumed within the past 24 hours in a score from 0 to 10. We do not differentiate by gender. Instead, we use the same score for both male and female respondents. Consuming at least five different food groups is considered adequate dietary diversity (ibid). Dietary diversity is a key metric in evaluating home garden interventions (Waid et al., 2023). MDD-W is a good proxy for malnutrition (Chakona & Shackleton, 2017) and, hence, for dietary quality. Pearson's correlation indicates a weak negative relationship between FCS and severe food insecurity classification (-0.21) and a moderate positive correlation with MDD-W (0.26) (see Figure A1 in the Appendix), suggesting that these measures capture distinct but complementary dimensions of food security. Since food security is a multidimensional concept, assessing robustness using different indicators is reasonable. By incorporating severe food insecurity classification and MDD-W, we specifically examine food access with the former and dietary quality with the latter, allowing us to determine the extent to which HGIs affect both dimensions. Furthermore, the three indicators cover different time frames. Although the indicators are not directly comparable, the time frames enable us to suggestively differentiate between acute and year-round food security. This approach provides a more comprehensive analysis of food security outcomes.

For the mediation analysis, we examine five pathway domains. We assess these using proxy scores for each domain. First, we assess participants' knowledge using two distinct indicators: a nutritional knowledge score and an agricultural knowledge score. Participants evaluated statements on general agricultural and nutritional topics aligned to the

HGI training topics, identifying each statement as true or false. We calculated the scores separately for nutrition and agriculture based on the number of correct responses. The maximum number of correct answers is twelve for nutrition and nine for agriculture. The nutritional knowledge module was inspired by Baliki et al. (2019). Second, we use two indicators to measure practice: garden diversity and adoption of good home gardening practices. For the first indicator, we constructed a home garden diversity score, which captures the number of different vegetables grown in the home garden, from a total of 18 vegetables common in the study area. The second indicator measures the number of adopted home garden practices, with a maximum of eleven practices common in the study area. Third, to assess women's agency in horticultural production, we use a score based on eight statements, where respondents indicated their level of agreement (strongly agree, agree, neutral, disagree or strongly disagree) related to women's agency following Baliki et al. (2019). We aggregated the responses to a score ranging from 0 to 32, with higher values reflecting greater female agency. Fourth, to measure income effects, we constructed a commercialization indicator. Our indicator reflects the number of different vegetables the household sold at least 50% of the harvest in the past season. We considered all home garden crops. The maximum in our sample is six commercialized crops. Researchers commonly use crop commercialization to reflect the economic potential of home gardens (Carletto et al., 2017; Issahaku et al., 2023). Fifth, to capture the mediating impact of asset accumulation, we use a home gardening asset score, which counts the number of different home gardening assets common in the study area that the household owns. A total of seven assets are considered. Asset ownership is a common proxy of productive development (Johnson et al., 2016). We provide a more detailed description of the computation of the mediators in Appendix A.2.

For comparability across all mediator variables, we normalized the seven indicators to a range of 0 to 1, where the highest within-sample score is set to 1. We opted for normalized scores to interpret changes as percentage shifts. Instead of using a score from a principal component analysis, we chose this approach to maintain an intuitive metric for direct interpretability. For example, a score of 0.4 indicates that a respondent answered 40% of the knowledge test questions correctly, that a household owns 40% of the assets or cultivated 40% of the home garden vegetables, all relative to the maximum within-sample score.

We control in our analysis for household-specific covariates, including the gender, age, literacy and marital status of the household head, the number of household members, the share of household members with disabilities and whether they received any support from other organizations in the past twelve months. Moreover, we account for self-reported experiences of adverse shocks in the past 12 months before each wave, namely severe illness or an accident of one of the main breadwinners, experience of conflict or violence and theft. Variables highly correlated with the treatment are inadequate as control variables since multicollinearity reduces the statistical precision of the treatment effect estimate. Since the flood experience was the targeting criterion for the cash distribution, we do not include it in the control variables either. Likewise, we have information on whether the household head regards crop farming as their main occupation and if their land has water access, which we do not use as a control variable since it might be impacted by the treatment. Still, we assess these variables in our balance tests.

We imputed missing data in key variables. A total of 15 out of 2,316 observations in our panel had missing data in at least one of the FCS components, all in Follow-up 2. Since the outcome modules were not mandatory in the data collection and the missing values are unsystematic, the missing data likely result from the unintentional skipping of specific module components. To avoid excluding affected households from the analysis, we imputed missing values using the group and wave mean for each respective component. We test the sensitivity of imputation by running our models without imputation as a robustness check. We did the same for missing values in FIES, MDD-W, women's agency and time-varying covariates. For other mediator variables, we treated missing values as zeros, i.e., as a wrong answer, not adapted, not cultivated, not sold or not owned. We imputed missing values in time-fixed covariates with values from the same household from other waves.

4.4 Econometric Approach

To causally estimate the average treatment effect on the treated (ATT), we employ difference-in-differences (DiD) regressions, as defined in Equation 1. The dependent variable Y_{it} represents food security for individual (or household) i in period $t \in \{0, 1, 2\}$. $treat$ and $wave$ are binary variables, taking the value of 1 for the household being part of the treatment group or the interview being conducted in a follow-up, respectively and 0 otherwise. The coefficient of interest, β_3, reflects the causal ATT and is only included in the regression if $treat = 1$ and $wave = 1$. β_0 is the intercept while u_{it} is the error term reflecting deviations of the estimate from the true outcome. We include a vector of control variables X_{it} to improve the precision of and minimize the confounding of the estimation. All regressions are adjusted for enumerator-fixed effects. We run the regressions separately for each follow-up to differentiate between short-term impacts at $t = 1$ and medium-term impacts at $t = 2$. We focus on the ATT, rather than the average treatment effect, given the non-randomized nature of treatment assignment and the lack of confirmed information on who actually received the intervention.

$$Y_{it} = \beta_0 \; + \beta_1\, treat_i + \beta_2\, wave_t + \beta_3\, treat_i * wave_t + \beta_4\, X_{it} + u_{it}. \tag{1}$$

For a causal interpretation of the ATT in a DiD regression, the parallel trends assumption is pivotal: The average change observed in the control group should mirror the average change of the treatment group in the absence of assistance (Wooldridge, 2013). Given that we only have access to one data wave before the treatment, we cannot assess the pre-treatment trends. Nevertheless, the comparability between the control and treatment group at Baseline serves as a strong indicator that the common trend assumption holds. A detailed analysis of the sample balance follows in Section 5.1. Moreover, using the balanced panel reduces the risk that changes in the sample composition compromise the common trend.

To improve comparability between the control and treatment group and to reinforce the integrity of the common trend assumption, we implement entropy balancing following (Hainmueller, 2012), which is commonly used in the related literature (for example, Kayaoglu et al., 2023). This method calibrates weights for the control households to minimize the entropy distance, thereby aligning the distributions of selected variables between the two groups. Specifically, we derive weights for the FCS based on the outcome itself and pivotal covariates at Baseline, namely whether the household had gained its main income from farming and whether the household was exposed to floods within twelve months before Baseline. These variables played a pivotal role in treatment assignment and, therefore, need to be balanced across both groups for a causal interpretation. Additionally, we balance on whether the household head was polygamously married at Baseline, whether the household was exposed to theft in the past twelve months before Baseline and on the nutritional knowledge score to further strengthen the comparability, as these variables are unbalanced without weighting. With this method, we ensure that the households started on average from similar levels of food insecurity. Given that even minor deviations in food security status can lead to vastly distinct realities, this approach enables a more precise comparison by effectively addressing these subtle discrepancies.

Entropy balancing involves a trade-off regarding the effective sample size (ESS): the more variables are included in the balancing, the smaller the ESS becomes. We closely monitored the ESS while selecting balancing variables. Our final specification results in an effective control group size of 138, suggesting some degree of overfitting. To prevent excessive overfitting, we refrain from adding further balancing variables to achieve a perfect balance. We perform the same balancing for the robustness tests, replacing FCS with the other outcome variables. We favor entropy balancing over alternative matching methods for two primary reasons. Firstly, entropy balancing does not exclude any observations from the analysis through pruning. Secondly, as a non-parametric approach, entropy balancing does not need assumptions about the functional form, affording greater flexibility in capturing complex relationships (Hainmueller, 2012).

