ENGINEERING Agriculture

Engineering Journals

RESEARCH ARTICLE

2026 / Volume 13 / Issue 6 / 26702

When tradition meets adaptation: African indigenous vegetables as resilience enhancing production systems in Kenya

Sindu W. KEBEDE (✉)[1], Mary ABUKUTSA-ONYANGO[2], Wolfgang BOKELMANN[3]

1 International Food Policy Research Institute, 5689 Addis Ababa, Ethiopia.
2 Jomo Kenyatta University of Agriculture and Technology, 00200 Nairobi, Kenya.
3 Humboldt University of Berlin, 10117 Berlin, Germany.

KEYWORDS

African indigenous vegetables, food security, production shocks, household resilience, dietary diversity, Kenya, anthropometric outcomes

HIGHLIGHTS

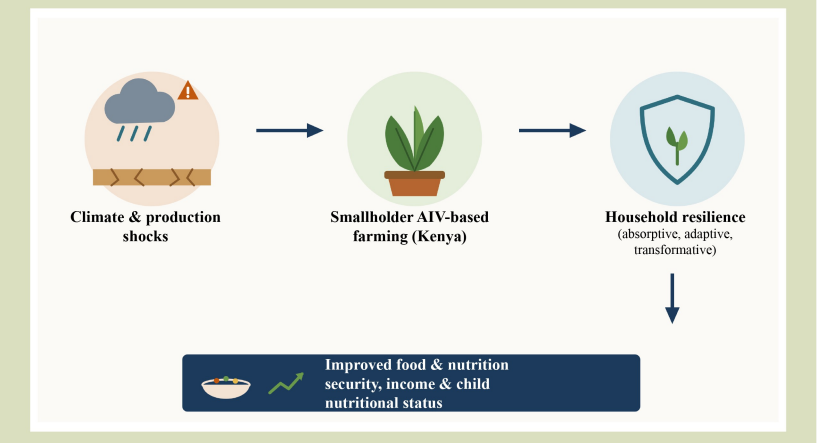
- Production shocks increase use of consumption based coping strategies.
- Dietary diversity remains stable despite production shocks.
- Underweight and wasting are sensitive to production shocks.
- Scaling indigenous vegetables strengthens adaptive capacity of smallholder systems.

Received January 29, 2026;
Accepted August 4, 2026.

Correspondence: sine.kebede@gmail.com

Special Issue: Building Resilient Agrifood Systems

GRAPHICAL ABSTRACT



ABSTRACT

Agricultural production systems in Sub-Saharan Africa are increasingly exposed to climate-related shocks that threaten food security and livelihood stability. This study examines how African indigenous vegetables function as resilience-enhancing strategies within smallholder production systems in Kenya. Using panel data from Kenya, we analyze how production shocks such as drought, crop failure, and heavy rainfall affect selected dimensions of household food security: coping strategies index, household dietary diversity score, and child anthropometric indicators. Results show that all production shocks significantly increase the coping strategies index, indicating heightened short-term food stress and reduced absorptive capacity. In contrast, dietary diversity remains stable across shock events, suggesting that African indigenous vegetables production helps sustain nutritional quality through its agroecological robustness, short growth cycles, and buffering role in household diets—enhancing adaptive capacity. Anthropometric outcomes reveal that underweight and wasting are sensitive to production shocks. These findings highlight that despite production shocks; households may sustain food

group diversity through AIVs and lower-cost staples while overall energy and micronutrient intake may fall below thresholds sufficient to protect child nutritional status. Policy interventions that promote African indigenous vegetables can enhance resilience by supporting diversified, low-input, and climate-adapted production systems in Kenya and similar contexts.

© The Author(s) 2026. Published by Higher Education Press. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0)

1 Introduction

Globally, agricultural and food systems are confronting increasing exposure to climate variability, extreme weather events and market disruptions, pressures that are especially acute for smallholders in sub-Saharan Africa. The 2025 report on the State of Food Security and Nutrition in the World estimates that 673 million people, about 8.2% of the global population, experienced hunger in 2024, with undernourishment affecting about 20% of all Africans: more than 300 million people[1]. These challenges reflect not only persistent lack of food security but also growing vulnerability within agricultural production systems, underscoring the urgency of strengthening their resilience.

Compounding these climate-driven pressures, human-made crises, including armed conflicts and geopolitical tensions, alongside the COVID-19 pandemic have further destabilized food systems by disrupting supply chains, driving input price inflation and eroding household purchasing power[2,3]. In sub-Saharan Africa, in particular, the simultaneous occurrence of natural disasters and human-made shocks has deepened agricultural vulnerability, especially among smallholder households that lack the ability to absorb overlapping shocks[2,3]. These converging pressures underscore the need for food systems that are resilient not only to climatic variability but also to human caused disruptions[4].

