Household determinants of food security among leafy vegetable producers in semi-arid central Tanzania

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ABSTRACT

This study examined household-level determinants of food security among smallholder leafy vegetable producers in semi-arid central Tanzania, focusing on the roles of gender dynamics, household structure, and enabling conditions. A cross-sectional survey was conducted with 385 vegetable-producing households in Dodoma City and Singida Municipal Council. Food security was measured using the Household Food Insecurity Access Scale (HFIAS) and was analysed as a binary outcome (food secure versus any food insecurity). Data were analysed using hierarchical binary logistic regression. Results indicated that 52.7% of households were fully food secure, with very low prevalence of severe food insecurity, suggesting a stabilising effect of vegetable-based livelihoods. Female-headed households exhibited 55.2% lower odds of food insecurity compared to male-headed households (OR = 0.448, $p < 0.001$), challenging conventional assumptions about gender vulnerability. Married households had 45.8% lower odds of food insecurity (OR = 0.542, p = 0.030). High crop diversification was associated with increased food insecurity (OR = 2.473, p = 0.001), suggesting distress-driven diversification rather than a causal pathway. Climate-smart agriculture adoption showed a clear dichotomy between near-universal uptake of traditional practices and minimal adoption of technology-intensive approaches. Nearly one third of households employed vegetable-based coping strategies, predominantly distress sales, underscoring the dual role of leafy vegetables as food sources and liquid assets. The findings highlighted that household demographic characteristics, particularly gender of household head and marital status, were stronger predictors of food security than individual agricultural practices within vegetable-producing communities. Policy implications included strengthening gender-responsive agricultural interventions, investing in complementary water infrastructure, and integrating leafy vegetable production into national food security strategies.

Keywords: Climate-Smart Agriculture, Food Security, Female-Headed Households, Gender, Household Food Insecurity, Leafy Vegetables, Smallholder Farmers, Semi-Arid Tanzania

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I. INTRODUCTION

Food security remains a pressing development challenge across sub Saharan Africa, where approximately 257 million people are undernourished (FAO, 2023). In Tanzania, agriculture employs more than 65 percent of the population and contributes nearly 30 percent of national gross domestic product. Despite this importance, food insecurity persists due to erratic rainfall, inadequate infrastructure, limited access to productive inputs, and strong dependence on rain fed farming systems (NBS, 2022; WFP, 2023). Between November 2023 and April 2024, nearly 900,000 people in mainland Tanzania experienced acute food insecurity classified as Integrated Food Security Phase Classification Phase 3 or higher, underscoring the urgent need to strengthen climate resilient agricultural systems (IPC, 2024).

Leafy vegetable production has emerged as an increasingly important livelihood strategy within semi arid farming systems. These crops have short production cycles ranging from four to eight weeks, tolerate moisture stress better than most staple crops, and allow multiple harvests within a single season (Bua & Onang, 2017; Kapari *et al.*, 2023). The multifunctional role of leafy vegetables, serving simultaneously as food sources, income generating commodities, and liquid assets during periods of stress, positions vegetable-based livelihood systems as a potentially important pathway for food security in climate vulnerable regions.

Climate-Smart Agriculture (CSA) has emerged as a strategic response to production challenges in such environments, seeking to increase agricultural productivity, enhance resilience, and promote environmental sustainability (World Bank, 2024). In Tanzania, the National CSA Programme promotes context specific interventions in semi arid regions such as Dodoma and Singida (URT, 2015). However, most empirical work on CSA and food security in Tanzania has concentrated on staple crops such as maize, sorghum, and pigeon peas (Yusuph *et al.*, 2023; Kamuzora, 2023; Nindi, 2024). Recent work by Erick *et al.* (2025) examined behavioural determinants of CSA adoption among leafy vegetable agripreneurs in the same study region (Erick *et al.*, 2025a), while Erick *et al.* (2025b) assessed CSA contributions to food security through a mixed methods approach. Nevertheless, limited attention has been directed toward understanding household level determinants of food security among smallholder vegetable producers, particularly the roles of gender dynamics and household structure in shaping food access outcomes.

This study addresses this gap by examining how household characteristics, adaptive agricultural practices, and enabling conditions shape household food security among leafy vegetable producers in semi arid central Tanzania. The study contributes to the literature in three ways: first, by providing empirical evidence on determinants of food security within a vegetable based livelihood context; second, by illuminating gender dynamics in household food security outcomes, including evidence that challenges conventional assumptions about the vulnerability of female headed households; and third, by examining how contextual enabling conditions interact with food security in ways that underscore the complexity of resource to outcome relationships in semi arid environments. In doing so, the study offers evidence-based insights to inform gender-responsive and context-specific food security interventions within climate-vulnerable smallholder vegetable production systems.

1.1 Research Objective (s)

This study examines determinants of household food security among leafy vegetable producers in semi-arid central Tanzania. Specifically, the study pursues three objectives:

(i) To assess the prevalence and severity of household food insecurity among leafy vegetable producing households using the Household Food Insecurity Access Scale.

(ii) To analyse the influence of household characteristics and adaptive agricultural practices, particularly crop diversification, on household food insecurity.

(iii) To evaluate the role of enabling conditions, including proximity to water sources and market access, and to determine their relative contribution to food insecurity outcomes within a hierarchical logistic regression framework.

II. LITERATURE REVIEW

2.1 Theoretical Review

This study is grounded in an integrated theoretical perspective combining the Sustainable Livelihoods Framework (SLF), CSA theory, and Food Security theory. No single theory sufficiently captures the interconnected dimensions of household assets, adaptive strategy, and livelihood outcomes within climate stressed smallholder systems.

2.1.1 Sustainable Livelihoods Framework

The SLF provides the foundational lens for understanding household level dynamics under vulnerability (Chambers and Conway, 1992; DFID, 1999). It conceptualises livelihoods as combinations of capabilities, assets, and activities, identifying five forms of capital: human, natural, financial, physical, and social. In this study, gender of household head, marital status, and household size represent elements of human and social capital that influence decision making authority, labour allocation, and resource mobilisation. Gender of household head is of particular analytical interest given conflicting evidence: while female headed households are conventionally associated with greater food insecurity (Lutomia et al. 2019; Hailemariam *et al*., 2024), emerging evidence suggests that women's roles in food provisioning may confer protective effects under certain livelihood configurations (Egah *et al*., 2023; Awoke *et al*., 2025).

2.1.2 Climate-Smart Agriculture Theory

CSA theory provides a production focused perspective on agricultural adaptation (FAO, 2013; Lipper *et al*., 2014), emphasising increased productivity, strengthened resilience, and environmental sustainability. Within vegetable systems, CSA practices provide the production context within which household level determinants of food security operate. However, the relationship between individual CSA practices and food security is not necessarily straightforward: adoption may reflect proactive risk management, reactive coping, or response to extension advice, and may not uniformly translate into improved food security in cross sectional observation. This study examines CSA adoption patterns descriptively while testing crop diversification as an indicator of adaptive engagement in regression analysis (Bongole *et al.*, 2022; Egah *et al.*, 2020; Mutengwa *et al.*, 2023; Mthethwa *et al.*, 2022).