In addition to estimating the main analysis with two alternative food security outcomes, we evaluate the robustness of our findings by testing our primary regression model against different specifications. First, we run the main analysis with the unbalanced panel to assess whether systematic attrition may have influenced the results. Second, we employ a two-way fixed-effects model to ensure that unobserved time-invariant factors do not drive the observed effects. For this model, we only include time-varying control variables. Third, we test the overall impact by pooling the two follow-ups, which increases statistical power and enhances the detection of smaller effects. Fourth, we repeat our main analysis without imputing missing values in FCS to assess whether the imputation procedure may have biased the results. Fifth, we replace the binary food insecurity indicator derived from the FIES domains with an ordinal food insecurity indicator from 1-4 to test the sensitivity of our findings to a more gradual classification of food insecurity severity. Sixth, we evaluate the sensitivity of our balancing approach, particularly in light of overfitting, by testing the results under stricter and more relaxed balancing specifications. Similarly, we substitute entropy balancing weights with weights derived from full propensity score weighting based on key covariates. These robustness checks provide additional confidence that our findings are not driven by specific modeling choices or sample restrictions.

To systematically study the mechanisms through which HGIs impact food security, we conduct a mediation analysis. We decompose the total ATT into the direct and indirect ATTs. Equations 2 and 3 display the mediation regressions. The product of the ATT on the mediator, β_{M3}, and the association between the mediator and the outcome, β_{Y5}, represents the indirect treatment effect. To derive test statistics for the indirect ATT, we bootstrap the mediation analysis with 1,000 iterations. The direct ATT on the outcome Y_{it} is given by β_{Y3}. The sum of the direct and the indirect ATT equals the total effect (Hayes, 2018). Our mediators are conceptually and empirically correlated (see Figure

A1). Hence, we conduct a multiple-mediation analysis that includes all mediator variables simultaneously to estimate the effects of each pathway while accounting for the other mechanisms. This approach reduces omitted variable bias and provides a more conservative and realistic assessment of mediation effects. As part of the robustness analysis, we complement the main specification with separate mediation regressions to assess the sensitivity of each individual pathway. Moreover, we replace FCS with the alternative outcomes. In all mediation models, we include the same weighting and control variables as described above.

$$M_{it} = \beta_{M0} \ + \beta_{M1}\, treat_i + \beta_{M2}\, wave_t + \beta_{M3}\, treat_i, wave_t + \beta_{M4}\, X_{it} + u_{Mit}. \tag{2}$$

$$Y_{it} = \beta_{Y0} \ + \beta_{Y1}\, treat_i + \beta_{Y2}\, wave_t + \beta_{Y3}\, treat_i, wave_t + \beta_{Y4}\, X_{it} + \beta_{Y5}\, M_{it} + u_{Yit}. \tag{3}$$

Causality tests following Granger (1969) indicate a predictive power of food security on mediator variables in subsequent waves (not displayed). Hence, we refrain from causally interpreting the direct and indirect effects from the mediation analysis because we expect confounding between the outcomes and the mediators.

5 Results

5.1 Descriptive Statistics

Summary statistics suggest a high degree of vulnerability among the studied population. Column (1) in Table 3 presents Baseline values displayed as means with standard deviations in parentheses or as percentages for all relevant covariates, mediators and food security outcomes. At Baseline, the average age of the household head is 45 years. The literacy rate is low, with only 39% of household heads being able to read. Households are generally large, with an average size of 8 members, while 6% of household members have a chronic health impairment or disability. Farming is an important livelihood in our sample as it is the main occupation for 87% of household heads. 20% of households received support from another organization in the 12 months prior to Baseline. Respondents frequently reported exposure to severe adverse shocks. 58% of the households were affected by floods in the past twelve months before Baseline, while 46% experienced an illness or accident that affected an income earner. Furthermore, 28% of respondents reported an experience of conflict or violence and 69% experienced theft during the same period.

Regarding the mediator variables, the knowledge scores at Baseline are low. Both scores are close to the expected value of 50% correct answers, which would be obtained if respondents answered at random. On average, respondents correctly answered 56% of the nutrition statements and 48% of the agricultural statements. Households adopted only 13% of the home garden practices at Baseline, corresponding to an average of one practice per household. Similarly, they cultivated 13% of the 18 available home garden crops, which translates to an average of two crops per household. Additionally, most households did not sell significant portions of their harvest: only 6% of crops were commercialized on average, meaning that every third household sold one crop. Households owned, on average, 24% of the available garden assets, which translates to one to two assets per household. The women's agency score of 0.50 suggests that respondents, on average, held a neutral opinion on the agency statements. The standard deviation indicates that most responses were fairly close to the average, suggesting limited variation in perceptions of agency.

The food security situation at Baseline is alarming. The FCS averages 27.4 points, with 53% of households classified as having borderline food consumption and 29% experiencing poor food consumption. According to the FIES-based food insecurity classification, the majority of households (87%) were food insecure. Regarding MDD-W, respondents consumed an average of 3.3 different food groups per day and only 19% met the threshold for adequate dietary diversity at Baseline.

Table 3: Baseline Characteristics and Predictors of Treatment Assignment

	(1) Overall (Mean (SD)/Share)	(2) Treatment (Coef (SE))	(3) Treatment (Coef (SE))
Demographic and socioeconomic characteristics			
Female HHH	49.4%	-0.060 (0.038)	-0.076* (0.043)
Age of HHH	45.4 (14.0)	0.003** (0.001)	0.003** (0.001)
HHH is literate (at least read)	38.5%	0.011 (0.037)	0.043 (0.043)
HHH is married (monogamously)	57.6%	-	-
HHH is married (polygamously)	22.4%	-0.231*** (0.041)	-0.047 (0.052)
HHH is not married	19.9%	-0.001 (0.044)	-0.059 (0.047)
HH size	8.38 (4.04)	0.003 (0.004)	0.002 (0.005)
Share of HH members with disability	6.0%	-0.288* (0.173)	-0.171 (0.196)
HHH is a farmer (main occupation)	87.0%	0.289***(0.050)	0.077 (0.074)
Support from another organization (12M)	20.3%	0.030 (0.041)	0.059 (0.046)
Water access	61.7%	-0.033 (0.035)	-0.071* (0.040)
Experience of adverse shocks (12M)			
Floods	57.6%	0.292*** (0.033)	0.004 (0.040)
Illness/accident of an income earner	46.0%	-0.053 (0.035)	-0.077** (0.039)
Conflict/violence	27.8%	0.096** (0.039)	0.091** (0.042)
Theft	68.5%	0.134*** (0.037)	-0.033 (0.044)
Mediators			
Nutritional knowledge score	0.557 (0.132)	-0.394*** (0.123)	0.009 (0.140)
Agricultural knowledge score	0.484 (0.191)	0.094 (0.088)	0.140 (0.102)
Home garden diversity score	0.125 (0.172)	-0.211* (0.123)	-0.300** (0.139)
Home garden practice score	0.132 (0.220)	-0.066 (0.096)	-0.122 (0.104)
Women's agency	0.502 (0.121)	0.108 (0.140)	0.241 (0.157)
Crop sale score	0.061 (0.126)	0.049 (0.133)	0.164 (0.143)
Asset score	0.236 (0.194)	0.124 (0.087)	0.083 (0.100)
Food security			
FCS	27.4 (10.6)	-0.006*** (0.002)	-0.001 (0.002)
Acceptable FCS	18.4%	-	
Borderline FCS	53.1%	-	
Poor FCS	28.5%	-	
Food insecurity classification (FIES)			
Food secure	2.6%	-	
Mildly food insecure	0.9%	-	
Moderately food insecure	9.1%		
Severely food insecure	87.4%		
MDD-W	3.30 (1.72)	-	
Adequate dietary diversity	18.8%	-	
Observations	772	772	772
Entropy balancing	-	No	Yes
R^2	-	0.253	0.070

Notes. Column (1) displays average values of variables. Continuous variables are displayed by means with standard deviations in parentheses. Categorical variables are shown in percentages. Columns (2)-(3) report the coefficients from OLS regressions on treatment assignment with standard errors in parentheses. HH=household, HHH=household head, 12M = reference period of 12 months. Statistical significance is denoted by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Column (2) in Table 3 identifies differences between the control and the treatment group with linear regression on the treatment dummy using Baseline covariates, the mediator variables and our main outcome, FCS. Overall, the regressions emphasize that many variables are comparable between the two groups at Baseline and that there is no consistent evidence of one group being more vulnerable than the other. However, we observe some significant differences. The heads of treatment households are on average slightly older ($p < 0.05$) while the household heads in the control group are more likely to be polygamously married ($p < 0.01$). Treatment households have marginally fewer household members with disabilities or chronic diseases ($p < 0.1$) while they are 29% points more likely to have stated farming as their main occupation ($p < 0.01$). Since the interest in farming is a key targeting criterion, this group imbalance is reasonable. Treatment households are more likely to have experienced floods or conflict situations in the 12 months before Baseline. Five of the seven mediator variables are balanced between the two groups, while nutritional knowledge is significantly lower in the treatment group at Baseline ($p < 0.01$) as well as home garden diversity ($p < 0.1$). The FCS is also slightly lower in the treatment group at Baseline compared to the control group ($p < 0.01$).