While, food security remains central to global development commitments, its multi-dimensionality continues to pose conceptual and measurement challenges. Although, established indicators, such as caloric intake and anthropometric measures, are longstanding tools to evaluate food availability, access and utilization, these do not fully capture the dynamic and behavioral responses that occur when households face acute shocks[5]. Over time, conceptualizations of food security have expanded to include agency, sustainability and stability, reflecting the growing recognition that food systems must not only meet immediate needs but also remain functional under conditions of stress and uncertainty.

Consequently, a range of complementary indicators has been developed to assess different dimensions of food security[6,7]. Dietary diversity measures, such as the household dietary diversity score (HDDS), capture the quality of diets and micronutrient access, while behavioral indicators such as the coping strategies index (CSI) reflect short-term responses of households to food scarcity[8]. These indicators are particularly valuable in contexts where agricultural production shocks are pervasive, as they can reveal the extent to which households absorb shocks or resort to crisis behaviors. Importantly, differential sensitivity of indicators to shocks can shed light on the resilience of specific production systems and livelihood strategies.

Production shocks, including drought, crop failure and extreme rainfall, are among the most frequent factors undermining rural livelihoods in Africa[9,10]. Such shocks typically disrupt food supply, destabilize income and force shifts in consumption patterns. However, emerging evidence indicates that the structures of local production systems, and the types of crops cultivated, are key to moderating these effects. Specifically, indigenous and agroecologically rooted crops are increasingly recognized as contributing to adaptive capacity at the household and system levels.

In Kenya, African indigenous vegetables (AIVs) have re-emerged as important components of smallholder production systems. These crops are nutritionally dense, culturally embedded, and agronomically suited to local ecological conditions. Their ability to thrive under variable rainfall, low soil fertility and limited input use makes them especially relevant for resilience-building strategies. As AIVs support both dietary and livelihood diversification, they also provide a buffer against the nutritional and economic impacts of production shocks[11].

AIVs are typically ready for harvest, after only three to four weeks growth. Unlike exotic vegetables, such as kales and cabbages, AIVs require minimal fertilizers and pesticides, thus making them well-suited to the resource-constrained, variable-rainfall conditions typical of East African smallholder production systems[12]. Examples of AIVs include African nightshade (*Solanum nigrum*), amaranth (*Amaranthus hybridus*), cowpea leaves (*Vigna unguiculata*), Ethiopian kale (*Brassica carinata*) and spider plant (*Cleome gynandra*). Regarding nutritional quality, AIVs markedly outperform exotic vegetables in provitamin A (beta-carotene), iron and calcium content, positioning them among the most micronutrient-dense food sources accessible to rural and peri-urban households across sub-Saharan Africa[13,14]. Economically, AIV-based enterprises are also more competitive, garnering significantly higher gross margins and lower variable costs than those growing exotic vegetables, thus reflecting the minimal purchased-input requirements of AIVs[12,15].

This potential aligns with growing evidence that indigenous and underutilized crop species are critical assets for food system resilience in sub-Saharan Africa, offering agricultural diversification, dietary quality and adaptive capacity under both climate variability and human-induced shocks[16–18]. Scaling up the production and integration of such crops into food systems has been identified as a promising strategy for achieving food and nutrition security in a changing climate, yet the absence of policy focus and limited access to quality seed continue to constrain their contribution[18].

Despite their growing prominence, however, AIVs have been historically marginalized within formal agricultural research, extension systems and food systems, a process rooted in colonial and post-colonial food system trajectories[19]. Also, limited research has empirically examined how households engaged in AIV production experience agricultural shocks across multiple dimensions of food security

To address this gap, and in response to the growing urgency of building food systems resilient to both nature-made disasters and human-made crises, this study investigated the relationship between production shocks and alternative food security outcomes among AIV-producing households in rural and peri-urban Kenya. Specifically, the study pursued three objectives: (1) to examine how major production shocks affect behavioral coping responses as measured by the CSI; (2) to assess whether production shocks influence household dietary diversity as measured by the HDDS; and (3) to evaluate the sensitivity of child anthropometric outcomes to production shocks. By focusing on a producer group embedded in a traditional yet adaptable production system, the study contributes empirical evidence on how AIV-based systems enhance resilience, in particular adaptive capacity, within smallholder agriculture.

This study is timely for both research and policy. As governments and development partners increasingly prioritize resilient and sustainable agricultural systems[20], evidence on the adaptive role of AIVs can inform targeted interventions that enhance resilience and reduce vulnerability, including seed system strengthening, irrigation investments and market support. The results offer a nuanced understanding of resilience pathways within African smallholder production systems and contribute to ongoing efforts to build climate-resilient, inclusive and nutrition-sensitive agricultural futures.

