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Benefits of farmer managed natural regeneration to food security in semi-arid Ghana

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Abstract

Promoting Farmer Managed Natural Regeneration (FMNR) aims to increase the productive capacities of farmer households. Under FMNR, farmers select and manage natural regeneration on farmlands and keep them under production. While FMNR contributes to the wealth of farming communities, its contribution to household food security has rarely been researched. We, therefore, used a mixed-methods approach to address the research gap by measuring FMNR's contribution to food security among farmer households in the Talensi district of Ghana. We adopted the Household Dietary Diversity Score (HDDS) and Food Consumption Score (FCS) to estimate food security status among 243 FMNR farmer households and 243 non-FMNR farmer households. Also, we performed a Chi-square test of independence to compare the frequency of each food group (present vs not present) between FMNR adopters and non-FMNR adopters to establish the relationship between adopting FMNR and consuming the FCS and HDDS food groups. Our results reveal that FMNR farmer households are more food secure than non-FMNR farmer households. The HHDS of the FMNR farmer households was 9.6, which is higher than the target value of 9.1. Conversely, the HHDS of the non-FMNR farmer households was 4.3, which is lower than the target value of 9.1. Up to 86% and 37% of the FMNR farmer households and non-FMNR farmer households fell within acceptable FCS; 15% and 17% of FMNR farmer households and non-FMNR farmer households fell within borderline FCS. While none of the FMNR farmer households fell within poor FCS, 46% of non-FMNR farmer households fell within poor FCS. Adopting FMNR is significantly related to consuming all food groups promoted and benefiting from FMNR practices. The paper recommends enabling farmers in semi-arid environments to practice and invest in FMNR for long-term returns to food security.

Keywords Farmer managed natural regeneration · Food consumption score · Food security · Ghana · Household dietary diversity score · Talensi

Abbreviations

AGRA	Alliance for a Green Revolution in Africa
CAP	Commonwealth Association of Planners
FAO	Food and Agriculture Organization
FCS	Food Consumption Score
FMNR	Farmer Managed Natural Regeneration
GHS	Ghana Health Service
GIP	Ghana Institute of Planning
GMEF	Ghana Monitoring and Evaluation Forum
GSS	Ghana Statistical Service

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HDDS	Household Dietary Diversity Score
HLPE	High Level Panel of Experts on Food Security and Nutrition
IFAD	International Fund for Agricultural Development
MoFA	Ministry of Food and Agriculture
NTFPs	Non-timber Forest Products
NWFPs	Non-Wood-Forest Products
ODK	Open Data Kit
S4T	Savings for Transformation
SDG	Sustainable Development Goal
SPSS	Statistical Package for Social Science
TDA	Talensi District Assembly
TEDMAG	Technical Education Development for Modernized Agriculture in Ghana
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
WFP	World Food Programm
WHO	World Health Organization
WVA	World Vision Australia
WVG	World Vision Ghana

Introduction

Food security has become a critical issue in international development and policy agenda. It has received significant attention from scholars and resonates among institutions, international development cooperation, and global policy (Candel et al. 2014; Madsen 2022). This attention became evident after the 2007–2008 and 2010 global food price crises and the 2008 World Development Report (Madsen 2022; Headey and Hirvonen 2023). These reports made it clear that food insecurity is an ongoing problem. Furthermore, the importance of food security is recognised in the Sustainable Development Goal (SDG 2) (Food and Agriculture Organization [FAO] et al. 2021), which justifies its prominence. Food insecurity is a major challenge in Ghana, especially across the northern savannah agro-ecological zone, where semi-arid ecological conditions and poor natural resource base lead to low productivity, poverty and food insecurity (Ministry of Food and Agriculture [MoFA] et al. 2020). Food insecurity is a significant national challenge in Ghana. The country's food insecurity rate stands at 11.7%. Notably, 78% of this demographic, predominantly smallholder farmers, are in rural areas (MoFA et al. 2020; Acheampong et al. 2022). There is a marked variation in the prevalence of food insecurity across the different agro-ecological zones in Ghana (MoFA et al. 2020). The Guinea Savannah agro-ecological zone is home to most (46%) of Ghana's food-insecure population. Within this zone, the Upper East region has the highest food insecurity rate, with a prevalence rate of 49%. Specifically, in the Upper East region, the Talensi district, which is the focus of this study, holds the highest food insecurity prevalence in Ghana, with 39.1% of all households estimated to be food insecure (World Food Programme [WFP] 2012; Ghana Statistical Service [GSS] 2022).

There is, therefore, a higher concentration of agriculture-related interventions in the zone. Here, successive governments and civil society organisations have been instrumental in addressing poverty and food insecurity (Adu et al. 2018; Dazé and Echeverría 2016). One such intervention is World Vision Ghana's (WVG) Farmer Managed Natural Regeneration (FMNR). FMNR is a burgeoning regreening approach gaining support with a growing evidence base for its efficacy. It is practised mainly in agropastoral communities and households that combine crop farming and pastoralism (Chomba et al. 2020). According to Rinaudo et al. (2019) and Rinaudo et al. (2021), FMNR involves systematic regrowth and management of shrubs and trees from felled tree stumps, seeds or sprouting root systems or in woody thickets. Communities and households promote natural regeneration by pruning, mulching, and protection. Because planting trees is not required, FMNR is comparatively accessible and cheaper, with a higher survival rate of trees (Lohbeck et al. 2020). This success is because the species regenerate naturally and are locally adapted (Lohbeck et al. 2020). FMNR's technical potential is high in almost all drylands as no inputs, such as seedlings or labour for planting and watering, are required. The single requirement is in-situ germplasm, the soil's roots or seeds (Binam et al. 2017).

As a full rural development model, FMNR is often combined with enterprises such as livestock rearing, apiculture, and local value chain for wood, timber as well as Non-timber Forest Products (NTFPs), including fruits and medicinal herbs, among others (Reij and Garrity 2016; Nakyeyune et al. 2018). Many interventions that complement FMNR also provide essential benefits that motivate land users to commit to FMNR (Rinaudo et al. 2019; Rinaudo et al. 2021). The integrated approach of FMNR contributes to improved food access and nutrition, diversified food options, improved livestock production and increased crop yields (Rinaudo et al. 2019). Most sectors benefit from this no-regrets technology (Rinaudo et al. 2019), and the food security, nutrition, agriculture and income generation and economic development sectors are not left out (Rinaudo et al. 2021).

A substantial body of knowledge has been generated on FMNR in Ghana and other drylands, particularly in sub-Saharan African (Chomba et al. 2020; Weston et al. 2015; Westerberg et al. 2019; Francis et al. 2015; Binam et al. 2017; Kandel et al. 2022). This wealth of information on FMNR recognises its clear and diverse social, health and environmental benefits. Like all other smallholder farmer households (United Nations Development Programme [UNDP] 2021; Alliance for a Green Revolution in Africa [AGRA 2020]), FMNR farmer households mainly own an average of two hectares of farmland, which are degraded. Hence, they are crucial for agricultural-related interventions which improve food security, livelihoods, and climate resilience (Fraval et al. 2019; Weston et al. 2015; Westerberg et al. 2019). Despite its documented advantages in regenerating farmland productivity and contributing to the wealth of farming communities (Rinaudo et al. 2021; Rinaudo et al. 2019; Westerberg et al. 2019), its contribution to improved food security among FMNR farmer households in Ghana has rarely been researched, emphasising the need to explore this relationship further.