Table 3, Column (3) displays the predictive power of all key variables on treatment assignment with the entropy-weighted approach. Most importantly, the balancing approach reduces the joint predictive power of the Baseline variables remarkably, as indicated by the drop in R^2 from 0.25 to 0.07 when applying the weights. After entropy weighting, only a few variables indicate significant predictive power on treatment assignment and none of the differences is highly significant at the 1%-level. This suggests that the weighting procedure effectively improves covariate balance, strengthening the credibility of the causal interpretation.

5.2 The Impacts of HGIs on Food Security

Table 4 displays the DiD regression analysis on FCS for both short-term and medium-term effects in Columns (1) and (2) and on the alternative food security outcomes in

Columns (3)-(6). The DiD estimators reveal that the HGI did not impact the outcomes significantly in the short term. However, two years after the first implementation of the HGI, we observe significant positive impacts across all measured food security indicators. Specifically, FCS improved on average by 4.4 points (90% CI [2.8, 6.1], $p < 0.01$) within two years due to the intervention. This translates into an improvement of 33% with respect to the intercept. The HGI reduced the share of households with poor food consumption by 23% (-18.1pp, 90% CI [-26.7, -9.5], $p < 0.01$, not displayed). Particularly, the consumption of pulses, fruits, meat and eggs, sugar and oil increased among the treatment group (not displayed). Generally, the FCS increased by 21% (2.7 points, 90% CI [1.4, 4], $p < 0.01$) throughout the study period for the whole sample.

Table 4: The Impacts of Home Garden Interventions of Food Security

	(1) FCS	(2) FCS	(3) Severe food insecure	(4) Severe food insecure	(5) MDD-W	(6) MDD-W
Intercept	13.06 ***	13.28 ***	1.015 ***	0.944 ***	3.59 ***	3.60 ***
	(2.32)	(2.57)	(0.085)	(0.102)	(0.43)	(0.44)
Treatment	0.55	0.05	-0.038 *	0.002	-0.06	-0.05
	(0.65)	(0.71)	(0.021)	(0.025)	(0.10)	(0.10)
Follow-up 1	1.19 *	-	-0.028	-	0.12	-
	(0.72)		(0.023)		(0.11)	
Follow-up 2	-	2.73 ***	-	0.120 ***	-	0.61 ***
		(0.79)		(0.028)		(0.11)
ATT	-1.20	4.42 ***	0.004	-0.174 ***	0.25 *	0.43 ***
	(0.89)	(1.00)	(0.029)	(0.035)	(0.14)	(0.14)
Observations	1544	1544	1544	1544	1544	1544
Term scope	Short	Medium	Short	Medium	Short	Medium
Controls	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.316	0.269	0.475	0.252	0.179	0.207

Notes. Difference-in-differences estimations with interviewer-fixed effects. The control group is weighted using entropy balancing based on the following Baseline values: whether the household head's primary income source was farming, whether they were polygamously married, whether the household was affected by floods in the past 12 months, whether the household was affected by theft in the past 12 months, the nutritional knowledge score and the respective outcome variable. Control variables include gender, age, literacy and marital status of the household head, the number of household members, the share of household members with disabilities and if they received any support from other organizations in the past twelve months, if the household experienced a severe illness or an accident of one of the main income earners, conflict or violence and theft in the past 12 months. Statistical significance is denoted by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

The alternative food security outcomes support our findings. The incidence of severe food insecurity based on FIES decreased by 18% (-17.4pp, 90% CI [-24.3, -10.5], $p < 0.01$) due to the treatment, while the overall incidence increased by 13% (12.0pp, 90% CI [6.5, 17.4], $p < 0.01$) with respect to the intercept throughout the study period. The HGI led to a 12% increase in MDD-W in the medium term (0.43 points, 90% CI [0.16, 0.71], $p < 0.01$). Treatment households reported consuming 0.4 more food groups per day compared to control households. Across the study period, the number of food groups consumed increased by 17% (0.61pp, 90% CI [0.39, 0.83], $p < 0.01$) for the whole population as indicated by MDD-W. Notably, the mean values of the three food security indicators remain alarming for the treatment group at Follow-up 2 with a mean FCS of 32 points, which is an average borderline classification and 17% of the treatment households classified to have a poor food consumption (not displayed). Moreover, 73% remain severely food insecure according to the classification based on FIES, where 54% of the respondents spent at least one day without eating in the past year (not displayed).

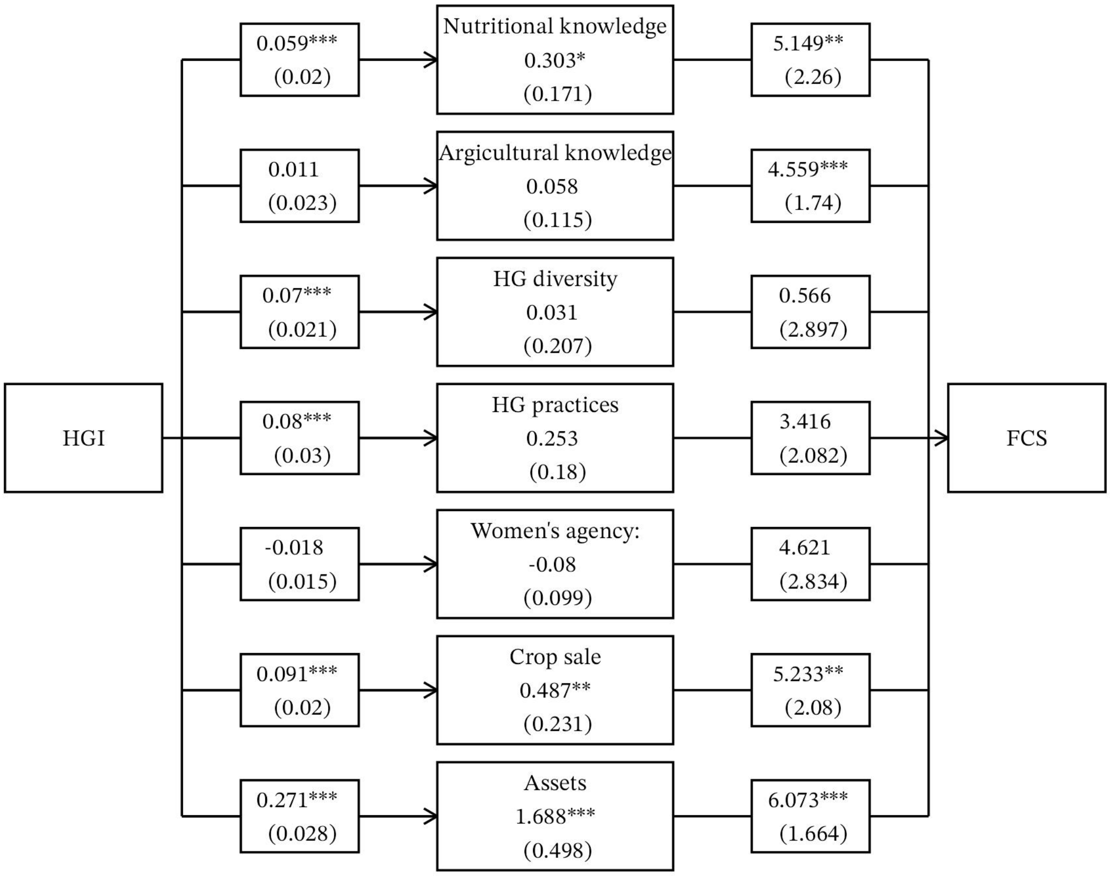
The results remain robust across different model specifications, including the same DiD model using the unbalanced panel, a two-way fixed-effects model, a DiD model pooling both follow-ups, a DiD model incorporating full propensity score weighting with the same weighting variables as used in our entropy balancing approach, as shown in Table A2 in the Appendix. Furthermore, the findings remain consistent for the DiD model without imputing missing variables for FCS in the medium-term, as shown in Table A3 in the Appendix. If we use a gradual indicator for food insecurity based on FIES instead of the binary variable, we find significant decreases in food insecurity in the short run, in addition to the significant medium-run effect observed in the main analysis. Furthermore, Table A4 in the Appendix presents the sensitivity of our findings to alternative entropy balancing approaches. We test more relaxed weighting specifications, balancing solely on FCS at Baseline in Columns (1)–(2) and balancing only on previously selected covariates while excluding FCS in Columns (3)–(4). Finally, we assess our results under a stricter balancing approach, ensuring that no relevant Baseline covariate exhibits a statistically significant difference between the treatment and control group. These robustness checks consistently confirm the significance of the medium-term ATTs at the 1%-level, as reported in our main analysis. The estimated impact sizes range between 3.9 and 7.5 points of increase in FCS attributed to the HGI, suggesting that the ATT provided in the main analysis is relatively conservative, reinforcing the reliability of our interpretations. Additionally, the robustness tests largely confirm the absence of a statistically significant ATT of the HGI on food security in the short term.