2.1.3 Food Security Theory

Food security exists when all people at all times have physical, social, and economic access to sufficient, safe, and nutritious food for an active and healthy life (World Food Summit, 1996). This study focuses on household food access, measured using the Household Food Insecurity Access Scale (HFIAS) developed under the Food and Nutrition Technical Assistance project (Coates *et al.*, 2007). The integration of Food Security theory with the SLF and CSA theory enables a structured linkage between household assets, adaptive practice, contextual conditions, and food insecurity outcomes.

2.1.4 Empirical Evidence on Food Security Determinants in Tanzania and East Africa

Empirical research on household food security determinants in Tanzania and the broader East African region has identified several consistent predictors. Lutomia *et al*. (2019) found that female-headed households in Tanzania experienced greater food insecurity, attributing this to limited access to land and productive inputs. However, Egah *et al*. (2023) provided contrasting evidence from West Africa, suggesting that women's income control can positively influence household food security. In the East African context, Hailemariam *et al*. (2024) documented persistent gender gaps in Climate-Smart Agriculture adoption across sub-Saharan Africa, with implications for food security outcomes. Within Tanzania specifically, Warning (2022) demonstrated that access to irrigation significantly improved food security, while Kapari *et al*. (2023) emphasised the contribution of smallholder farmers to food security through diversified production systems. Erick *et al*. (2025b) examined CSA contributions to food security among leafy vegetable agripreneurs in the same study region, finding that mulching and integrated soil and water management significantly reduced food insecurity risk. Collectively, these studies highlight the importance of gender dynamics, agricultural practices, and resource access as determinants of food security, while revealing that the direction and magnitude of these effects vary across livelihood contexts. The present study extends this evidence base by examining these determinants specifically within vegetable-based livelihood systems, a context that has received limited empirical attention.

2.1.5 Integrated Conceptual Framework

The integrated framework positions household characteristics as central determinants of food security, with adaptive agricultural practice and contextual enabling conditions as complementary factors. Household characteristics shape decision making capacity, labour availability, and resource mobilisation. Crop diversification represents the operational indicator of adaptive practice, conceptualised as potentially bidirectional: it may reflect proactive strategy or reactive coping, a distinction that cross-sectional data cannot fully resolve. Proximity to water sources and market access represent structural characteristics of the livelihood environment. District location is included as a control variable to account for contextual heterogeneity between Dodoma City and Singida Municipal Council.

The integrated relationships can be expressed formally. Let *FI* denote household food insecurity status (binary). The general conceptual model posits:

$$FI = f(\mathbf{H}, \mathbf{A}, \mathbf{E}, \mathbf{C})$$

where:

H = household characteristics vector (gender, marital status, household size)
A = adaptive agricultural practice (crop diversification)
E = enabling conditions vector (water proximity, market access)
C = control (district location)

The framework implies a hierarchical structure: household characteristics (**H**) represent the foundational determinants grounded in the Sustainable Livelihoods Framework, while adaptive practice (**A**) and enabling conditions (**E**) represent complementary factors derived from CSA and food security theory. This hierarchical logic motivates the nested model specification detailed in Section 3.5, where Model 1 tests the independent contribution of **H** and Model 2 adds **A** and **E** to assess their incremental explanatory value.

III. METHODOLOGY

3.1 Study area

The study was conducted in Ihumwa and Iyumbu Wards of Dodoma City District, and Uhamaka and Unyambwa Wards of Singida Municipality District, all located in central Tanzania. These districts are part of the country's semi-arid ecological zone, characterized by high temperatures ranging from 15°C to 35°C and limited annual rainfall between 500 and 600 mm, primarily received from November to April (Ekka & Mjawa, 2020; Swamila *et al.*, 2020). The selection of Dodoma City and Singida Municipality was informed by agricultural extension records, which identified them as the leading leafy vegetable-producing districts in their respective regions. This production advantage is attributed to their relatively greater access to irrigation water, the presence of established supply chains, and proximity to major regional markets.

These selected wards also reflect variation in farming practices, agro-ecological conditions, and degrees of market integration, making them ideal for examining the dynamics of climate change adaptation. This targeted approach ensured that the study focused on the most relevant production zones where farmers are actively engaged in navigating climate-related risks and implementing adaptive responses. Figure 1. Maps depicting the study area location and administrative divisions.
(A) Map of Tanzania, with the study regions highlighted.
(B) Map of Dodoma and Singida regions within Tanzania.
(C) Map of Singida Municipality, highlighting the Uhamaka and Unyambwa wards where data were collected.
(D) Map of Dodoma City, highlighting the Ihumwa and Iyumbu wards where data were collected.
Data sources: National Bureau of Statistics (NBS) and OpenStreetMap Contributors.

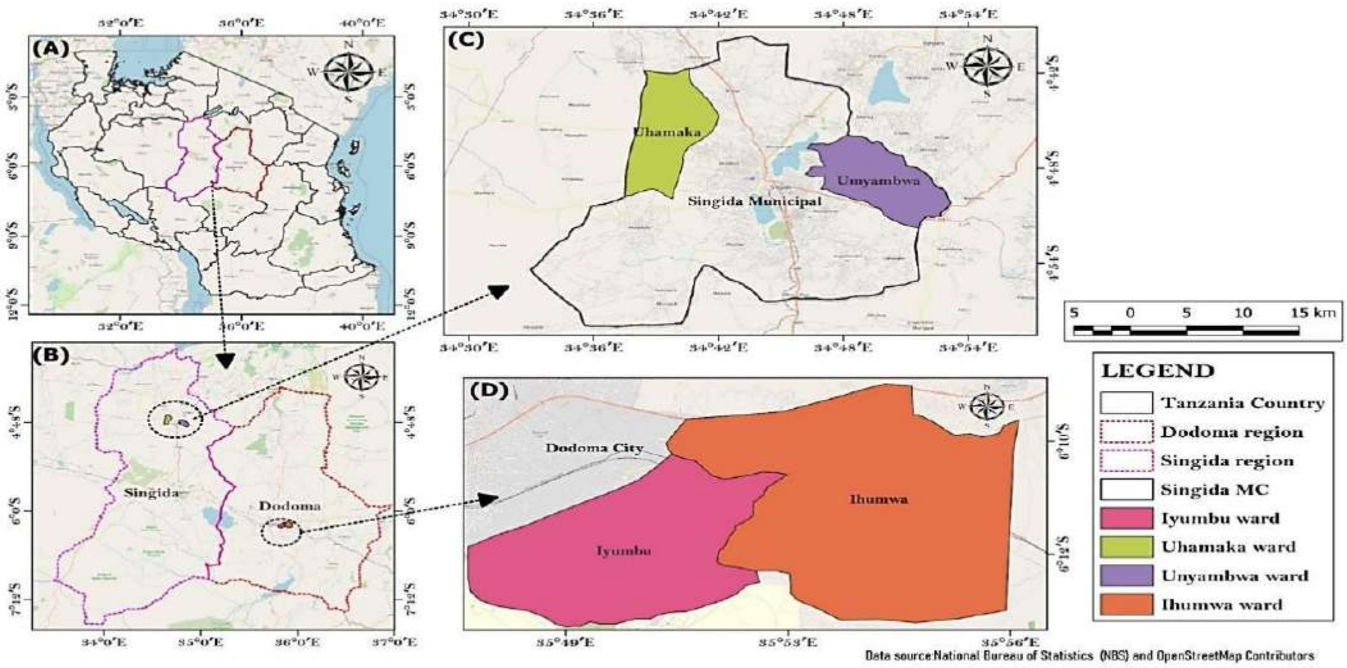

Figure 1
The maps of the Study Area

3.2 Research Design and Sampling

A cross sectional research design was employed with multistage sampling. Two districts were purposively selected, followed by two wards per district based on concentration of vegetable farming. Households were randomly selected from village registers maintained by ward agricultural extension officers. The sample size was determined using Yamane (1967) formula:

$n = N / [1 + N(e)^2]$

where N represents the estimated population of vegetable producing households (approximately 8,500, based on ward-level vegetable-producing household registers compiled by district agricultural extension offices in Dodoma City and Singida Municipal Council) and e represents the desired margin of error (0.05), yielding a minimum sample of 382. After adding a buffer, 400 questionnaires were distributed; data cleaning removed 15 incomplete responses, yielding a final analytical sample of 385 valid cases (96.25% response rate). With 182 food insecure cases and seven predictors, the study provides approximately 26 events per variable, exceeding the minimum of 10 recommended for binary logistic regression (Vittinghoff and McCulloch, 2007).

3.3 Data Collection Instruments

Data were collected using a structured questionnaire administered through face to face interviews. Section A captured socio demographic characteristics (gender, age, education, marital status, household size). Section B assessed adoption of nine CSA practices using a five-point Likert scale (1 = Never to 5 = Always): crop rotation, organic fertiliser application, improved seed use, mulching, crop diversification, inorganic fertiliser use, agroforestry, greenhouse production, and drip irrigation. Section C employed the HFIAS comprising nine occurrence questions spanning anxiety about food supply, insufficient food quality, and insufficient food quantity (Coates *et al.*, 2007), plus three vegetable specific coping items. Section D collected information on land ownership, land size, proximity to water sources, and market access. The questionnaire was pre-tested with 20 households.

3.4 Variable Measurement

3.4.1 Dependent Variable

HFIAS responses were scored on the standard 0 to 3 frequency scale and summed across nine items (theoretical range: 0 to 27). In this sample, scores ranged from 0 to 5 ($M = 0.76$, $SD = 1.01$), with 52.7% scoring zero. The standard four-category FANTA classification (food secure, mildly food insecure, moderately food insecure, severely food insecure) yielded 94.8% food secure, 3.4% mildly food insecure, 1.8% moderately food insecure, and 0% severely food insecure. The apparent discrepancy between 94.8% food secure under the four-category classification and 52.7% under the binary classification reflects the differing thresholds: the FANTA algorithm classifies households as food secure if they report no food insecurity experience or only rarely experience worry about food, whereas the binary classification used in this study treats any non-zero HFIAS score (including rare experiences of worry) as food insecurity. This more conservative binary approach captures the full spectrum of food access difficulties and yields a more balanced outcome distribution. Because the extreme concentration of scores under the four-category classification renders ordered logistic regression inappropriate, the dependent variable was operationalised as binary: food secure (HFIAS = 0) versus any food insecurity (HFIAS ≥ 1). The resulting 52.7/47.3 split provides a balanced outcome suitable for binary logistic regression, consistent with approaches used in comparable studies (Gebreyesus *et al.*, 2015).

3.4.2 Independent Variables

Among the nine CSA practices assessed, crop diversification was selected as the sole practice-level indicator for the regression model based on two criteria. First, it was the only CSA practice that showed a statistically significant bivariate association with food insecurity ($\chi^2 = 6.74$, $p = 0.009$); the remaining eight practices showed no significant bivariate relationship with food insecurity status. Second, the near-universal adoption of traditional practices (79–97%) produced insufficient variation to meaningfully differentiate food security outcomes, whereas crop diversification exhibited a more balanced distribution (79.2% high adoption) providing adequate statistical variation for regression analysis. Table 2 summarises the definitions, measurement, and expected direction of all variables included in the model.

Seven independent variables were included: (1) Gender of household head (binary: 1 = female, 0 = male; 57.1% female). (2) Marital status (binary: 1 = married, 0 = not married; 81.6% married). (3) Household size (continuous: range 1 to 12, $M = 5.4$). (4) District (binary: 1 = Singida, 0 = Dodoma). (5) Crop diversification (binary: 1 = high adoption scoring 4 or 5; 0 = low adoption scoring 1 to 3). Among the nine CSA practices, only crop diversification was significantly associated with food insecurity at the bivariate level ($\chi^2 = 6.74$, $p = 0.009$). (6) Proximity to water **sources** (binary: within vs. beyond 100 metres). (7) Market access (binary: good vs. poor/average). Education level and land size were collected but excluded from the primary regression specification based on non-significant bivariate associations with food insecurity status. For education, food insecurity prevalence varied modestly across categories (no formal/adult education: 63.2%, n = 19; primary incomplete: 37.8%, n = 74; primary complete: 49.8%, n = 231; secondary or above: 44.3%, n = 61), but this variation was not statistically significant ($\chi^2(3) = 5.372$, $p = 0.146$). When collapsed to a binary indicator (secondary education or above vs. below), the association remained non-significant ($\chi^2(1) = 0.140$, $p = 0.709$). For land size, food insecurity rates were similarly uniform across categories (less than one acre: 48.9%, n = 188; one to two acres: 41.3%, n = 92; two to three acres: 50.0%, n = 100; more than three acres: 40.0%, n = 5; $\chi^2(3) = 1.928$, $p = 0.587$). A t-test comparing mean land size between food secure ($M = 1.80$, $SD = 0.86$) and food insecure households ($M = 1.79$, $SD = 0.89$) confirmed no significant difference ($t = 0.132$, $p = 0.895$).

To assess whether the exclusion of these variables might bias the remaining estimates, a sensitivity analysis was conducted by estimating an extended model including education (binary: secondary or above vs. below) and land size (binary: greater than one acre vs. one acre or less) alongside the seven original predictors. The likelihood ratio test comparing the extended model to Model 2 was non-significant ($\Delta LR\ \chi^2(2) = 2.114$, $p = 0.347$), indicating that education and land size do not contribute significant explanatory power beyond the existing predictors. Neither variable was individually significant in the extended model (education: OR = 0.856, p = 0.618; land size: OR = 0.688, p = 0.174). Critically, the inclusion of these variables produced negligible changes in the odds ratios of the primary predictors: female household head (OR changed from 0.448 to 0.446), married status (0.542 to 0.541), crop diversification (2.473 to 2.419), and water proximity (2.381 to 2.707). The extended model showed marginally higher AIC (516.7 vs. 514.8) and BIC (556.2 vs. 546.4), confirming that the more parsimonious specification is preferred. These results support the exclusion of education and land size from the primary analysis, though their omission is acknowledged as a limitation.