We, therefore, seek to address this research gap by calculating the Food Consumption Score (FCS) and Household Dietary Diversity (HDDS) of FMNR and non-FMNR farmer households to measure their degree of food security. FCS and HDDS are standard measures of food security (FAO 2021). Also, we seek to establish the relationship between adopting FMNR and consuming the FCS and HDDS food groups.

FMNR and food security

Forests, trees and agroforestry support food security. This support is often undervalued (Gitz et al. 2021). For instance, agroforestry systems, which integrate trees with crops and livestock on farmlands, promote the production of diverse tree and non-tree foods. The High Level Panel of Experts on Food Security and Nutrition [HLPE] (2017) and Gitz et al. (2021) categorised the contributions of forests and trees to food security into four main categories. These contributions include providing nutritious food, such as fruits, nuts, vegetables (leaves, roots, flowers), tubers, bushmeat, oils, fish, mushrooms, herbs, saps, insects, and livestock feed. It includes providing woodfuel for cooking and boiling water, especially in developing countries where woodfuel is used to prepare many nutrient-rich foods. Forests and trees offer formal and informal income and employment generation opportunities through wood and Non-Wood-Forest Products (NWFPs) sales. Forests and trees deliver non-provisioning ecosystem services necessary to sustain agricultural activities and food production now and in the future. According to HLPE (2017), research on the role of forests and trees in food security has arguably been slow to materialise and called for a more holistic integration of food security issues within forestry-related research and policies (HLPE 2017; Obodai et al. 2018). Within this context, we seek to explore the benefits of FMNR to food security in semi-arid Ghana.

According to FAO (2006), food security occurs when all people, at all times, have economic and physical access to safe, sufficient and nutritious food which meets their dietary food preferences and needs for a healthy and active life. This definition integrates the four dimensions of food security: food availability, food accessibility, food utilisation and food stability. Food availability is the physical presence of sufficient quality and quantity of food. It includes food from markets, farms, home gardens and food gifts/aid (FAO 2008). Food accessibility exists when all individuals, households and communities have adequate resources to acquire sufficient food for nutritious diets by combining home production, purchase, stocks, barter, food aid, gifts or borrowing (FAO 2008). FAO (2008) defines food utilisation as getting nutrients and energy from food for a healthy life. It involves how the body uses the food it consumes. Food stability involves both availability and accessibility. To achieve food security, households should be able to access food at all times and not be at risk of food insecurity from shocks or cyclical events, including seasonal food shortages. This situation must be enduring and stable over time, but not temporary and subject to fluctuations (FAO 2006). As shown in Table 1, FMNR contributes to the four dimensions of food security for individuals, households and communities.

Materials and methods

The agro-ecological context of talensi district

The Talensi district is located in the Upper East region of Ghana. It has an unimodal rainfall pattern and is dominated by smallholder farmer households. The district is environmentally fragile and not irrigated (Opoku Mensah et al. 2023a). It is among Ghana's most climate-vulnerable districts (Tangonyire and Akuriba 2021; Opoku Mensah et al. 2023a). As many as 91% of households are dependent on agriculture. They are primarily smallholders who heavily rely on a favourable climate for their agricultural activities (Abunyewah et al. 2024). Crop farming and livestock production are the main agricultural activities, with some silviculture and aquaculture also practised. Industrial activities in the district include the processing of African locust bean (*Parkia biglobosa*) seeds from the African locust bean tree and shea nuts from the shea tree (*Vitellaria paradoxa*) (GSS 2014; Talensi District Assembly [TDA] 2022).

The district has the highest proportion of households facing food insecurity in the Upper East region, which has the highest food insecurity prevalence in Ghana (GSS 2022; Opoku Mensah et al. 2023b), with 39.1% (severely = 10.5% and moderately = 28.6%) of all households estimated to be food insecure (WFP 2012). It also has the longest history of implementing FMNR in the region (Weston et al. 2015). The district has higher levels of poverty and reliance on food purchases (WFP 2012; MoFA 2019). Farmers in the district have witnessed annual rainfall decline and temperature rise because of climate change, biodiversity and forest cover disappearance,

Table 1 Relationship between FMNR and food security

Dimension of food security	Mechanism
Food availability	FMNR increases crop yields. For example, in the Maradi district of Niger, FMNR-adopted areas produced 173 kg of millet and 77 kg per hectare of other crops such as sorghum, cowpeas, peanuts and hibiscus. Areas that did not adopt FMNR produced only 149 kg of millet and 10 kg per hectare of other crops. Through FMNR practices, communities usually stop burning bushlands and grass, resulting in increased fodder from grasses, tree leaves, and seed pods, thereby increasing the number of domestic animals and animal products.
Food accessibility	FMNR increases access to food, meat, fruits, nuts, leaves and honey. Usually, such products are available when conventional agriculture is out of season. It increases disposable income from enterprises such as livestock rearing, apiculture and the local value chain for wood, timber, and NTFPs, including fruits and medicinal herbs.
Food utilisation	Through FMNR's integrated approach, households have diversified and increased nutritious food such as wild fruits, edible leaves, nuts, honey and meat. Pruned branches provide fuelwood for cooking to improve dietary intake.
Food stability	FMNR reduces food shortages and famine impacts because households can sell FMNR products to buy food items. Also, when FMNR is practised, the number of households that would have sold their livestock at low prices or watched them die in drought is significantly reduced because trees provide edible leaves and seed pods even in drought. They provide shade and may reduce water evaporation. Trees from FMNR provide a buffer against climatic extremes that directly affect crops and livestock. Fallen leaves from many trees significantly improve soil fertility for improved productivity.

Compiled from Mbow et al. 2014; Nakyeyune et al. 2018

productivity loss from soil infertility, deforestation and land degradation, and declining food security and loss of livelihoods. To address these challenges, FMNR was introduced in the district in 2009 to combine with other low-cost sustainable agriculture and tree-dependent livelihood interventions to increase household resilience, improve food security and income and employment opportunities from community-led natural resource management (Weston et al. 2015; Nakyeyune et al. 2018; Kandel et al. 2022).