5.3 Mechanisms of HGIs Impacts on Food Security

In the next step, we examine the mechanisms through which the treatment may have influenced food security. Figure 2 presents the ATTs for the mediator variables in the left-side boxes, the associations between mediators and outcomes in the right-side boxes and the indirect ATTs inside each mediator box. Since the treatment effects only showed after two years, we focus in this analysis only on data from Baseline and Follow-up 2.

The results indicate that the HGI significantly enhanced several mediator variables. Specifically, the HGI increased knowledge as reflected in a 5.9pp improvement in nutritional knowledge (90% CI [2.6, 9.2], $p < 0.01$). Interestingly, we do not observe a significant impact of the HGI on agricultural knowledge, despite expectations that the training modules would enhance this dimension. Moreover, the intervention induced behavioral change, as shown by a 7pp increase in home garden diversity (90% CI [3.6, 10.4], $p < 0.01$) and an 8pp increase in the adoption of good home garden practices (90% CI [3.1, 12.9], $p < 0.01$). Moreover, the HGI enhanced the commercialization of garden crops by 9pp (90% CI [5.8, 12.4], $p < 0.01$) and increased the home garden asset stock by 27pp (90% CI [22.5, 31.7], $p < 0.01$). We do not find significant impacts on women's agency.

Figure 2: Mechanisms of Increases in Food Security



Notes. Mediation analysis using difference-in-differences estimations with interviewer-fixed effects. Indirect effects are bootstrapped with 1,000 iterations. Left boxes display ATTs on the respective mediator, right boxes display associations between FCS and respective mediator, and center boxes display the indirect ATTs through the respective mediators. The control group is weighted using entropy balancing based on the following Baseline values: whether the household head's primary income source was farming, whether they were polygamously married, whether the household was affected by floods in the past 12 months, whether the household was affected by theft in the past 12 months, the nutritional knowledge score and the outcome variable. Control variables include gender, age, literacy and marital status of the household head, the number of household members, the share of household members with disabilities and if they received any support from other organizations in the past twelve months, if the household experienced a severe illness or an accident of one of the main income earners, conflict or violence and theft in the past 12 months. Statistical significance is denoted by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

In turn, better nutritional and agricultural knowledge ($p < 0.05$ and $p < 0.01$, respectively), more crop commercialization ($p < 0.05$) and a higher asset stock ($p < 0.01$) are associated with better food security outcomes. The mediation analysis reveals three key mechanisms of the impacts of HGIs on food security. Specifically, improvements in FCS are associated with increased nutritional knowledge ($p < 0.1$), with an increase in crop commercialization ($p < 0.05$) and, most remarkably, with an increase in asset stocks ($p < 0.01$), suggesting that the impact of HGIs on FCS is strongly mediated through knowledge, commercialization and assets and less through behavioral change or women's agency. In total, the three significant mediators account for 56% of the ATT, indicating a strong mediation that explains a substantial portion of the variation in impacts. When accounting for the seven mediators, the direct treatment effect on FCS becomes insignificant (not displayed).

Turning to the alternative measures for food security in Figures A2 and A3, the food insecurity dummy based on FIES does not indicate any significant association between the mediators and the outcome, nor any indirect effects. For MDD-W, we observe more substantial indirect effects through asset ownership on MDD-W ($p < 0.01$). Our separate mediation analyses in Table A5 in the Appendix support the main findings, indicating more substantial indirect effects of nutritional knowledge, crop commercialization and asset endowment (all $p < 0.01$) compared to the estimates in the multiple mediation specification. Furthermore, practice-related mediators exhibit significant indirect effects in these separate models, which are absorbed when included alongside other mediators in the main specification. All mediators exhibit a strong and positive association with FCS ($p < 0.05$).

6 Discussion

6.1 The Impacts of HGIs on Food Security

Our findings on the positive impact of HGIs on food security in a polycrisis setting are in line with the mainstream of evidence on horticultural interventions from more stable settings (compare, Baliki et al., 2019, 2022; Blakstad et al., 2021, 2022; Depenbusch et al., 2022) as well as from related interventions implemented in crisis-affected contexts (compare, Al Daccache et al., 2024). However, our findings contrast with those of Depenbusch et al. (2021), who examined HGIs in more stable neighboring countries of our case study in South Sudan, namely Kenya, Tanzania and Uganda. A potential explanation for this divergence may lie in the characteristics of the target population. While their study focused on resident households that were already engaged in vegetable cultivation, owning on average more than a hectare of farmland and household assets worth several hundred USD, we study an intervention targeting displaced herder communities with extremely low economic capacity. The severe economic constraints may have motivated our treatment population to make the most of the intervention, seizing the opportunity to rebuild their livelihoods through home gardening. Similarly, Leuveld et al. (2018) find no significant impacts of agricultural extension services combined with input subsidies on food security in a neighboring crisis context in DRC. In contrast to our study, subsidies may represent a key difference. In our case, the free provision of support, along with the additional provision of tools and a cash transfer, may have played an important role in encouraging uptake and engagement among beneficiary households and in enhancing their productivity. These comparisons underscore the importance of intervention design. The comprehensive and unconditional support package appears to be essential for motivating households to engage in horticulture and equip them with the capacity to translate horticultural productivity gains into substantial improvements in food security.

Despite these improvements, food insecurity persists among HGI beneficiaries. The year-round FIES-based indicator reveals that 53% of HGI beneficiaries reported going at least one day without food during the final year of the study. This finding suggests that seasonal food insecurity remains a challenge, highlighting the potential value of complementing HGIs with food storage and processing strategies to buffer seasonal bottlenecks and extend the benefits of production beyond the harvest period.

The robust positive impact of HGIs on food security after the second round of support underscores their potential to enhance resilience against food insecurity. This is particularly relevant in (poly-)crisis contexts where access to markets is unreliable and food systems are disrupted due to conflict, displacement, climatic events or other shocks. The scale of the observed effects after two years reflects the repeated support provided to households, suggesting that continuity and reinforcement of such interventions can be critical for meaningful improvements. In contrast, the absence of significant effects after the first year of support may be attributed to the extreme conditions of the year 2020, which was marked by severe flooding and widespread market and mobility restrictions due to the COVID-19 pandemic. These findings suggest that the effectiveness of HGIs may be diminished under severe polycrises.

6.2 Mechanisms of HGIs Impacts on Food Security

Although our study design does not allow us to attribute impacts to specific treatment components causally, the mediation analysis points to mechanisms through which the HGI contributed to improved food security outcomes. First, improvements in nutritional knowledge played a key role in shaping dietary outcomes, likely reflecting the influence of the training component. While not exclusively tied to gardening activities, improvements in nutritional knowledge appear to have extended to broader household decision-making, potentially guiding healthier food choices. This aligns with existing literature on nutrition-sensitive training interventions (Baliki et al., 2019; Hirvonen & Headey, 2018; Karanja et al., 2022; Kumar et al., 2024; Schreinemachers et al., 2016).