3.4.3 CSA Index Reliability

Cronbach's alpha for the nine item CSA index was 0.655, below the 0.70 threshold. The five-item traditional sub index approached acceptability ($\alpha = 0.693$), while the three-item technology intensive sub index was unreliable ($\alpha = -0.263$). These results justify using crop diversification as an individual indicator rather than a composite index.

3.5 Data Analysis

Data were analysed using IBM SPSS Statistics (Version 27). Descriptive statistics, chi square tests, independent samples t tests, and hierarchical binary logistic regression were performed. A hierarchical binary logistic regression was employed to operationalise the conceptual model $FI = f(\mathbf{H}, \mathbf{A}, \mathbf{E}, \mathbf{C})$. The binary nature of the dependent variable (food secure vs. any food insecurity) motivates the logistic specification. The log odds of food insecurity are modelled as a linear function of predictors:

$$\ln [P(Y_i = 1) / P(Y_i = 0)] = \beta_0 + \Sigma^{k}_{j=1} \beta_j X_{ij}$$

where $Y_i = 1$ if household i is food insecure (HFIAS ≥ 1) and $Y_i = 0$ if food secure (HFIAS = 0); X_{ij} denotes the value of the jth predictor for household i; and β_j is the corresponding coefficient. Two nested models were specified to test the hierarchical structure:

Model 1 (Household characteristics only):

$$\text{logit}(FI) = \beta_0 + \beta_1\text{Gender}_i + \beta_2\text{Marital}_i + \beta_3\text{HHSize}_i + \beta_4\text{District}_i$$

Model 2 (Full model with CSA and enabling conditions):

$$\text{logit}(FI) = \beta_0 + \beta_1\text{Gender}_i + \beta_2\text{Marital}_i + \beta_3\text{HHSize}_i + \beta_4\text{District}_i + \beta_5\text{CropDiv}_i + \beta_6\text{Water}_i + \beta_7\text{Market}_i$$

The variables correspond to the theoretical domains as follows: **H** = {β_1Gender, β_2Marital, β_3HHSize} captures household characteristics from the Sustainable Livelihoods Framework; **A** = {β_5CropDiv} represents the adaptive agricultural practice indicator from CSA theory; **E** = {β_6Water, β_7Market} represents contextual enabling conditions; and **C** = {β_4District} is the control. All binary predictors are coded 1/0 as specified in Section 3.4.

The incremental contribution of Model 2 over Model 1 is assessed using the likelihood ratio difference test:

$$\Delta G^2 = G^2_{\text{Model 2}} - G^2_{\text{Model 1}} \sim \chi^2 (df = 3)$$

where ΔG^2 follows a chi square distribution with three degrees of freedom (the number of additional parameters in Model 2). A significant ΔG^2 indicates that **A** and **E** contribute explanatory power beyond **H** alone. Results are reported as odds ratios ($OR = e^{\beta}$) with 95% confidence intervals. An OR > 1.0 indicates increased odds of food insecurity; OR < 1.0 indicates a protective effect. Model fit was assessed using McFadden's pseudo R^2, Nagelkerke R^2, AIC, BIC, classification accuracy, and the Hosmer–Lemeshow goodness of fit test. Multicollinearity was evaluated through variance inflation factors (VIF). Statistical significance was set at $\alpha = 0.05$.

The modest overall explanatory power of the model is consistent with the multifactorial nature of food security, which is influenced by numerous variables beyond the scope of the present instrument. Results should be interpreted as identifying significant associations among the examined variables rather than as a comprehensive predictive model of food insecurity.

3.6 Ethical Considerations

Ethical clearance was obtained from relevant institutional review boards. Informed consent was obtained from all participants, who were informed of their right to withdraw. Confidentiality was maintained through anonymisation and secure data storage.

IV. FINDINGS & DISCUSSIONS

4.1 Socio demographic Characteristics

The 385 respondents were drawn from Dodoma City ($n = 208$, 54.0%) and Singida Municipal Council ($n = 177$, 46.0%). Female respondents constituted the majority (57.1%), consistent with the feminisation of smallholder agriculture in Tanzania. Most were married (81.6%) and had completed primary education (60.0%). The mean household size was 5.4 members ($SD = 1.7$). Nearly half (48.8%) cultivated less than one acre. Most households (91.4%) were located beyond 100 metres from water sources, and 74.0% reported good market access. Table 1 presents the full socio demographic profile.

Table 1
Socio demographic Characteristics of Respondents (N = 385)

Characteristic	Category	*n*	%
District	Dodoma City	208	54.0
	Singida MC	177	46.0
Gender of HH head	Female	220	57.1
	Male	165	42.9
Marital status	Married	314	81.6
	Not married	71	18.4
Education level	No formal/Adult ed.	19	4.9
	Primary incomplete	74	19.2
	Primary complete	231	60.0
	Secondary or above	61	15.8
Water proximity	Within 100 m	33	8.6
	Beyond 100 m	352	91.4
Market access	Good	285	74.0
	Poor/Average	100	26.0
Household size	Mean (SD)	5.4	(1.7)

4.2 Climate-Smart Agriculture Practice Adoption

A pronounced adoption gradient was evident across practice types (Figure 1). Traditional practices showed near universal uptake: mulching (97.1%), crop rotation (95.6%), improved seeds (94.3%), organic fertiliser (87.5%), and crop diversification (79.2%). In contrast, technology intensive practices showed markedly lower adoption: greenhouse production was virtually absent (0%), drip irrigation was minimal (5.2%), and agroforestry was intermediate (67.5%) (Awoke *et al.*, 2023). District comparisons revealed significantly higher adoption of crop rotation, organic fertiliser, inorganic fertiliser, and agroforestry in Singida compared to Dodoma (all $p < 0.05$). Cronbach's alpha confirmed that the nine CSA practices do not form a coherent unidimensional construct ($\alpha = 0.655$).