The FMNR project was a strategic response to the pressing challenges of land degradation, deforestation, and the adverse effects of climate change. Its core objectives were to foster sustainable environmental management, improve food security, bolster household resilience and diversify household income and employment opportunities through community-driven natural resource management (World Vision Australia [WVA] 2018; 2020; Kandel et al. 2022). It was implemented as a foundational and complementary intervention (Rinaudo et al. 2019; Rinaudo et al. 2021). Designed as a holistic rural development model, the FMNR project seamlessly integrated various complementary activities. It ventured beyond mere land regeneration, anti-erosion techniques, field mulching, bulk composting, preventing bush fires and field burning and promoting fuel-efficient wood stoves, intertwining enterprises like apiculture, livestock production, income growth and creating local value chains for a diverse range of forest products, including timber, wood, fruits, and medicinal herbs (Nakyeyune et al. 2018; Weston et al. 2015). Such multidimensional interventions, as posited by Rinaudo et al. (2019), provide essential benefits that motivate land users to commit to FMNR.

At its essence, FMNR was structured to regenerate and increase degraded land's productivity and farmers' ability to produce more food crops and livestock products. Among the many ecological restorations, the project emphasised the regeneration of specific tree species known for their diverse utilities, including but not limited to edible fruits, leaves, and medicinal products (Weston et al. 2015). A crucial objective was to boost fodder availability from various trees and shrubs and enhance grass growth, subsequently supporting livestock production. This intervention held dual significance – it supplied vital protein sources for households. It increased access to firewood to make cooking easier and improve access to nutrients in foods (WVA 2018; Westerberg et al. 2019).

The vision of the FMNR project extended beyond ecological regeneration. It aimed to usher in a sustainable economic model. By promoting the production of sustainable tree products, be it firewood, fruits, fodder, or timber, the project aimed to open new avenues for income and employment generation. Furthermore, by enhancing land productivity and ensuring its resilience against environmental shocks, the FMNR project aspired to provide households with a consistent income stream even in challenging times. The economic aspect of FMNR was further strengthened by integrating it with value-addition initiatives, savings and loan schemes, and market linkage strategies, all designed to maximise income generation and economic development opportunities for households (Westerberg et al. 2019; Kandel et al. 2022; Weston et al. 2015).

Data collection

We employed a mixed-methods approach that combined quantitative and qualitative approaches and implemented them in three phases. In the first phase of data collection, we selected the study communities. With the support of three staff members from WVG and one from the Talensi district's Department of Agriculture, we selected four communities: Namolgo, Yamsok, Yameriga, and Yamdankorug. Given the positive relationship between food security and farming experience (Oluyole et al. 2009), we selected the communities because they had implemented FMNR since its introduction to reap its benefits and speak knowledgeably on a range of other issues. We then conducted reconnaissance visits to the communities, established contacts and acquired entry into the communities. We also conducted transect walks to observe the communities' settings, farming, and FMNR practices.

In the second phase, we determined our unit of analysis and the sample size for the quantitative survey. Naturally, we identified FMNR and non-FMNR farmer households as our unit of analysis. To calculate the sample size with the desired degree of accuracy, we used Slovin's formula (Slovin 1960):

$$n = \frac{N}{1 + N(\alpha)^2} \quad n = \frac{620}{1 + 620(0.05)^2} \quad n = 243$$

Where n = sample size to be calculated; N = total households (sampling frame), and α = Type 1 error (0.05) to select 243 FMNR farmer households. We obtained the list of project participants (N) from WVG. We sampled equal numbers of FMNR and non-FMNR farmer households from each study community based on probability proportional to size. We selected participating and non-participating households from the same intervention communities to provide a robust understanding of the overall impact and ensure we capture the direct and indirect effects of the FMNR interventions. For example, non-participating households could provide an outside perspective on the intervention and offer feedback on why they chose not to participate. Such feedback is valuable to refine and enhance future iterations of interventions (Hamelin et al. 2011; Newing 2011; Gaworek-Michalczenia et al. 2022).

We sampled 39, 46, 95 and 63 FMNR and non-FMNR farmer households each from Namolgo, Yamsok, Yameriga and Yamdankorug, respectively. We selected the households through a snowball sampling approach (Johnson 2014), a technique where those already sampled help to pinpoint new potential research subjects for the investigators to interview (Noy 2008; Chenani et al. 2021). To increase the diversity and representativeness of the sample and minimise the potential for selection bias, we selected multiple diverse seed participants. These participants represented different facets of the farmer households to ensure a wider variety of referrals. Also, we limited the number of referrals a participant could make to avoid over-representing a particular subgroup. Additionally, to prevent the clustering of participant samples in specific locations, we sampled households from multiple locations in each community, including sections that we further removed from major landmarks and roads. Such selection criteria provide information-rich cases for in-depth study (Hamelin et al. 2011).

We used a questionnaire for the survey, which focused primarily on household food supply and consumption, household livelihoods and income and employment generation, crop yields, and benefits and trade-offs of FMNR. We collected data with a questionnaire coded with the Open Data Kit (ODK) mobile app to enhance the quality and efficiency of data collection (Pagnani et al. 2021; Musafiri et al. 2022). We pre-tested the questionnaire with selected farmer households and modified it where necessary. Because of the considerable seasonal variation between pre-harvest, harvest and post-harvest seasons (FAO 2016; Roba et al. 2019), we accounted for seasonality in production and consumption by collecting data from July to December 2022 (MoFA et al. 2022; MoFA et al. 2020; Aweke et al. 2020). This period embodies all three seasons, which is appropriate to capture households' habitual diet and complete picture of consumption (Carletto et al. 2013; Kennedy et al. 2010) as opposed to diets on the day (Aweke et al. 2020) or week of the survey. Each household survey lasted 30 to 45 minutes. Only household heads or agricultural decision-makers in the households participated in the survey.

Based on the initial analysis of the survey data, we conducted eight focus group discussions (2 in each community, 1 for FMNR farmer households and another for non-FMNR farmer households) in the third phase of data collection. All focus group discussions comprised, on average, seven discussants. For FMNR farmer households, we purposefully selected discussants based on their extensive FMNR knowledge, experience and practices. There was no criterion for selecting non-FMNR farmer households except for their non-involvement (Newing 2011) in FMNR practices. Each discussion lasted for three hours on average and centred on household food supply and consumption, household livelihoods and income and employment generating activities, crop yields and benefits and trade-offs of FMNR. The research team moderated the discussions. Four research assistants supported them.

The patriarchal nature of the study communities has resulted in power dynamics between women, youth and men. Therefore, the research team and research assistants were comprised of men and women to encourage women and youth to express themselves and speak up to capture different perspectives freely. Time and financial constraints did not allow us to conduct male-only, female-only, and youth-only discussions. We conducted the discussions in the communities' local languages: Guruni and Talen. We recorded all the discussions with the discussants' consent.

This research adhered to principles of academic excellence and integrity (Gaworek-Michalczenia et al. 2022). We prioritised the rights and dignity of our research participants. We informed all respondents about the research purpose and conditions and obtained informed consent before the interviews. We maintained data protection, guaranteed confidentiality and anonymity and upheld participants' right to withdraw from the study at any time.