Second, increased asset endowment resulted as an important mechanism for the impact of HGIs on food security. The increased asset endowment may result from both the direct provision of cultivation tools and from productive investments enabled by income from surplus production or by the cash transfer. Owning (more) assets most likely improves productivity (as confirmed by related agricultural literature (Asfaw et al., 2011)), which results in better access to food directly or in more household income that may be spent on food. This finding underscores the significance of asset accumulation as a means to (re-)build livelihoods and resilience in (poly-)crisis settings. Identifying asset accumulation as a key pathway expands upon the mechanisms discussed in the influential review by

Ruel et al. (2018) on nutrition-sensitive agriculture.

Third, commercialization is likely to be driven by higher garden productivity, enabling households to generate a marketable surplus. The farmer networks may have further contributed to social capital, facilitating the exchange of market knowledge and access to buyers within producer groups. Additionally, increased consumption of food items not typically produced in home gardens indicates enhanced participation in local markets. These effects suggest that the intervention contributed not only to subsistence food security but also to broader economic recovery.

In contrast to Ruel et al. (2018), we do not find a significant mediating role of women's agency in the relationship between the HGI and food security. This may be due to differences in how agency is conceptualized and measured. In our survey, respondents rated agreement with statements that place sole decision-making responsibility on one gender, for example, "The woman should make decisions on her own regarding children's health." A high score may therefore capture individual responsibility in decision-making rather than joint decision-making, for which one could argue is the best case. In contexts where such responsibility falls disproportionately on women, this could reflect burden rather than empowerment, potentially limiting the interpretability of our measure.

While including a cash transfer distinguishes our study from many existing HGI evaluations, our results do not indicate that cash alone explains the observed effects. The transfer was provided months before Follow-up 1, when the substantial treatment effects had not yet unfolded. Moreover, substantial impact on key mediator variables suggests that the intervention led to meaningful improvements in home gardening itself, beyond short-term consumption gains. It remains plausible that the cash was strategically invested in garden inputs or assets, enhancing its impact over time.

6.3 Limitations

We acknowledge several limitations of our study. First, while we aimed to disentangle the pathways through which the home garden intervention affected food security with mediation, we were unable to establish causal relationships between mediators and outcomes. While still informative, the observed associations should therefore be interpreted as correlational rather than causal.

Second, our study relies on proxy indicators to capture complex constructs such as knowledge, practices and economic engagement. While using proxies offers practical advantages in resource-constrained and low-literacy settings, it inevitably introduces limitations in measurement precision. For instance, we were unable to collect reliable data on income from surplus production due to challenges in recall and reporting accuracy among respondents. In this least developed and highly fragile context, characterized by low literacy rates, attempts to gather more granular data on exact production and economic activity proved unreliable. Although we acknowledge the possibility of measurement error, we have chosen commonly applied proxy measures to approximate the underlying dynamics of interest and offer valuable insights, given the constraints of the study setting.

Third, we rely on an intention-to-treat design because we cannot confirm whether all households in the treatment group actually received each intervention component. This could introduce additional measurement error into our treatment estimates. Acknowledging the difficulty in assessing such data, this also highlights the necessity of investing in high-quality monitoring and evaluation data from implementing organizations.

7 Contribution and Policy Implications

Through a rigorous quasi-experimental design and following up on 772 displaced herder households over two years in fragile post-war South Sudan during severe floods and the COVID-19 pandemic, we provide causal evidence that HGIs have large and significant positive impacts on food security in a polycrisis setting. Identifying nutritional knowledge, crop commercialization, and, most remarkably, asset ownership as key mediators provides mechanism-based evidence on *how* programming enhances food security, bolstering the external validity of our findings for comparable crisis settings. With our study, we are the first to rigorously assess the impact of HGIs on food security in the context of a (poly-)crisis and to systematically and empirically examine the pathways through which these interventions impact food security at the micro-level.

The findings of our study offer three important policy implications around HGI programming in crisis-affected settings. First, our findings highlight that HGIs with a comprehensive design are impactful in crisis settings. The strong and positive impact on food security confirms that HGIs can serve as an effective strategy to improve access to and availability of food where markets and livelihoods are disrupted. Given their relatively low cost, HGIs are a cost-effective and sustainable choice in broader food security and resilience policies in fragile contexts.

Second, we demonstrate that different components of HGIs play a complementary role in realizing the full potential of HGIs. These elements contribute not only to immediate improvements in food consumption but also to higher capacity and economic returns. Programs should therefore be designed in an integrated manner, ensuring that these support components are aligned with the needs and capacities of the target population.

Third, our study demonstrates that rigorous research is possible even in crisis settings if carefully designed. Key factors of success include the use of context-appropriate indicators, proxy-based measurement strategies, thorough enumerator training and close tracking of local developments. However, the limitations of this study also underscore the pressing need for more robust local and humanitarian data systems. Enhanced data infrastructure would support more precise evidence generation and programming.

Declaration of generative AI and AI-assisted technologies in the writing process:

During the preparation of this work, the authors used ChatGPT to support language refinement, improve phrasing and assist with coding tasks. After using AI tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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A Appendix

A.1 Attrition

Table A1 shows predictors of participating in all three interviews using Baseline data, including our whole set of Baseline covariates, mediators and the main food security outcome. The regression reveals several key drivers influencing participation. Households receiving treatment are 16pp more likely to participate in all three rounds of data collection ($p < 0.01$). This higher participation rate may be attributed to the fact that treatment households are regularly visited by the implementing organization, which facilitates tracking the households. Households with older heads and those with heads whose main livelihood is farming are also more likely to participate in all three interviews ($p < 0.05$). Farming households, in particular, might show greater engagement due to their interest in the home garden intervention offered. Households with a higher proportion of members with disabilities or chronic diseases are less likely to participate in all three rounds ($p < 0.05$). This might reflect that the garden interventions are not suitable for these households, which may have different needs. Households with a higher garden diversity score or asset score at Baseline are more likely to drop out ($p < 0.05$). This suggests that households with more resources or established gardens may not perceive the same level of benefit from the intervention, leading to reduced interest in participation. Households with a lower FCS at Baseline are more likely to drop out ($p < 0.05$). This may indicate that particularly vulnerable households are more likely to be displaced or refuse the interview. Overall, the attrition analysis reveals various factors that influence survey participation, suggesting that interest in HGIs may be a key driver of participation.

Differential attrition can introduce selection bias and compromise both representativeness and statistical power. In our case, statistical power remains robust despite attrition. Post-hoc power analysis for panel data indicates that a minimum of 235 observations per group would be sufficient to detect a minimum detectable effect of 0.2 with 80% power at a 10% significance level, which our sample exceeds. A strategy to account for selection bias and compromised representativeness is inverse probability weighting, where household profiles that are more likely to attrit are given more weight (Robins et al., 1994). We do not apply this strategy because we apply weighting approaches to improve the balance between the control and treatment group. To avoid overfitting, we deprioritize additional weighting for attrition. As a result, we caution against interpreting the findings as fully representative of the broader beneficiary population.

Table A1: Drivers of Attrition

	Overall (Mean (SD)/Share)	Remained (Coef (SE))
Treatment	49.9%	0.155 *** (0.030)
Demographic and socioeconomic characteristics		
Female HHH	49.0%	-0.002 (0.031)
Age of HHH	44.6 (13.9)	0.002 ** (0.001)
HHH is literate (at least read)	39.7%	0.004 (0.030)
HHH is married (monogamously)	58.1%	-
HHH is married (polygamously)	22.5%	0.030 (0.033)
HHH is not married	19.5%	-0.001 (0.037)
HH size	8.53 (4.37)	-0.004 (0.003)
Share of HH members with disability	6.4%	-0.301 ** (0.132)
HHH is a farmer (main occupation)	85.0%	0.097 ** (0.040)
Support from another organization (12M)	19.7%	0.043 (0.034)
Water access	62.5%	-0.017 (0.029)
Experience of adverse shocks (12M)		
Floods	55.8%	-0.010 (0.028)
Illness/accident of an income earner	47.5%	-0.008 (0.029)
Conflict/violence	28.4%	-0.003 (0.032)
Theft	68.9%	-0.030 (0.030)
Mediators		
Nutritional knowledge score	0.558 (0.134)	0.080 (0.100)
Agricultural knowledge score	0.487 (0.198)	0.032 (0.071)
Home garden diversity score	0.136 (0.182)	-0.209 ** (0.096)
Home garden practice score	0.137 (0.222)	0.075 (0.077)
Women's agency score	0.507 (0.126)	-0.043 (0.114)
Crop sale score	0.066 (0.132)	-0.067 (0.104)
Asset score	0.245 (0.200)	-0.152 ** (0.070)
Food security		
FCS	28.1 (11.0)	-0.003 ** (0.001)
Observations	1002	1002
R^2 / Adjusted R^2	0.092 / 0.071	