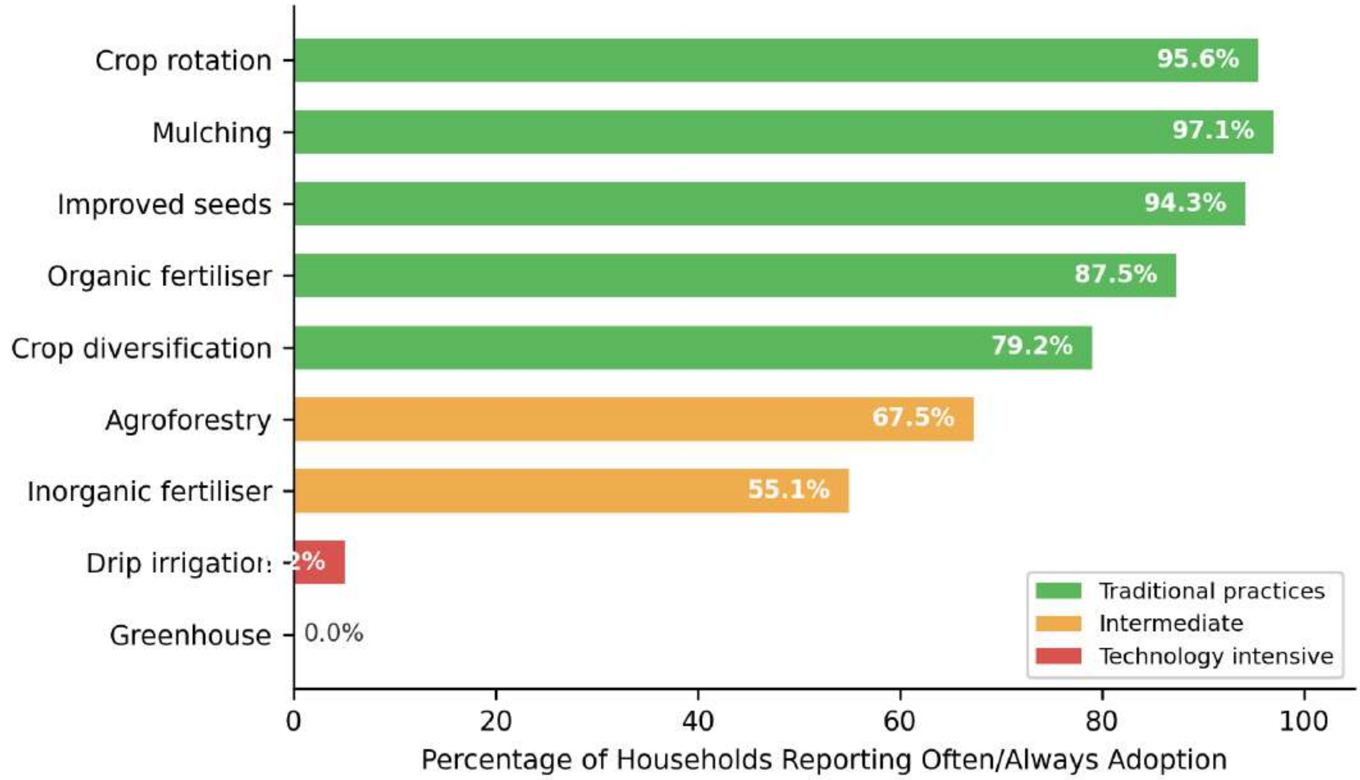

Figure 1
Climate-Smart Agriculture practice adoption among leafy vegetable producers (N = 385).

Bars represent percentage of households reporting 'often' or 'always' adoption. Green = traditional practices; amber = intermediate; red = technology intensive.

4.3 Household Food Security Status

The mean HFIAS score was 0.76 (*SD* = 1.01), with scores ranging from 0 to 5 (Figure 2). Among households experiencing any food insecurity (47.3%), the most commonly reported experiences were eating fewer meals (19.2%), eating unwanted food varieties (16.6%), limited food variety (10.1%), and eating smaller meals (8.3%). Severe food deprivation was rare: 1.3% reported going to bed hungry, 0.8% went to bed without food, and no household reported spending an entire day and night without eating.

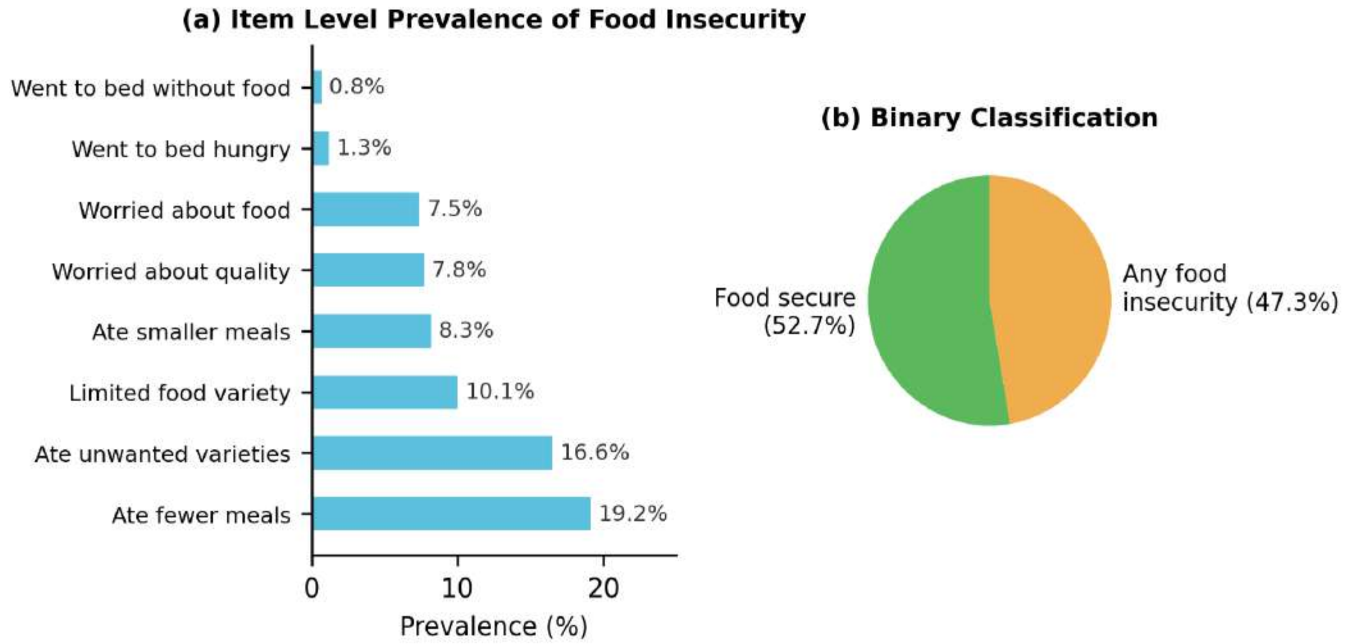

Figure 2
Household Food Security Status

(a) item level prevalence of food insecurity experiences; (b) binary classification used for regression analysis (N = 385).

4.4 Vegetable Based Coping Mechanisms

Overall, 32.7% of households employed at least one vegetable based coping strategy: selling vegetables at reduced prices (31.9%), food shortage before harvest (20.8%), and consuming more vegetables due to unavailability of other foods (5.7%). No significant association was found between vegetable-based coping and HFIAS based food insecurity ($\chi^2 = 0.41$, $p = 0.523$), suggesting that vegetable coping may operate through pathways not fully captured by the HFIAS access dimension.

A supplementary analysis examined whether household characteristics were associated with the use of vegetable-based coping strategies. No significant differences were found between households employing and not employing vegetable-based coping across gender of household head (54.0% vs. 58.7% female, $\chi^2 = 0.590$, p = 0.442), marital status (81.0% vs. 81.9% married, $\chi^2 = 0.005$, p = 0.941), household size (M = 5.3 vs. 5.4, t = −0.280, p = 0.780), district (41.3% vs. 48.3% Singida, $\chi^2 = 1.399$, p = 0.237), crop diversification (77.0% vs. 80.3% high, $\chi^2 = 0.385$, p = 0.535), or market access (74.6% vs. 73.7% good, $\chi^2 = 0.003$, p = 0.955). The absence of significant predictors suggests that vegetable-based coping strategies are employed broadly across household types rather than being concentrated among particular demographic or agricultural profiles, consistent with the widespread role of leafy vegetables as a common livelihood asset in the study area.