Data analysis

We ensured that data were complete, validated and addressed the research objective. We used Microsoft Excel 2019 to generate descriptive statistics (means, frequencies and percentages) (Yeleliere et al. 2023; Aboye et al. 2023) for indicators measuring food security and other variables, including household food supply and consumption, household livelihoods and income-generating activities, crop yields and benefits and trade-offs of FMNR. Also, we used Statistical Package for Social Science (SPSS) Statistics 28 to perform a Chi-square test of independence to compare the frequency of each food group (present vs not present) between FMNR adopters and non-FMNR adopters to establish the relationship between adopting FMNR and consuming the FCS and HDDS food groups.

Household dietary diversity score

HDDS captures the consumption of 12 food groups. These are staple roots and tubers, cereals, fruits, vegetables, meat, poultry, offal, fish and seafood, milk and milk products, eggs, oil and fats, sugar and honey, condiments and seasonings and pulses, legumes and nuts. For greater accuracy in collecting information on household food consumption, a 24-hour recall method is used. Due to imperfect recall, longer reference periods tend to yield less precise data (Swindale and Paula 2006). We derived HDDS by aggregating the 12 HDDS food groups (after Swindale and Paula 2006) as:

First, we calculated the HDDS variable for each household (total number of food groups consumed by household members). The value of this variable ranged from 0 to 12. Values for the food groups were either 0 or 1.

$$\begin{aligned} HDDS = & \text{ sum (roots and tubers + cereals + fruits + vegetables} \\ & + \text{meat, poultry, offal + fish and seafood + milk and milk products} \\ & + \text{eggs + oil/fats + sugar/honey + condiments, seasonings + pulses, legumes, nuts)} \end{aligned}$$

Second, we calculated the average HDDS indicator for the sample population (after Swindale and Paula 2006) as:

$$\frac{Sum\ (HDDS)}{Total\ number\ of\ Households\ surveyed}$$

No established threshold exists for the number of food groups to determine adequate dietary diversity or otherwise. However, the Food and Nutrition Technical Assistance III Project (FANTA) suggested two ways to use this indicator in reporting (Swindale and Paula 2006). Firstly, assuming poorer households will diversify food expenditure as their incomes increase and mirror wealthier households' consumption patterns, their dietary diversity patterns could be used as a target. Where there is income data, the sample can be divided into income terciles (three income groups). The average dietary diversity is then computed for the richest income tercile and used as a guide to set the HDDS target level. Where income data are unavailable, as in this study, income groups are defined with proxies highly correlated with income. Secondly, where income or economic data are unavailable, the HDDS target is set by calculating the average diversity of the upper tercile (33% with the highest diversity).

Because of the unavailability of income data, we defined income groups using major proxies identified during the household surveys and focus group discussions. The proxies include beekeeping and honey production, rearing of livestock, involvement in local value chain development, and Savings for Transformation (S4T) activities. These proxies are highly correlated with income in the Talensi district (Weston et al. 2015). We categorised the farmer households in all four proxies into the highest wealth tercile. We also categorised farmer households involved in three and two or fewer of the proxies into medium and lowest wealth tercile, respectively.

Food consumption score

We used eight food groups consumed by a household and weighted them according to their relative nutritional value to calculate FCS (Leroy et al.2015). These food groups were staples, pulses, vegetables, fruit, meat and fish, milk, sugar and oil). The food groups' weights are subjectively defined to describe their quality by caloric density, micro- and macronutrient content, and actual quantities consumed. Higher weights are assigned to food groups that contain relatively high energy, a range of bioavailable micronutrients and good-quality protein. Lower weights are given to food groups that have high energy but are low in micronutrients and protein. The assigned weights are staples (w=2.0), pulses (w=3.0), vegetables (w=1.0), fruit (w=1.0), meat and fish (w=4.0), milk (w=4.0), sugar (w=0.5), and oil (w=0.5) (WFP 2008; Leroy et al. 2015). We calculated FCS by summing the weighted frequencies for consumption of the different food groups (after Leroy, Ruel, Frongillo, Harris and Ballard 2015):

$$\begin{aligned} FCS = {} & Wstaple\ .\ Fstaple + Wpulse\ .\ Fpulse + Wvegetable\ .\ Fvegetable \\ & + Wfriut.\ Ffruit + Wmeat\ and\ fish.\ Fmeat\ and\ fish \\ & + Wmilk\ .\ Fmilk + Wsugar\ .\ Fsugar + Woil\ .\ Foil \end{aligned}$$

Where W_j is the weight of each food group, and F_j is the frequency of consumption (in the past seven days). FCS status is determined from the following thresholds (cutoff points): 0-21: Poor; 21.5-35: Borderline; >35: Acceptable (WFP 2008).

We analysed the qualitative data from the focus group discussions using thematic and narrative analysis. We used NVivo 12 software to code the transcripts to identify recurrent and interconnected themes. In emphasising stories articulated by discussants, we used narrative analysis in the form of quotations to substantiate claims and interconnection between themes (Bryman 2012; Opoku Mensah et al. 2023b).

Results

Household dietary diversity score

The aggregation of the 12 HDDS food groups for the FMNR and non-FMNR farmer households resulted in an average HDDS of 9.66 and 4.3, respectively. Thus, on average, while all FMNR farmer households consumed food from 10 out of the 12 food groups, non-FMNR farmer households consumed food from 4 out of the 12 food groups. The average HDDS in the highest wealth tercile was 9.1, which we set as the HDDS target level. Hence, the average HHDS of the FMNR farmer households of 9.6 indicated that they were food secure relative to the target level. However, the average HHDS of the non-FMNR farmer households of 4.3 indicated that they were not food secure relative to the target level. This finding confirms Weston et al.'s (2015) conclusion that through FMNR, diets improved along with farmers' harvests in the Talensi district.

Food consumption score

The distribution of FCS for the FMNR farmer households showed that up to 86% of them fell within acceptable FCS, 15% fell within borderline FCS, and none fell within poor FCS. Conversely, the distribution of FCS for the non-FMNR farmer households showed that up to 37% of them fell within acceptable FCS, 17% within borderline FCS, and 46% within poor FCS. The FCS distributions align with Binam et al.'s (2017) findings that households with acceptable FCS and borderline FCS generally manage high and diversified numbers of trees on their farmlands.