Notes. Column (1) displays average values of variables. Continuous variables are displayed by means with standard deviations in parentheses. Categorical variables are shown in percentages. Column (2) reports the coefficients from OLS regressions on remaining in the study with standard errors in parentheses. HH=household, HHH=household head, 12M = reference period of 12 months. Statistical significance is denoted by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

A.2 Computation of Variables

Food Security Outcomes

Food Insecurity Classification: The classification is based on the eight items of the FIES (Cafiero et al., 2018). The data were collected in the questionnaire using the following questions: *During the past 12 months, was there a time when, because of lack of money or other resources:*

1. *you were worried you would not have enough food to eat?*
2. *you were unable to eat healthy and nutritious food?*
3. *you ate only a few kinds of foods?*
4. *you had to skip a meal?*
5. *you ate less than you thought you should?*
6. *your household ran out of food?*
7. *you were hungry but did not eat?*
8. *you went a whole day without eating?*

Households are classified into four categories based on their responses following Balana et al. (2023):

- Food secure: Respondents did not answer "yes" to any of the eight questions.
- Mildly food insecure: Respondents answered "yes" to at least one of questions 1-3, but not to questions 4-8.
- Moderately food insecure: Respondents answered "yes" to at least one of questions 4 or 5, but not to questions 6-8.
- Severely food insecure: Respondents answered "yes" to at least one of questions 6-8.

MDD-W is computed by summing all food groups consumed by the respondent in the past 24 hours, unweighted, resulting in a score ranging from 0 to 10. The data were collected in the questionnaire using the following questions:

Please let us know if you, personally, have consumed the following food items yesterday

- *Any ugali or posho, bread, biscuits or any other foods made from millet, sorghum, maize, rice, wheat, potatoes, yams, cassava, roots or tubers?*
- *Any foods made from beans, peas, lentils or cowpeas?*
- *Any foods made groundnuts, peanut or certain seeds?*
- *Any milk or other milk products (not including butter or cream)?*
- *Any organ meat and blood-based foods products, other meat, poultry, fresh or dried fish?*
- *Any eggs?*
- *Any dark green leafy vegetables?*
- *Any other vitamin A-rich fruits and vegetable?*
- *Other vegetables?*
- *Other fruits?*

Mediators

The **nutritional knowledge score** is computed by summing the correct answers to twelve yes-no statements resulting in a score ranging from 0 to 12. The data were collected in the questionnaire using the following statements with correct answers in parenthesis:

I will read out a number of statements about NUTRITION. For each statement, can you please tell me if you think it is correct or incorrect, in your opinion?

- *Potatoes are an important source of vitamins and minerals. [TRUE]*
- *It is important for young children to eat food rich in proteins such as meat, pulses and dairy. [TRUE]*
- *Cooking vegetables for a long time makes them more nutritious. [FALSE]*
- *Carrots and sweet potatoes are both sources of Vitamin A. [TRUE]*
- *Not eating enough Vitamin A can result in eye disease. [TRUE]*

- *Pregnant women should avoid foods high in iron such as leafy vegetables. [FALSE]*
- *Amaranth is a very healthy vegetable. [TRUE]*
- *For a healthy diet, it is important to eat a diverse range of foods. [TRUE]*
- *Eggplants are generally more nutritious than leafy vegetables. [FALSE]*
- *For children, eating meat is more important than eating vegetables. [FALSE]*
- *You should first cut leafy vegetables and then wash them. [FALSE]*
- *Cutting vegetables in medium-sized pieces is better than tiny pieces. [TRUE]*

The **agricultural knowledge score** is computed by summing the correct answers to nine yes-no statements resulting in a score ranging from 0 to 9. The data were collected in the questionnaire using the following statements with correct answers in parentheses:

I will read out a number of statements about agriculture. For each statement, can you please tell me if you think it is correct or incorrect, in your opinion?

- *Maize seeds are planted at 10 cm depth. [FALSE]*
- *Maize fields should be weeded three times before harvesting. [TRUE]*
- *After processing, the remaining groundnut shells do not have any additional use. [FALSE]*
- *Manure can be used as an organic fertilizer. [TRUE]*
- *You spread the organic fertilizer in a garden by burying it between the lines. [TRUE]*
- *Seedbeds do not help in saving seeds. [FALSE]*
- *Goats are pregnant for 8 months. [FALSE]*
- *Goats can produce milk for up to 12 months. [FALSE]*
- *Groundnut shells are an alternative source of fodder that improves the health of goats. [TRUE]*

The **home garden diversity score** is computed by summing the number of cultivated vegetables in the last agricultural season from a total of 18 vegetables, resulting in a score ranging from 0 to 18. All vegetables are common in the study area. The data were collected in the questionnaire asking for the following vegetables: amaranthus, beans, cabbage, cowpea, cowpealeaf, carrots, cucumber, eggplant, greenrocket, karkade, kudra, okra, onion, pepper, pumpkin, parsley, sukumawiki and tomato.

Adaptation of good horticultural practices is computed by summing the number of adapted good horticultural practices from a total of nine practices, resulting in a score ranging from 0 to 9. The data were collected in the questionnaire asking for the following practices:

Which of the following practices did you apply in your home garden in the past 12 months?

- *Raised planting beds or planting on ridges*
- *Strong fences to keep out animals*
- *Animal manure*
- *Inorganic fertilizer*
- *Composting*
- *Mulches*
- *Bio-pesticides*
- *Chemical pesticides*
- *Nursery beds to raise seedlings*
- *Purchased mini seed packs*
- *Seed saved from previous harvest*

Women's agency is computed summing responses to eight statements assessing the extent of women's decision-making power, resulting in a score ranging from 0 to 32. TResponses are weighted as follows: strongly agree [4], agree [3], neutral [2], disagree [1] and strongly disagree [0]. We adapted this module from (Baliki et al., 2019). Some statements are reverse-coded, as indicated in parentheses. The data were collected in the questionnaire using the following statements:

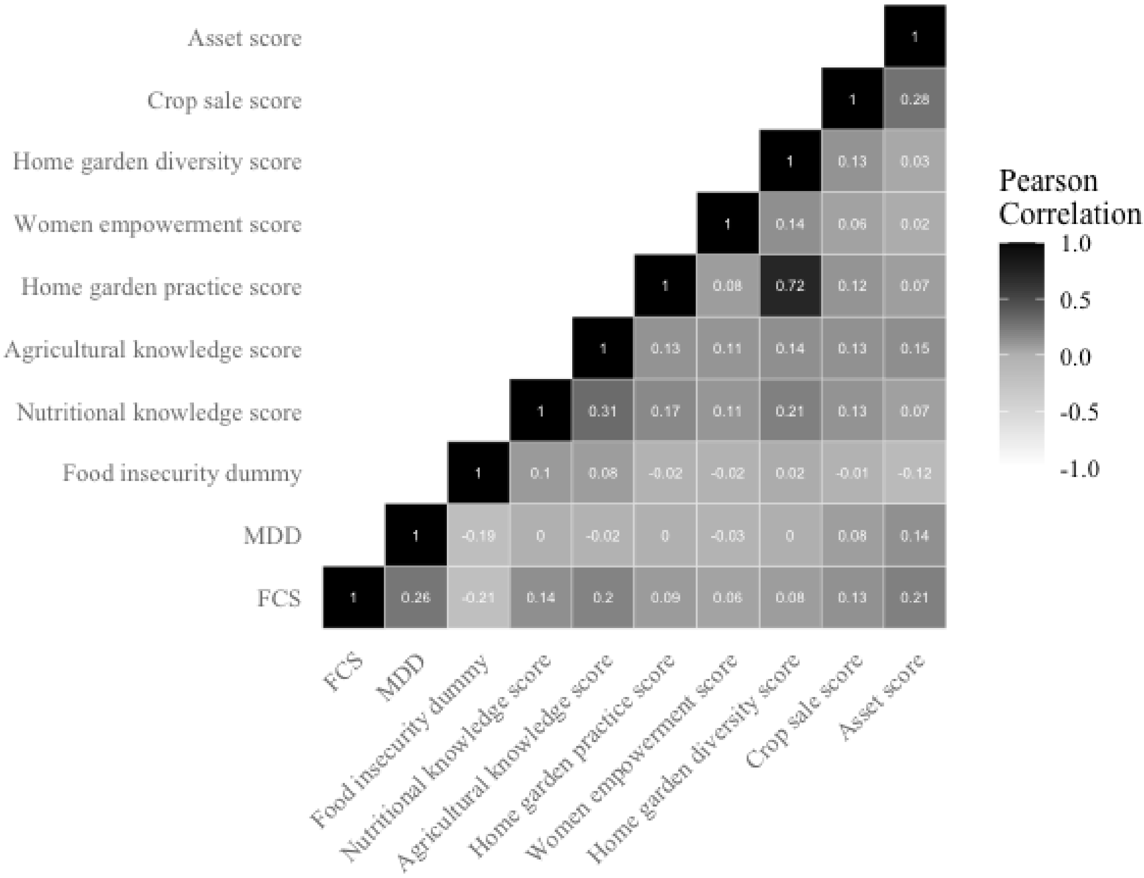
Now, I am going to say a number of statements. Let us know if you agree or disagree with these statements. You have 5 choices: "Strongly Agree", "Agree", "Neutral", "Disagree" and "Strongly Disagree".