4.5 Bivariate Associations with Food Insecurity

Figure 3 presents bivariate associations between predictor variables and food insecurity status. Gender showed the strongest bivariate association: 39.5% of female headed households were food insecure compared to 57.6% of male headed households ($\chi^2 = 11.58$, $p < 0.001$). Marital status approached significance, with married households showing lower insecurity (45.2%) than unmarried households (56.3%). Among CSA practices, crop diversification was the only practice significantly associated with food insecurity: high adoption households had higher food insecurity prevalence (50.8%) than low adoption households (36.7%, $p = 0.009$). Water proximity approached conventional significance (63.6% vs. 45.7%, $p = 0.074$). Household size, market access, education, and district were not significantly associated.

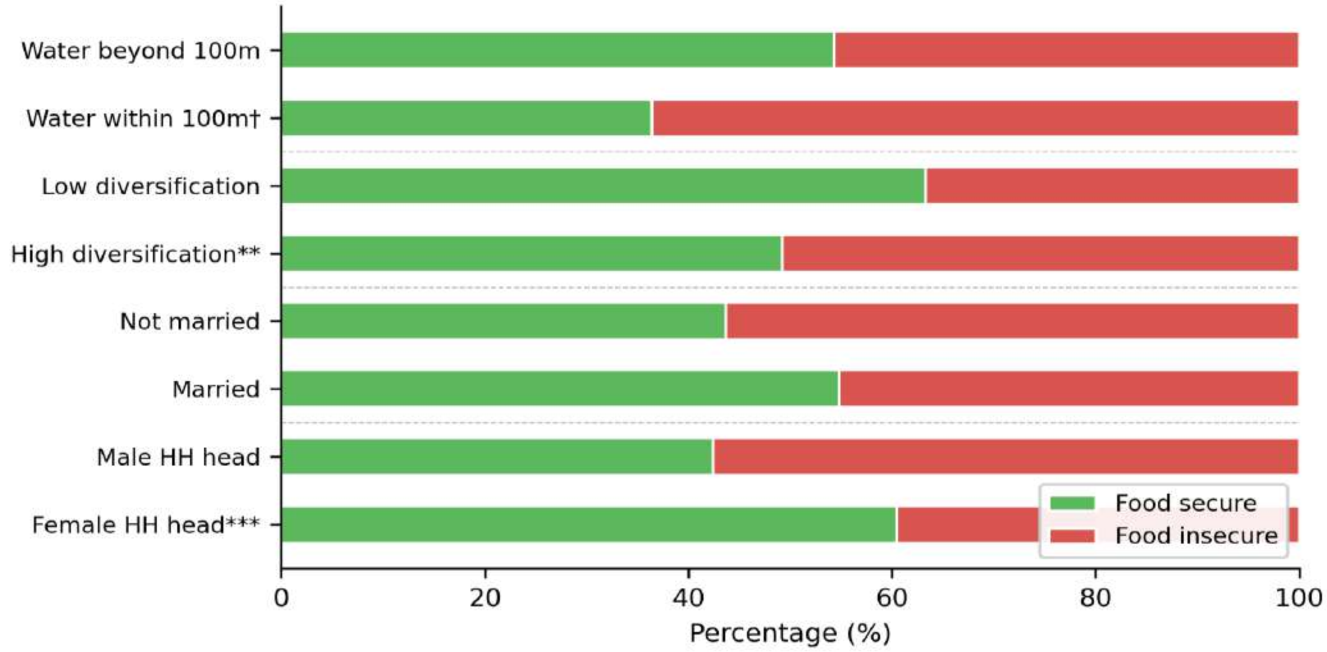

Figure 3

*Bivariate Associations between Predictor Variables and Food Insecurity Status (N = 385). Significance levels: ***p < 0.001, **p < 0.01, †p < 0.10.*

4.6 Determinants of Household Food Insecurity

Table 2 presents the hierarchical binary logistic regression results and Figure 4 displays the odds ratios from Model 2. Model 1 was statistically significant (LR $\chi^2(4) = 17.03$, $p = 0.002$, Nagelkerke $R^2 = 0.058$). Model 2 significantly improved fit (ΔLR $\chi^2(3) = 16.77$, $p < 0.001$). The full model was highly significant (LR $\chi^2(7) = 33.80$, $p < 0.001$) with Nagelkerke $R^2 = 0.112$ and classification accuracy of 62.1%. The Hosmer–Lemeshow test indicated acceptable fit ($\chi^2(8) = 14.53$, $p = 0.069$). All VIF values were below 1.2. Four significant predictors emerged:

Gender of household head (OR = 0.448, 95% CI [0.288, 0.696], $p < 0.001$). Female headed households had 55.2% lower odds of food insecurity, the strongest predictor in the model, robust across both specifications. *Marital status* (OR = 0.542, 95% CI [0.311, 0.941], $p = 0.030$). Married households had 45.8% lower odds of food insecurity, strengthening from marginal significance in Model 1. *Crop diversification* (OR = 2.473, 95% CI [1.433, 4.269], $p = 0.001$). High adoption households had 2.47 times higher odds of food insecurity, consistent with distress diversification rather than a causal pathway from diversification to insecurity. *Proximity to water sources* (OR = 2.381, 95% CI [1.086, 5.219], $p = 0.030$). This result should be interpreted cautiously given the small water proximate group ($n = 33$) and its distinct compositional profile.

Table 2

Hierarchical Binary Logistic Regression: Determinants of Food Insecurity (N = 385)

	Model 1			**Model 2**				
Variable	***B***	**SE**	**OR**	***p***	***B***	**SE**	**OR**	***p***
Female HH head	−0.758	0.214	0.468	<.001***	−0.803	0.225	0.448	<.001***
Married	−0.521	0.271	0.594	.054†	−0.613	0.282	0.542	.030*
Household size	0.061	0.062	1.063	.327	0.072	0.064	1.075	.263
Singida district	−0.134	0.219	0.874	.540	−0.290	0.231	0.748	.210
Crop divers. (high)	—	—	—	—	0.905	0.279	2.473	.001**
Water ≤ 100 m	—	—	—	—	0.867	0.400	2.381	.030*
Good market access	—	—	—	—	0.391	0.259	1.479	.131
Model fit	LR χ^2 (4) = 17.03, p = .002				LR χ^2 (7) = 33.80, p < .001			
Nagelkerke R²	0.058				0.112			
AIC / BIC	525.6 / 545.3				514.8 / 546.4			

Note. DV: Food insecurity (1 = any insecurity, 0 = food secure). OR = Odds Ratio. †p < 0.10, *p < 0.05, **p < 0.01, ***p < 0.001. — = variable not included. Hosmer–Lemeshow χ^2 (8) = 14.53, p = .069. All VIFs < 1.2.