Contributions of FMNR to food security

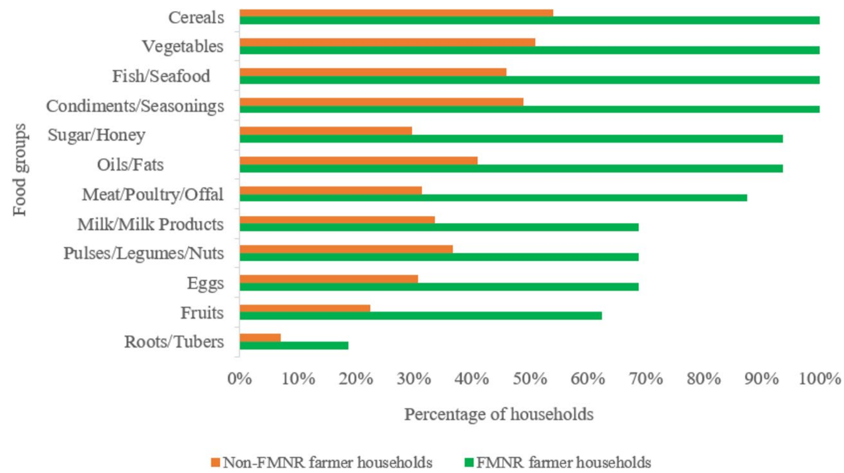
The results from the HDDS and FCS indicated that FMNR positively contributed to food security among its practitioners. This impact is particularly notable in a district with the highest proportion of households facing food insecurity within the Upper East region. The Upper East region has the highest prevalence of food insecurity in Ghana, with 39.1% (severely = 10.5% and moderately = 28.6%) of all households in this region estimated to be food insecure (WFP 2012; GSS 2022). This section focused on analysing how FMNR contributed to consuming the HDDS and FCS food groups by the FMNR farmer households and, hence, their food security status compared to non-FMNR farmer households. FMNR enhanced all four dimensions of food security: availability, access, utilisation and stability.

Food availability

As shown in Fig. 1, we found that cereals, vegetables, fish/seafood, and condiments/seasonings were consumed by all FMNR households relative to the other food groups.

By adopting FMNR practices such as more mature trees and higher tree densities in the field, tree pruning, intercropping with legumes, composting, crop rotation and preventing fires, FMNR farmer households experienced increased crop yields. Specifically, we found from the household data that yields of maise, millet, sorghum/guinea corn, groundnut, beans, rice, and vegetables were higher for FMNR farmer

Fig. 1 The percentage of FMNR and non-FMNR farmer households that consumed food groups from each category within the recall periods HDDS and FCS



households than non-FMNR farmer households. About 6% of the FMNR farmer households reported average increases of between 600 kg and 1,500 kg of their crops; 33% recorded average increases of above 200 kg but less than 600 kg, and 61% reported average increases between 50 kg to 200 kg compared to the years before they adopted FMNR practices. For the non-FMNR farmer households, no household recorded increases of 600 kg and 1,500 kg of crops relative to the years before FMNR was introduced. While only 4% recorded increases of above 200 kg but less than 600 kg, the remaining 96% reported increases between 50 kg and 200 kg relative to the years before FMNR was introduced. A youth in Yameriga happily commented:

> *"Enough food has been available for our households after we adopted FMNR. We have increased the number of bags we harvested from the same land. I do not remember the last time my family purchased food. We always have enough food to sustain us. The difference comes from FMNR. We have enough to consume and sell".*

Another farmer in Yamsok commented:

> *"Since I can sell some of the crops I grow, my household can buy other food items like meat and fish to enrich our diet".*

For example, we found that composting worked well in the communities because FMNR-generated and other organic materials from livestock, fallen fruits, crop residues and household waste were used as compost materials in specially constructed bays. From Fig. 1, only 19% of the FMNR farmer households consumed roots and tubers, and 7% of non-FMNR farmer households, because unlike yam and sweet potato, cassava, which is the dominant root crop in Ghana and cocoyam, which are alternative root/tuber crops (Dapaah 1994), do not thrive in the Talensi district and are not considered local staple foods. We found that soybean cultivation was intentionally introduced through FMNR, in addition to purple-and orange-fleshed sweet potato, to increase the consumption of legumes and diverse diets and improve income when they are produced in excess of consumption and sold.

To improve consumption and income, we found that FMNR was complemented with many interventions such as apiculture (beekeeping and honey production), livestock production (goat, sheep, poultry, pigs and rabbit rearing), local value chain for wood, timber as well as NTFPs such as fruits and medicinal herbs. These interventions provided beneficial sources of food and income. They contributed to the consumption of sugar/honey and meat/poultry/offal at 94% and 88%, respectively, among the FMNR farmer households, compared to the paltry 30% and 32% of sugar/honey and meat/poultry/offal for non-FMNR farmer households (cf. Fig. 1). For example, because of emerging forests, beekeeping and honey production were viable, particularly in areas where good bee forage trees such as African locust bean trees, shea trees, neem trees *(Azadirachta indica),* Baobab trees (*Adansonia digitata*), Tamarind (*Tamarindus Indica*), and Acacia species such as acacia gourmaensis had been regenerated. The primary bee species utilised for these practices were Apis mellifera adansonii and Apis mellifera scutellata.

The communities were equipped with beehives and trained in beekeeping and the sustainable harvesting of honey. All apiarists reported that beekeeping and honey production were profitable with low upfront capital required. Apiarists in all focus groups reported that they consume and sell honey. They reported that the demand for honey often exceeded the supply. A focus group discussion in Yameriga revealed that while they extracted some quantities of honey, they could not quantify the volume. An apiarist commented in Yameriga:

> *"Beekeeping is very profitable. We are sometimes unable to meet the demand for honey. As we restore the forest, we create a conducive environment to keep bees and make honey. We consume and sell a lot of honey. I can say I have increased my income and yield. I can now meet my household's food, nutrition, financial, educational, and health needs".*

The comment below from a lead farmer in Yameriga was encapsulating:

> *"As a lead farmer, when it comes to FMNR, I am at a loss for where to begin. It has benefited us immensely. Our yields have gone up. We obtain fodder for our livestock, our women can access firewood, our children enjoy fruits, and we even collect honey from the FMNR site".*

We found that most farmers have limited information on pollinators and pollination. Also, though it is established that parasites such as the varroa mite (varroa destructor), Aethina tumida and Braula coeca and others that attack honey bees have spread in Ghana (Llorens-Picher et al. 2017), most of the apiarists were unaware. This situation is worrisome because these parasites and pathogens are directly linked to colony collapse (Llorens-Picher et al. 2017; Rinkevich 2020). During the discussion in Yameriga, an apiarist commented:

> *"As an agricultural officer and beekeeper in Yameriga, I have observed a substantial improvement in vegetation and tree cover since the implementation of FMNR in 2009. This change has significantly boosted honey production. Yet, I am increasingly concerned. Introducing large numbers of honeybees could dominate the resources on which our native pollinators rely. Even more worrying is the potential spread of diseases. We cannot ignore how increased honeybee numbers might change how our native pollinators behave. So, while FMNR holds a lot of promise, we must combine it with beekeeping in a balanced way to ensure we get more honey without putting our precious native pollinators at risk".*

We found that fodder from the growth of shrubs, trees, and grass from FMNR practices supported livestock rearing. During our community and farm transect walks, we observed how the protection of trees on farms and grazing fields provided shade and fodder to livestock. All the focus group discussions showed that protecting trees on farms and grazing lands significantly supported livestock rearing. We found that livestock rearing provided households with a consistent source of high-quality protein. It also offered households diverse income streams, enhancing their resilience against food shortages. A farmer in Yamdankorug commented:

> *"In my years of farming, I have seen firsthand how raising livestock has been our lifeline. Not only do we get meat, milk, and eggs to feed our households, but it also gives us an extra income, helping us get through the tough times and ensuring we always have food on our table".*

Bush fires and field burning were major hindrances to FMNR in the communities. Also, free-range livestock grazing created browsing pressures that inhibited natural regeneration. We found that in addition to local bye-laws and fines systems that were put in place for fire infringements, FMNR farmer households created and cleared fire belts around their farmlands and reduced dry grass to protect trees from fire. We found that the majority of trees were regenerated without the use of fencing. Similar to Rinaudo et al. (2019), we found that households practising FMNR implemented strategies to prevent livestock from damaging trees. Some households limited livestock access until the trees were well-established, while others prohibited livestock access to the regenerating areas. Instead, they cut grass from these fields daily to feed their livestock. Some adopted a rotational grazing system, moving livestock from one designated area to another before any tree damage could occur during the regeneration phase. When it was not feasible to exclude livestock, FMNR households employed protective measures such as surrounding trees with thorny pruned branches or tying multiple stems together. These practices made it challenging for livestock to cause damage.

Food accessibility

The FMNR farmer households were introduced to tree-dependent local value chain development, mainly processing shea nuts into the precious 'white gold' – shea butter and African locust bean into dawadawa. We found that 98% of FMNR households were involved in the processing activities compared to 42% of non-FMNR farmer households. The focus group discussions revealed that shea butter was used as oil for cooking (94% of the FMNR farmer households consumed oils/fats compared to only 41% of non-FMNR farmer households). The African locust bean tree seeds were processed into dawadawa in all FMNR farmer households and consumed under the condiments/seasoning category, as shown in Fig. 1. More importantly, processing shea nuts and African locust bean seeds provided major sources of employment and income to the community processors. Also, income from the sale of honey and livestock supported the households in buying other nutrient-rich foods they did not produce. We found that the income households gained from selling these products supported them in diversifying their food sources and ensuring various nutrient-rich options. A female farmer in Namolgo noted:

"As a processor, I can tell you more about our practices and the benefits. We process the seeds from the African locust bean tree into dawadawa, which we use as food additives. Additionally, we process shea nuts into shea butter, which has multiple purposes, including cooking. We sell these products and get income to support our households. With the income, we can buy food items we do not produce ourselves".

We found that these employment and income-generating opportunities provided FMNR farmer households with an additional GH¢615/hectare/year (US$55/hectare/year) in present value terms (1US$ = GH¢11.13). This amount equates to GH¢1,230 per household per year (US$110) since FMNR farmer households own an average of two hectares of farmland. This amount is higher than Ghana's lower food poverty line – what is needed to meet the nutritional requirements per adult equivalent per year, GH¢ 792 (US$71) (GSS 2018).

Also, FMNR interventions integrated S4T to build a savings culture and create access to lower interest rates microcredit for productive investment in agriculture, business start-ups and meeting family needs. All FMNR farmer households engaged in S4T and brought members together in cycles of saving and borrowing for their business initiatives and family needs. In contrast, only 11% of the non-FMNR farmer households were involved in S4T activities. As high as 85% of the S4T group members reported having regular income and access to credit with lower interest rates. A woman in Yamsok commented:

"I can attest that processing and S4T has greatly benefited us. Now, women can sit alongside our husbands and make joint decisions for our households, especially when meeting basic needs like food, clothing, and shelter".

The improved financial position of the FMNR farmer households through these processing and S4T activities generated more sustainable incomes for the purchase and consumption of a wider range of food groups, such as fish/seafood. For instance, the focus group discussions with the FMNR farmer households revealed that with their increased income from the FMNR interventions, they could buy and consume fish/seafood (Fig. 1) even though fishing and fish farming were non-existent in their communities. A woman commented during a focus group discussion in Namolgo:

"We are not into fishing or fish farming, but you can easily find fish in many households and every diet. Knowing the benefits of consuming fish, we use our improved incomes from FMNR practices to buy and consume more".

Food utilisation

FMNR Farmer households in the Talensi district depended on fruits and berries collected seasonally from wild-growing trees, affecting their consumption availability. The district's most common and essential fruit trees were shea, African locust bean and Baobab trees. Others included red and black berries (*Vitex doniana*), tamarind and ebony (*Diospyros mespiliformis*). These fruit trees were protected through FMNR because of their nutrition, medicinal and economic values. Also, animal-sources foods (Gitz et al. 2021) and fruit trees from forests, such as honey and baobab, were vital food supplements and sources of bio-available micronutrients (Gitz et al. 2021; Oeba and Illiassou 2020) among the FMNR farmer households.

Additionally, edible leaves from trees and shrubs served as significant sources of protein, iron, calcium, folate, vitamin A, and vitamin C—essential nutrients often missing in staple-based diets (FAO and WHO 2004). Similarly, Powell et al. (2023) found that wild foods enhance income, food, and nutritional security due to their high micronutrient content. A female farmer in Namolgo noted:

"During the fruiting season, getting fruits is now easier. Unlike when we were not protecting the fruit trees, we now do not have to go deep into the wild to get them. They are now constantly in excess anytime during the fruiting season. Because they are in the wild, we eat them while farming to get the energy to work more and take the rest home to eat or sell".

We found that pruned branches provided fuelwood for cooking, smoking, heating food and boiling water. Surplus fuelwood was sold to generate extra household income for food purchases. Cooking is crucial for food safety and enhancing the bio-availability of micronutrients (HLPE 2017). Cutting down trees for fuelwood was reduced by introducing energy-efficient stoves that used less energy, mainly pruned branches of trees from FMNR fields. The households survey revealed that about 85% of the FMNR farmer households used these energy-saving stoves, as opposed to 7% of non-FMNR farmer households. A woman in Yamdankorug commented:

"We have noticed a big change since using these improved stoves. We do not cut down trees compared to when we used open fires and traditional stoves. These energy-saving stoves are good for our lands and health. We only use pruned branches from our lands. Cooking has become so much easier and faster for us. It has truly been a blessing for our households".

Food stability

We found that the usefulness of the African locust bean tree was heightened since it was harvested in the dry season when food was scarce (Teklehaimanot 2004). Also, ebony was especially valued for its fruits, which ripened during the dry season. As they matured, when households typically consumed less food, these fruits became a supplementary dietary addition for the FMNR farmer households. Our findings supported earlier research indicating that tree foods remain the only abundant source in some arid regions at the end of the dry season (Westerberg et al. 2019; Koffi et al. 2020). Moreover, we found that FMNR protected trees provided a buffer against crop failure. Restoring degraded lands and increasing tree cover mitigated the effects of drought, as trees acted as windbreaks, protecting crops and topsoil (Vira et al. 2015; Oeba and Illiassou 2020).