- *The woman should make decisions on her own regarding children's health.*
- *The man should make decisions by himself on how to spend the household money. [REVERSE]*
- *The woman should tell the man what food to buy and the man should do this.*
- *The woman does not have to consult the man on what to cook for dinner.*
- *The woman should always ask the man for permission to go outside the compound. [REVERSE]*
- *The man has the right to angrily scold his wife if she does something wrong. [REVERSE]*
- *The man should have the final word when making joint decisions in the household. [REVERSE]*
- *The woman should always do what the man thinks is best. [REVERSE]*

Garden commercialization is computed by summing the number of crops of which the household sold at least 50% of the harvest in the past season. All 18 home garden vegetables were considered. The score ranges from 0 to 6, which is the maximum of commercialized crops.

Asset accumulation is calculated as the total number of distinct cultivation assets owned by the household from a total of seven assets, resulting in a score ranging from 0 to 7. The assets considered include: hoe, rake, axe, wheelbarrow, watering can or jerry can, water pump and panga machete.

Figure A1: Correlation between Outcomes and Mediators



Notes. The graphs displays Pearson's correlations between outcomes and mediators with dark shaded cells reflecting positive correlation and white shaded cells negative correlations.

A.3 Robustness

Table A2: Robustness Tests: Different Model Specifications

	(1) FCS	(2) FCS	(3) FCS	(4) FCS	(5) FCS	(6) FCS	(7) FCS
ATT	-0.74	5.00 ***	0.60	6.10 ***	1.63 *	1.86 **	7.48 ***
	(0.84)	(0.93)	(0.93)	(1.14)	(0.85)	(0.92)	(1.04)
Observations	1861	1866	1544	1544	2316	1544	1544
Specification	Unbalanced panel		Two-way fixed-effects		Pooled regression	Propensity score weighting	
Term scope	Short	Medium	Short	Medium	Pooled	Short	Medium
Controls set	Full	Full	Time-varying	Time-varying	Full	Full	Full
R^2	0.322	0.257	0.064	0.160	0.264	0.359	0.299

Notes. The control group is weighted using entropy balancing for Columns (1) - (5) and using propensity score weighting in Columns (6) and (7). Weighting is based on the following Baseline values: whether the household head's primary income source was farming, whether they were polygamously married, whether the household was affected by floods in the past 12 months, whether the household was affected by theft in the past 12 months, the nutritional knowledge score and FCS. Control variables include gender, age, literacy and marital status of the household head, the number of household members, the share of household members with disabilities and if they received any support from other organizations in the past twelve months (Time-varying), if the household experienced a severe illness (Time-varying) or an accident of one of the main income earners (Time-varying), conflict or violence (Time-varying) and theft (Time-varying) in the past 12 months and the interview (Time-varying). Statistical significance is denoted by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A3: Robustness Tests: Different Outcome Variable Computations

	(1) FCS	(2) Food insecurity (gradual)	(3) Food insecurity (gradual)
ATT	3.91 ***	-0.21 ***	-0.52***
	(0.99)	(0.06)	(0.08)
Observations	1529	1544	1544
Specification	No Imputation	Gradual (1-4) Indicator	Gradual (1-4) Indicator
Term scope	Medium	Short	Medium
Controls set	Full	Full	Full
R^2	0.269	0.320	0.212

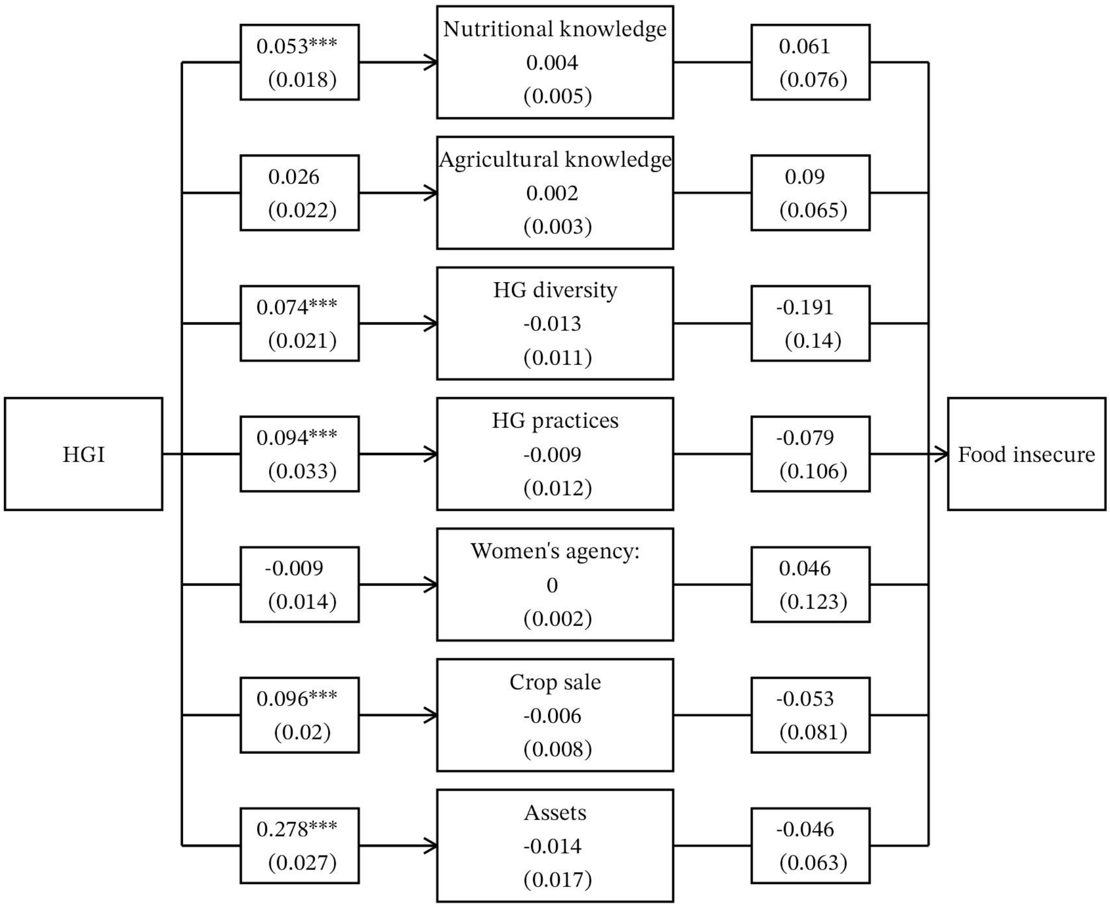
Notes. The control group is weighted using entropy balancing. Weighting is based on the following Baseline values: whether the household head's primary income source was farming, whether they were polygamously married, whether the household was affected by floods in the past 12 months, whether the household was affected by theft in the past 12 months, the nutritional knowledge score and FCS. Control variables include gender, age, literacy and marital status of the household head, the number of household members, the share of household members with disabilities and if they received any support from other organizations in the past twelve months, if the household experienced a severe illness or an accident of one of the main income earners, conflict or violence and theft in the past 12 months. Statistical significance is denoted by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A4: Robustness Tests: Different Entropy Balancing Approaches