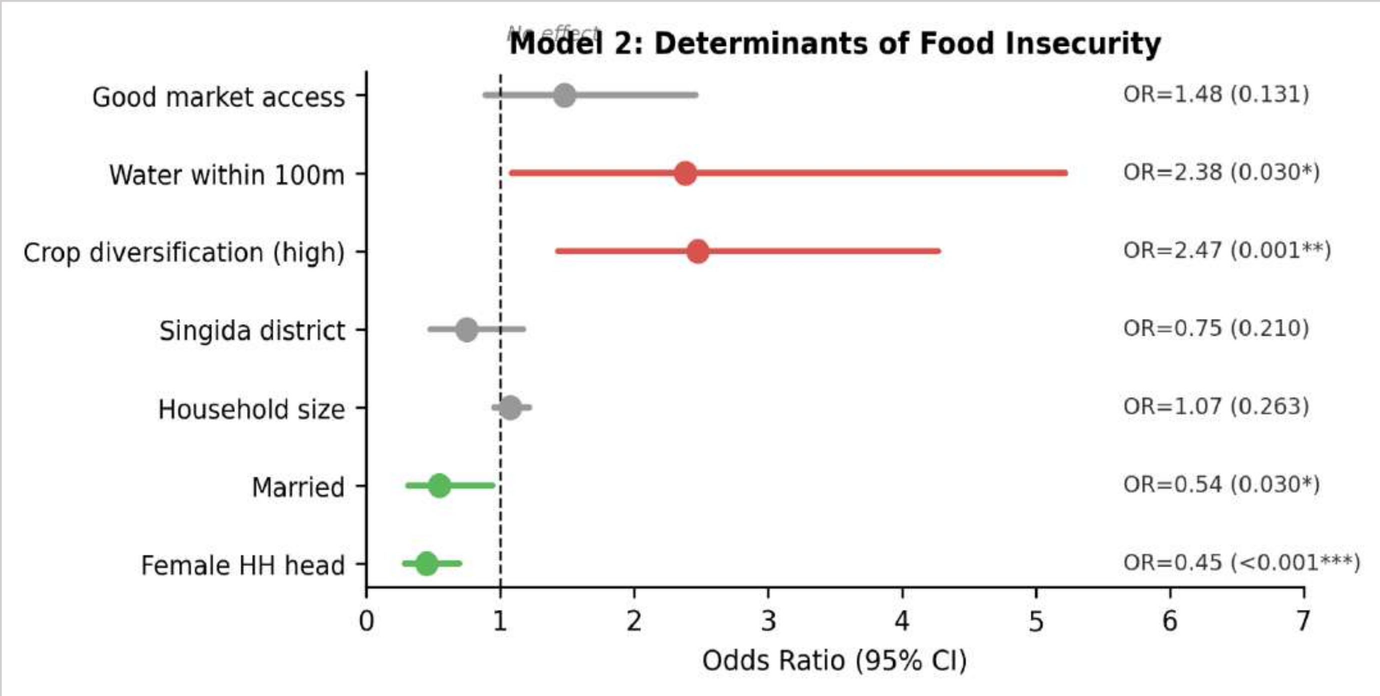

Figure 4

Forest plot of odds ratios (95% CI) from Model 2. Green = protective (OR < 1, significant); red = risk factor (OR > 1, significant); grey = not significant. Dashed line indicates no effect (OR = 1.0).

4.7 Discussion

4.7.1 The Protective Role of Female Headship

The most robust finding is that female headed households exhibited significantly lower odds of food insecurity, with this effect remaining strong across both model specifications. This challenges conventional assumptions that female headed households are uniformly more food insecure (Lutomia *et al*. 2019) and contributes to emerging evidence that the gender to food security relationship is context specific.

Several mechanisms may explain this within vegetable-based livelihoods. Women in sub Saharan Africa frequently bear primary responsibility for household food provisioning (FAO, 2024). When heading households, this responsibility is coupled with decision making authority, potentially translating into more deliberate prioritisation of food consumption. Women farmers often concentrate on food crops and vegetables rather than cash crops (Jacobs *et al.*, 2024; Jacobs *et al*., 2024), strengthening direct food access pathways. The feminisation of vegetable farming (57.1% female) suggests accumulated knowledge and networks that provide advantages in managing these systems. These findings resonate with Egah *et al*. (2023) and Awoke *et al*. (2025), while contrasting with global evidence of widening gender gaps (World Bank, 2024), underscoring that protective effects may be specific to livelihood systems where women's food management roles align with production system demands.

Interpreted through the Sustainable Livelihoods Framework (SLF), the female headship finding extends conventional understandings of human and social capital within livelihood systems. The SLF identifies human capital and social capital as key asset categories shaping livelihood outcomes (Chambers and Conway, 1992; DFID, 1999). The present results suggest that when women head households in vegetable-based livelihood systems, their accumulated knowledge of food crop management, social networks within vegetable marketing, and decision-making authority over food expenditure collectively constitute forms of human and social capital that the SLF framework does not explicitly gender. In this context, the conventional SLF assumption that female-headed households are asset-poor requires qualification: within livelihood systems where women's productive roles align with household food provisioning, female headship may represent a configuration of gendered capital that confers protective effects. This theoretical refinement is consistent with the divergence between the present findings and those of Lutomia et al. (2019), who studied broader Tanzanian household samples where women's livelihood roles may not align as closely with food access pathways. The contrast with Egah *et al.* (2023) in West Africa and Awoke *et al*. (2025) in semi-arid Dodoma likely reflects differences in the specific livelihood configurations examined: in vegetable-specialised systems, the alignment between women's productive expertise and food security outcomes may be stronger than in mixed or cereal-dominated farming systems.

4.7.2 Marital Status and Household Social Capital

The significant protective effect of marriage strengthens the case for household social structure as central to food access outcomes. Marriage may enhance food security through pooled labour, diversified income, and shared decision making. In vegetable production, spousal labour contributions are particularly important given the labour intensive and time sensitive nature of leafy vegetable production cycles. The strengthening of the marital status effect after controlling for agricultural and contextual factors suggests that the protective effect operates through channels distinct from agricultural practice or resource access.

4.7.3 Leafy Vegetables as Multifunctional Livelihood Assets

The favourable food security profile observed, with very low prevalence of severe food insecurity, may reflect the stabilising role of vegetable production. The finding that nearly one third of households relied on vegetable based coping strategies, predominantly distress sales (31.9%), underscores the dual role of vegetables as food and liquid capital. This aligns with Mwadzingeni *et al.* (2021) and with Erick *et al.* (2025b), who found that mulching and integrated soil and water management significantly reduced food insecurity risk among leafy vegetable agripreneurs in the same region. However, reliance on distress sales signals underlying vulnerability. When farmers sell produce at reduced prices due to immediate cash needs, they forfeit potential income that could improve household food security. This pattern indicates a need for two complementary interventions: first, improved post-harvest storage infrastructure and village-level aggregation centres that enable farmers to hold produce until market conditions are more favourable; and second, access to short-term agricultural credit, particularly harvest-time loans from microfinance institutions, that would provide households with liquidity during periods of food stress without requiring them to liquidate vegetable assets at below-market prices. These value chain improvements would help transform leafy vegetables from a distress-coping mechanism into a more sustainable and profitable livelihood asset.