FMNR farmer households reported a noticeable reduction in bushfires and soil erosion. Notably, only 13% of the FMNR farmer households reported experiencing crop failure since they adopted FMNR, compared to 89% of non-FMNR farmer households since FMNR was introduced. Echoing the findings of Gitz et al. (2020), we found that the root systems and canopy cover established through FMNR effectively protected soils from erosion, especially in areas of steep slopes and heavy rainfall, and from desertification and deforestation. A farmer from Yameriga commented:

> *"Since we began practising FMNR, I have seen fewer trees being cut down and more growing up. My land feels different and richer. The soil stays put when it rains, not washing away, and my land seems more fertile. Even when the rains are less or times change, we still harvest substantial produce. FMNR practices have made a difference, even in the dry seasons*".

To ascertain why some farmers are not practising FMNR despite its benefits, a comment from a non-FMNR farmer household's discussant in Yamdankorug was revealing:

> *"When World Vision Ghana first introduced FMNR in our community, I was sceptical about it. Over the years, I was introduced to different projects by different institutions without any results. I can say on authority now that the FMNR project is different. I had no idea how important it would be in protecting the environment, increasing yields and sustaining livelihoods. I have seen the benefits my friends and their households who bought into the idea are enjoying now. They now have enough food and money all year round".*

Another in Yameriga commented:

> *"I want to practice FMNR on my farm and enjoy its benefits. My major problem is that World Vision Ghana no longer works in this community. I am trying to learn from a lead farmer trained to support farmers like me to replicate it on our farmlands. It is challenging, but I am not giving up. I am motivated by the benefits my colleagues are enjoying".*

Relationship between FMNR adoption and consumption of food groups

Adopting FMNR was associated with consuming the food groups that were promoted or benefitted from FMNR practices (Table 2). FMNR adoption was highly related to consuming cereals, oil/fats, sugar/honey, condiments/seasonings and pulses/legumes/nuts. Also, consuming fruits, fish/seafood, and vegetables depended significantly on FMNR practices. This result was attributed to the protection of fruit trees under FMNR, increased incomes to buy fish/seafood, and increased access to credit to buy and produce more vegetables for sale and consumption.

Discussion

Tree-based systems and forests contribute to food security and nutrition worldwide, especially in tropical and dryland regions, through increased production and availability

Table 2 Chi-square results on the relationship between FMNR adoption and consumption of food groups

Food group	FMNR adopters	Non-FMNR adopters	Total	Pearson Chi-square
Roots/Tubers	46 (19%)	17 (7%)	63 (13%)	4.237
Cereals	243 (100%)	131 (54%)	374 (77%)	5.54***
Fruits	153 (63%)	56 (23%)	209 (43%)	4.987**
Vegetables	243 (100%)	124 (51%)	367 (76%)	7.586**
Meat/Poultry/Offal	214 (88%)	78 (32%)	292 (60%)	8.683*
Fish/Seafood	243 (100%)	112 (46%)	355 (73%)	9.341**
Milk/milk products	168 (69%)	83 (34%)	251 (52%)	4.953
Eggs	168 (69%)	75 (31%)	243 (50%)	4.985
Oil/Fats	228 (94%)	100 (41%)	328 (67%)	5.647***
Sugar/Honey	228 (94%)	73 (30%)	301 (62%)	9.682***
Condiments/Seasonings	243 (100%)	119 (49%)	362 (74%)	8.775***
Pulses/Legumes/Nuts	168 (69%)	90 (37%)	258 (53%)	4.266***

*, **, *** indicate significant statistical levels of $p < 0.1$, $p < 0.05$, $p < 0.01$, respectively

of nutritious fruits, leaves, and other products to general diversification of diets (Oeba and Illiassou 2020; Reed et al. 2017). Ickowitz et al. (2022) and Rasmussen et al. (2020) found that tree cover is associated with dietary diversity and consumption of fruits and vegetables. Nuts and the majority of fruits, which are typically rich in nutrients, grow on trees. Forests and trees are important habitats for animals that supply meat. Meat is a primary source of essential nutrients for many rural households. Moreover, farm trees provide fodder, allowing households to raise livestock. Livestock provides nutritionally valuable foods like meat and milk (Ickowitz et al. 2022; Franzel et al. 2014).

Where food insecurity is tied to limited income generation and employment opportunities, incomes from forests and trees contribute to rural households' income, food security and nutrition (FAO 2013; Ickowitz et al. 2022). Forests and trees support food security as direct sources of food and fuel, generate income, and provide ecosystem services. Leveraging on tree crops to produce non-food products further increases local incomes, improving food security. Additionally, tree crops bolster households' resilience against food insecurity caused by seasonal crop production fluctuations or outright crop failure. Forests are invaluable for the ecosystem services they provide, even if these services are not traded or straightforward to quantify in economic or food security terms (FAO 2013; HLPE 2017; Gitz et al. 2021).

Food availability occurs from trees and forests' direct and indirect contributions (Gitz et al. 2021). Our findings showed that FMNR practices directly provided a diverse range of plant and animal-sourced foods. These foods are essential to people's diets in or near forests, trees, and rural areas (HLPE 2017; Powell et al. 2023). Also, FMNR provided fodder to support livestock production and increased animal-sourced food consumption. The indirect contribution results from the critical ecosystem services forests and trees provide in support of agriculture (Gitz et al. 2021; Ickowitz et al. 2022). Emerging forests from FMNR, for instance, sheltered various auxiliary species, including pollinators. These species offer multiple benefits for availability across different scales (Reed et al. 2017). Also, forests or trees on FMNR farmlands provided animal fodder and supported households in rearing livestock. Livestock provides nutritious and essential foods like meat and milk (Franzel et al. 2014).

The role of forests and trees in food accessibility is associated with their capacity to generate income and employment (Aweke et al. 2020; HLPE 2017; Gitz et al. 2021; Ickowitz et al. 2022). Households remain food secured through direct access to food products and by selling them to purchase various other food items, enriching their diet with diverse nutrients essential for a healthy household. Foods obtained from forest and tree-based systems are sold, providing additional income and enabling households to buy other types of nutrient-rich foods for a healthier lifestyle (Oeba and Illiassou 2020; HLPE 2017; Gitz et al. 2021). FMNR provided various tree products which were consumed or sold, contributing to household income and well-being diversification. These tree products included home consumption or sale of fuelwood, shea butter, dawadawa and wild leafy vegetables, honey, nuts, fodder, fruits and edible seeds. The sale of these products supported households to meet their food and other basic needs and ensured all-year food security. Savings made from forest-tree-based activities were also invested in the agricultural sector. Thus, the indirect contribution of tree-based systems to food security remains paramount (Oeba and Illiassou 2020).