	(1) FCS	(2) FCS	(3) FCS	(4) FCS	(5) FCS	(6) FCS
ATT	-0.70	3.98 ***	0.66	6.31 ***	-0.73	4.11 ***
	(0.90)	(1.05)	(0.94)	(1.03)	(0.89)	(1.01)
Observations	1544	1544	1544	1544	1544	1544
Term scope	Short	Medium	Short	Medium	Short	Medium
Entropy balancing	Method 1	Method 1	Method 2	Method 2	Method 3	Method 3
Controls	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.298	0.232	0.318	0.265	0.309	0.257

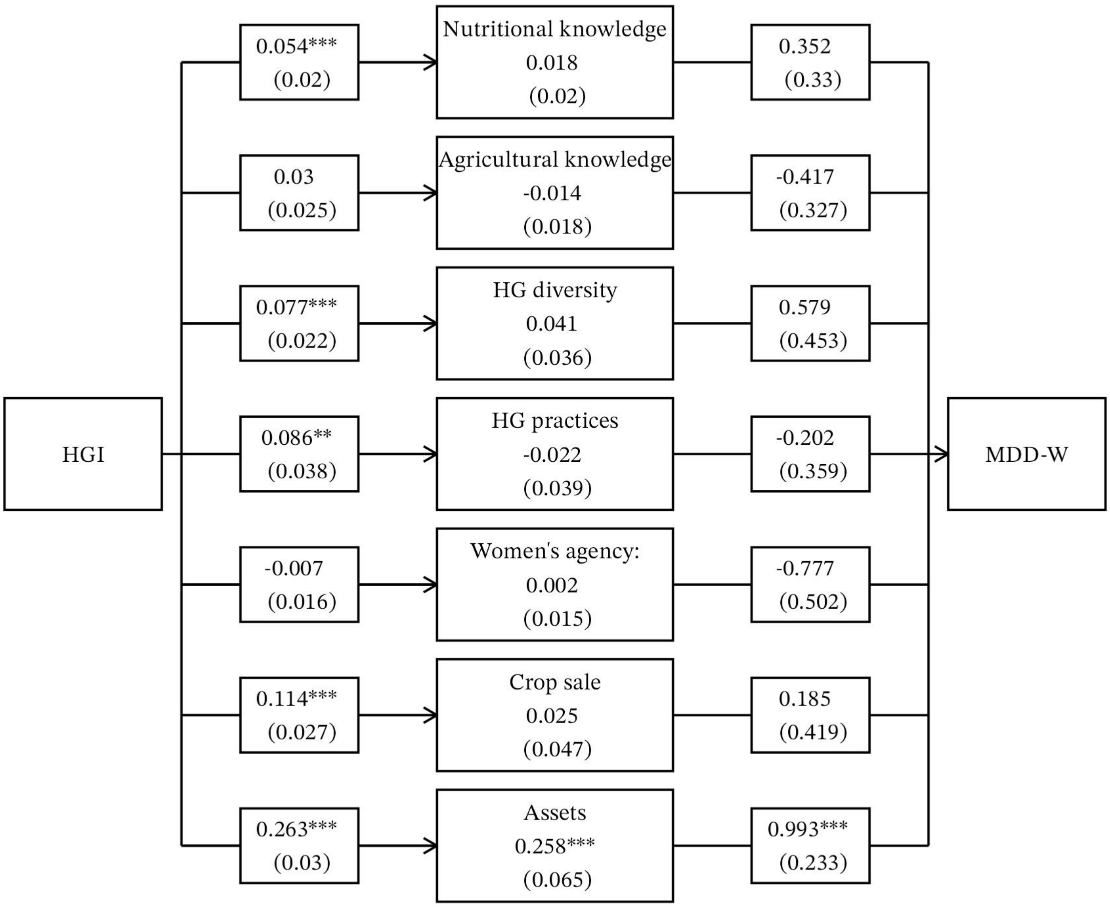
Notes. Difference-in-differences estimations with interviewer-fixed effects. The control group is weighted using entropy balancing. Method 1 only includes FCS. Method 2 includes whether the household head's primary income source was farming, whether they were polygamously married, whether the household was affected by floods in the past 12 months, whether the household was affected by theft in the past 12 months and the nutritional knowledge score. Method 3 includes whether the household head's primary income source was farming, whether they were polygamously married, whether the household was affected by floods in the past 12 months, whether the household was affected by theft in the past 12 months and the nutritional knowledge, FCS, the gender and age of the household head, if the household had access to water on their farmland, whether the household was affected by illness or an accident of an income earner in the past 12 months, whether the household was affected by conflict or violence in the past 12 months, the home garden diversity score and the Women's agency score. Control variables include gender, age, literacy and marital status of the household head, the number of household members, the share of household members with disabilities and if they received any support from other organizations in the past twelve months, if the household experienced a severe illness or an accident of one of the main income earners,of conflict or violence and theft in the past 12 months. Statistical significance is denoted by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Figure A2: Mechanisms of Increases in Severe Food Insecurity Classification



Notes. Mediation analysis using difference-in-differences estimations with interviewer-fixed effects. Indirect effects are bootstrapped with 1,000 iterations. Left boxes display ATTs on respective mediator, right boxes display associations between Severe Food Insecurity Classification and respective mediator, center boxed display the indirect ATTs through the respective mediators. The control group is weighted using entropy balancing based on the following Baseline values: whether the household head's primary income source was farming, whether they were polygamously married, whether the household was affected by floods in the past 12 months, whether the household was affected by theft in the past 12 months, the nutritional knowledge score and the outcome variable. Control variables include gender, age, literacy and marital status of the household head, the number of household members, the share of household members with disabilities and if they received any support from other organizations in the past twelve months, if the household experienced a severe illness or an accident of one of the main income earners, conflict or violence and theft in the past 12 months. Statistical significance is denoted by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Figure A3: Mechanisms of Increases in Dietary Diversity



Notes. Mediation analysis using difference-in-differences estimations with interviewer-fixed effects. Indirect effects are bootstrapped with 1,000 iterations. Left boxes display ATTs on respective mediator, right boxes display associations between MDD-W and respective mediator, center boxed display the indirect ATTs through the respective mediators. The control group is weighted using entropy balancing based on the following Baseline values: whether the household head's primary income source was farming, whether they were polygamously married, whether the household was affected by floods in the past 12 months, whether the household was affected by theft in the past 12 months, the nutritional knowledge score and the outcome variable. Control variables include gender, age, literacy and marital status of the household head, the number of household members, the share of household members with disabilities and if they received any support from other organizations in the past twelve months, if the household experienced a severe illness or an accident of one of the main income earners, conflict or violence and theft in the past 12 months. Statistical significance is denoted by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A5: Robustness Tests: Separate Mediation Models

	(1) Nutritional knowledge	(2) Agricultural knowledge	(3) HG diversity	(4) HG practices	(5) Women's agency	(6) Crop sale	(7) Assets endowment
HG	0.059***	0.011	0.07***	0.08***	-0.018	0.091***	0.271***
$\rightarrow$ *Mediator*	(0.02)	(0.023)	(0.021)	(0.03)	(0.015)	(0.02)	(0.028)
Indirect	0.436**	0.09	0.384**	0.374**	-0.127	0.715***	2.195***
effect	(0.203)	(0.167)	(0.165)	(0.163)	(0.134)	(0.253)	(0.521)
Mediator	7.333***	7.084***	5.662***	4.877***	7.277**	7.681***	7.911***
$\rightarrow FCS$	(2.284)	(1.657)	(2.048)	(1.491)	(2.871)	(1.991)	(1.686)
Observations	1544	1544	1544	1544	1544	1544	1544
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes. Mediation analysis using difference-in-differences estimations with interviewer-fixed effects. Indirect effects are bootstrapped with 1,000 iterations. The control group is weighted using entropy balancing based on the following Baseline values: whether the household head's primary income source was farming, whether they were polygamously married, whether the household was affected by floods in the past 12 months, whether the household was affected by theft in the past 12 months, the nutritional knowledge score and the outcome variable. Control variables include gender, age, literacy and marital status of the household head, the number of household members, the share of household members with disabilities and if they received any support from other organizations in the past twelve months, if the household experienced a severe illness or an accident of one of the main income earners, conflict or violence and theft in the past 12 months. Statistical significance is denoted by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.