4.7.4 CSA Adoption and Crop Diversification

The near universal adoption of traditional CSA practices means these lacks sufficient variation to differentiate food security outcomes. This suggests that in high-adoption contexts, the relevant policy question shifts from promoting adoption to optimising effectiveness and addressing household-level factors that determine whether practices translate into food security. When 79–97% of households already practise mulching, crop rotation, improved seed use, and organic fertiliser application, further adoption campaigns yield diminishing returns. Instead, policy efforts should shift toward improving practice quality through practice-quality audits that assess whether techniques are implemented correctly, peer-to-peer learning exchanges that enable farmers to share context-specific adaptations, and adaptive management training that helps households adjust practices to changing climatic conditions. Additionally, addressing complementary constraints such as market access, post-harvest storage, and credit availability may be more effective than promoting further adoption of practices that are already widespread. Erick *et al.* (2025) similarly found that attitudes, subjective norms, and perceived behavioural control significantly influence CSA adoption among vegetable agripreneurs in this region, highlighting the importance of behavioural and institutional factors beyond adoption per se.

The positive association between crop diversification and food insecurity is most plausibly explained by reverse causality: households experiencing food access challenges diversify as a reactive coping response. This is consistent with distress diversification patterns documented by Jones *et al.* (2023) and reinforces the need to distinguish proactive from reactive diversification. The cross-sectional design precludes determining temporal ordering; longitudinal research is needed.

4.7.5 Water Access: Proximity Does Not Equal Utilisation

The positive association between water proximity and food insecurity underscores the complexity of resource-to-outcome relationships. While proximity alone appears insufficient, this finding should be interpreted with caution given the small subsample ($n = 33$). A supplemental comparison of the characteristics of water-proximate versus water-distant households reveals significant compositional differences that may partially account for this counterintuitive result. Water-proximate households were disproportionately located in Singida district (72.7% vs. 43.5%, $\chi^2 = 9.26$, $p = 0.002$), had significantly larger land holdings ($M = 2.58$ vs. 1.72 acres, $t = 5.57$, $p < 0.001$), and had larger household sizes ($M = 5.9$ vs. 5.3, $t = 2.00$, $p = 0.046$). They also had lower rates of good market access (60.6% vs. 75.3%) and lower educational attainment (9.1% vs. 16.5% with secondary education or above), although these differences did not reach statistical significance. Notably, drip irrigation adoption was virtually identical between groups (6.1% vs. 5.1%), confirming that physical proximity to water did not translate into adoption of irrigation technology. These compositional differences, particularly the Singida concentration and poorer market access, suggest that the water proximity variable may be capturing locational disadvantages rather than a true negative effect of water access on food security.

Critically, proximity alone does not guarantee irrigation infrastructure or effective water management. The very low drip irrigation adoption (5.2%) illustrates the gap between physical access and effective utilisation. Kapari *et al.*

(2023) emphasise that smallholder food security gains from water access depend on complementary investments including affordable small-scale irrigation technologies, farmer training in water-efficient production methods, and institutional support for collective water management. Warning (2022) provides evidence from Tanzania that irrigation's food security benefits are contingent upon access to appropriate technology, extension services, and market linkages, recommending investments in small-scale drip irrigation systems, rainwater harvesting infrastructure, and solar-powered pumping alongside training in water scheduling and crop-water management. The present findings align with these recommendations: policies focusing solely on water proximity are insufficient without complementary investments in irrigation technology, management capacity, and market infrastructure.

4.7.6 Mechanisms Underlying the Female Headship Effect

The robustness of the female headship finding across both model specifications warrants dedicated consideration of the mechanisms through which this effect may operate. Several plausible pathways, individually or in combination, could explain why female-headed households exhibit lower food insecurity in this vegetable-producing context. First, decision-making authority over food expenditure may be a key pathway. When women head households, they exercise direct control over how household income is allocated, and evidence from sub-Saharan Africa consistently shows that women prioritise food expenditure over non-food consumption when they control household resources (FAO, 2024). In male-headed households, food expenditure decisions may be mediated through spousal negotiation, potentially diluting this prioritisation. Second, women in the study area may possess specialised knowledge and social networks specific to leafy vegetable production and marketing. The feminisation of vegetable farming (57.1% female) indicates that women have accumulated expertise in production techniques, pest management, harvest timing, and local market dynamics. Female household heads can deploy this knowledge directly without coordination costs, potentially translating into more efficient food provisioning. Third, women's social networks may facilitate food security through informal sharing arrangements, collective marketing, and information exchange about food prices and availability. These networks constitute a form of social capital that operates distinctly from male-dominated networks, which may be oriented more toward cash crops and off-farm opportunities. Fourth, dietary management practices may differ between female-headed and male-headed households, with women exercising greater care in food storage, meal planning, and dietary diversity. While the cross-sectional design precludes testing these mechanisms directly, each pathway is consistent with the observed protective effect and suggests specific lines of investigation for future research.

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

This study examined determinants of household food security among leafy vegetable producers in semi arid central Tanzania. Three principal contributions emerge. First, household demographic characteristics, particularly female headship (55% lower odds of food insecurity) and marriage (46% lower odds), are the strongest and most robust determinants, challenging simplistic gender vulnerability assumptions. Second, leafy vegetables serve multiple livelihood functions as food, income, and liquid assets, with the favourable food security profile suggesting a stabilising effect. Third, the analysis reveals important complexities in CSA to food security relationships: near universal traditional adoption limits differentiation, while positive diversification to insecurity association suggests distress-driven coping rather than a causal pathway to improved food security. Looking forward, as climate variability intensifies across semi-arid Africa, leafy vegetable production offers a scalable and gender-inclusive pathway for building climate-resilient food systems, provided that complementary investments in water infrastructure, market systems, and gender-responsive extension services are mobilised to unlock the full potential of vegetable-based livelihoods.

6.2 Recommendations

First, strengthen gender-responsive agricultural interventions by providing targeted extension services for women vegetable farmers, facilitating women's access to irrigation technology and improved inputs, and supporting women's inclusion in water user associations and farmer cooperatives. These interventions should build upon the existing food management competencies demonstrated by female household heads rather than treating women solely as vulnerable beneficiaries. Second, invest in complementary water infrastructure beyond physical proximity, specifically through small-scale drip irrigation kits suited to leafy vegetable production, rainwater harvesting structures, and solar-powered pumping systems, accompanied by maintenance training and water scheduling extension to ensure sustained utilisation. Third, support market systems to reduce distress sales through mobile-based market information systems that provide real-time vegetable price data, village-level aggregation centres that strengthen farmers' bargaining position, and partnerships with microfinance institutions for harvest-time loans that enable farmers to hold produce for better prices rather than resorting to distress sales. Fourth, promote context-appropriate CSA by shifting from adoption-focused campaigns to practice-quality optimisation, including practice-quality audits to assess implementation fidelity, peer-to-peer learning exchanges among experienced farmers, and adaptive management training that helps households adjust techniques to local conditions. Fifth, integrate leafy vegetable production into national food security strategies given its multiple co-benefits for nutrition, income, and climate resilience.

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