According to HLPE (2017) and Gitz et al. (2021), forests and trees play multiple roles in better food utilisation and nutritious diets. Forest and tree foods are rich in nutrients and vital for dietary diversity and quality, benefiting human health (Baudron et al. 2019; Rasmussen et al. 2020; HLPE 2017; Gitz et al. 2021). Forests contribute to food security, nutrition, and health by providing wood fuel for cooking and water sterilisation (HLPE 2017). Cooking and boiling of water prevent food and water-borne diseases and improve household nutritional status through improved food safety, the bioavailability of numerous micronutrients, dietary quality and diversity and food utilisation (HLPE 2017; Oeba and Illiassou 2020; Gitz et al. 2021). The FMNR Farmer households depended on fruits and berries collected seasonally from wild-growing trees protected through FMNR, affecting their consumption availability.

Also, animal-sources foods (Gitz et al. 2021) and fruit trees from forests, such as honey and baobab, were vital food supplements and sources of bio-available micronutrients (Gitz et al. 2021; Oeba and Illiassou 2020) among the FMNR farmer households. The FMNR farmer households also depended on pruned branches to provide fuelwood for cooking, smoking, heating food and boiling water. Surplus fuelwood was sold to generate extra household income for food purchases. Households benefit from woodfuel use as it allows them to consume nutrient-rich foods like meats and legumes. Without it, households might settle for foods that are easier to cook but less nutritious (Wan et al. 2011; Ickowitz et al. 2022).

Food stability pertains to the stability of the other three dimensions of food security: availability, accessibility and utilisation (Gitz et al. 2021). Forests and trees offer households alternative sources of food, feed, income, and employment that provide safety nets to households (Koffi et al. 2020). These safety nets are crucial during droughts, lean seasons, crises, and conflicts, especially for the most vulnerable populations (Angelsen and Dokken 2018; HLPE 2017; Powell et al. 2015). Generally, trees withstand extreme weather events better than annual crops, potentially making them more reliable food sources given the increasing frequency of such events due to climate change (Waldron et al. 2017). Notably, only 13% of the FMNR farmer households reported experiencing crop failure since they adopted FMNR, compared to 89% of non-FMNR farmer households since FMNR was introduced.

At the ecosystem and landscape level, forests and trees supply ecosystem services that enhance the resilience of food systems and ensure long-term food production stability (Gitz et al. 2021). The diversity of tree foods, each with different seasonal patterns and valued nutrient profiles, provided consistent food security throughout the year. FMNR farmer households sold various forest products, including tree foods, to buy other types of food. Whether these forest and tree products are directly consumed or for food purchases, they are often the only resources accessible to households when hardship strikes. Trees within FMNR systems filled seasonal gaps in food production and prevented or limited seasonal shortages in fruit supply (McMullin et al. 2019). For example, the usefulness of the African locust bean and ebony trees in the Talensi district was heightened since their fruits ripened during the dry season. As they matured, when households typically consumed less food, these fruits became a supplementary dietary addition for the FMNR farmer households. Domesticating indigenous trees and wild forest species offers significant potential for food production, employment opportunities, and income generation, even at the end of the dry season (Vira et al. 2015; Koffi et al. 2020).

Additionally, forests and trees play a pivotal role in soil formation and soil organic matter. This organic matter improves soil structural stability, reducing its vulnerability to wind and water erosion (Miccolis et al. 2019). Establishing woodlots reduces deforestation, improves biodiversity, enhances soil structure, and reduces erosion. Furthermore, it improves soil fertility and stabilises production during drought and climate variability (Vira et al. 2015; Oeba and Illiassou 2020).

Conclusion

Building considerable and robust evidence on the role of forests and tree-based systems in food security can achieve dual objectives: promoting biodiversity conservation and setting the agenda for policymakers to address agricultural and food security challenges. In this context, prioritising research that fosters a deeper understanding of forests, tree-based systems' priorities, and food security strategies becomes essential (Oeba and Illiassou 2020). Our results have adequately assessed the benefits of FMNR to food security in the Talensi district. Our findings showed that FMNR practices fostered sustainable environmental management, improved food security, bolstered household resilience and diversified household income and employment opportunities through community-driven natural resource management.

Our findings showed that the Talensi FMNR project promoted FMNR along with sustainable agricultural techniques, which were critical in its successful outcomes, such as improved soil fertility and crop yields, increased assets to tree stocks and improved livestock, increased wild resources for consumption and sale and associated dietary benefits and consistent and availability and access to food resources throughout various seasons. While FMNR is primarily recognised as a field and forest restoration technique, it also represents a broader approach to rural landscape management. This approach empowers land users and creates space for ecological dynamics to restore soil and natural resources (Rinaudo et al. 2019; Rinaudo et al. 2021). For African agriculture to adequately feed future generations, there is a need to increase productivity, restore degraded lands, and reduce small-scale farmers' climate vulnerability. FMNR validly contributes to achieving these objectives (Weston et al. 2015).

Given the relatively low cost and multiple benefits of FMNR adoption and the call on farmers to produce environmental outcomes and conserve biodiversity (Amato and Petit 2023; Boronyak and Jacobs 2023), we call on policymakers to create an enabling and conducive environment that encourages farmer households to practice and invest in FMNR to achieve long-term diversified returns. Policy initiatives integrating large-scale promotion and uptake of community-led natural resource management, such as FMNR, in local food systems require partnerships and knowledge sharing among communities, government agriculture institutions and civil society organisations. We also believe that improving farming practices through FMNR provides a critical entry point for interventions to improve nutrition and food security among smallholder farmer households throughout African dry lands (Westerberg et al. 2019; Fraval et al. 2019).

Beyond FMNR's significant role in food security, evaluating its environmental impact is essential. Recent research indicates that FMNR can improve soil quality, increase biodiversity, and enhance water retention, thus boosting agricultural productivity over time (Rinaudo et al. 2019; Rinaudo et al. 2021). However, concerns arise regarding the potential over-extraction of natural resources (Lohbeck et al. 2020; Westerberg et al. 2019; Binam et al. 2015). As we advocate for FMNR's role in food security, measuring its environmental impacts to ensure its practices remain environmentally sustainable is equally important. Striking this balance is crucial to ensure the long-term viability and success of FMNR initiatives.

FMNR offers numerous ecological and socio-economic advantages but requires a comprehensive understanding of local ecological dynamics for successful implementation

(Chomba et al. 2020). Specifically, we call for regularly monitoring bee populations, both domesticated honeybees and native species, to provide insights into potential issues, such as competition for resources, contamination by parasites and pathogens and honey bee health. Additionally, we call for integrated pest management strategies that could help control the spread of pests like varroa mites. Since beekeeping is a primary enterprise in FMNR systems in Ghana, training farmers on sustainable apiculture practices would be crucial to ensure that while honey production is maximised, the adverse effects on native pollinators are minimised.

Despite the positive findings of the study, upscaling of FMNR should be driven by evidence (Chomba et al. 2020; Lohbeck et al. 2020) and grounded in the empirical understanding of local contexts, including socio-political dimensions (Kandel et al. 2022; Chazdon et al. 2021; Marlène et al. 2021). Therefore, the study's concentration on the Talensi district might not represent other FMNR beneficiary districts in Ghana. Accordingly, we call for considering other districts in future studies to strengthen the case for wider adoption of FMNR.

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