2 Conceptual framework: African indigenous vegetables as resilience-enhancing production systems

Agricultural production systems across sub-Saharan Africa are increasingly challenged by climate variability, extreme weather events, market volatility and persistent ecological degradation. Consequently, resilience has emerged as a guiding paradigm for designing and evaluating agricultural systems that can withstand and adapt to shocks while sustaining food and livelihood functions. In this context, resilience refers to the capacity of food and agricultural systems to absorb, adapt to and recover from shocks while maintaining essential functions such as food availability, food access and nutritional quality. Following the 3D resilience framework, resilience is understood as comprising three interconnected capacities: absorptive capacity, adaptive capacity and transformative capacity[21,22]. Absorptive capacity refers to the ability to buffer shocks and maintain core functions in the short term. Adaptive capacity reflects the ability of households to make incremental adjustments in agricultural practices and livelihood strategies in response to evolving shocks. Transformative capacity refers to longer-term structural shifts, such as changes in institutional arrangements, governance and policy enforcement, that ultimately reduce underlying vulnerabilities and enable fundamental system changes[23].

AIVs have several ecological and socioeconomic attributes that are consistent with resilience-enhancing production systems. Agronomically, many AIV species are well-suited across diverse agroecological zones due not just to their drought tolerance, low external input requirements and rapid growth cycles, but also resistance to locally prevalent pests and diseases. These characteristics reduce reliance on purchased inputs and can enable faster recovery following adverse events, thereby strengthening absorptive capacity within smallholder farming systems.

AIVs also support adaptive capacity, particularly through production and dietary diversification. By integrating AIVs alongside staple crops, production risks are spread across crops with different sensitivities to weather variability and resource constraints, thus helping to stabilize food supply and reduce vulnerability to single-crop failure. Nutritionally, AIVs are nutrient-dense, providing essential vitamins (A and C), minerals (e.g., iron, calcium and magnesium) and antioxidants. Their inclusion in household diets can improve dietary diversity, support maternal health, and contribute to disease prevention[12,24]. This nutritional contribution is especially important when shocks reduce the availability or affordability of market-purchased foods, allowing households to preserve diet quality even under adverse production conditions.

Beyond buffering and adjustment, AIVs may also contribute to transformative capacity through longer-term shifts in production and market orientation. Increasing commercialization by integrating AIVs into urban and peri-urban markets, alongside growing policy recognition of indigenous crops, may support broader transitions toward diversified, climate-adapted and culturally embedded production systems. These processes can create pathways for income diversification, value addition and stronger linkages between traditional crops and modern food value chains. While these dynamics are typically realized over longer time horizons, they provide important context for understanding the transformative potential of AIV-based production systems.

These three resilience capacities directly inform the choice of food security indicators used in the empirical analysis. The CSI operationalizes absorptive capacity. It measures the extent to which households resort to consumption-based coping behaviors following a production shock, capturing their ability to buffer food access in the short term. The HDDS operationalizes adaptive capacity, which is the ability of households to adjust food sourcing and diversify strategies, through own production, market purchases and social networks, in ways that preserve nutritional quality under adverse conditions. Anthropometric indicators of child nutritional status capture both absorptive and transformative dimensions; short-term outcomes (weight-for-age and weight-for-height) are sensitive to acute fluctuations in food availability, while long-term outcomes such as height-for-age (stunting) reflects structural deprivation accumulated over longer time horizons. From this mapping, the framework generates three testable expectations: (1) production shocks will increase CSI, reflecting depletion of absorptive capacity; (2) dietary diversity will be relatively resilient to shocks, given the adaptive buffering properties of AIV-based systems; and (3) short-term child anthropometric outcomes will be more sensitive to shocks than stunting, which responds to long-term structural rather than acute conditions.

The shock-food security relationship is not uniform across households; it is moderated by socioeconomic and livelihood characteristics that condition the depth of available resilience capacities. For example, access to irrigation reduces rainfall dependence and stabilizes production even when shocks occur, thereby strengthening absorptive capacity. Participation in high-value markets and access to credit expand adaptive capacity by enabling households to substitute purchased food for production losses. The education level of the household head facilitates more effective adjustments in coping behavior and dietary strategy. These characteristics are incorporated into the empirical model as controls, thus helping to identify the underlying factors of the shock-food security relationship within the resilience framework.

Figure 1 summarizes the conceptual logic of the study. Production shocks, drought, crop failure, and heavy rainfall, directly disrupt agricultural production, with cascading effects on household food access, diet quality, and child nutritional status. The framework illustrates how AIV-based production systems mediate these effects through the three resilience capacities outlined above: absorptive capacity is operationalized through short-term coping behavior (CSI); adaptive capacity through maintaining dietary diversity under shock conditions (HDDS); and transformative capacity through longer-term nutritional trajectories, particularly child stunting. Household socioeconomic characteristics, including irrigation access, market participation, credit, and education, enter the framework as moderating factors that strengthen or

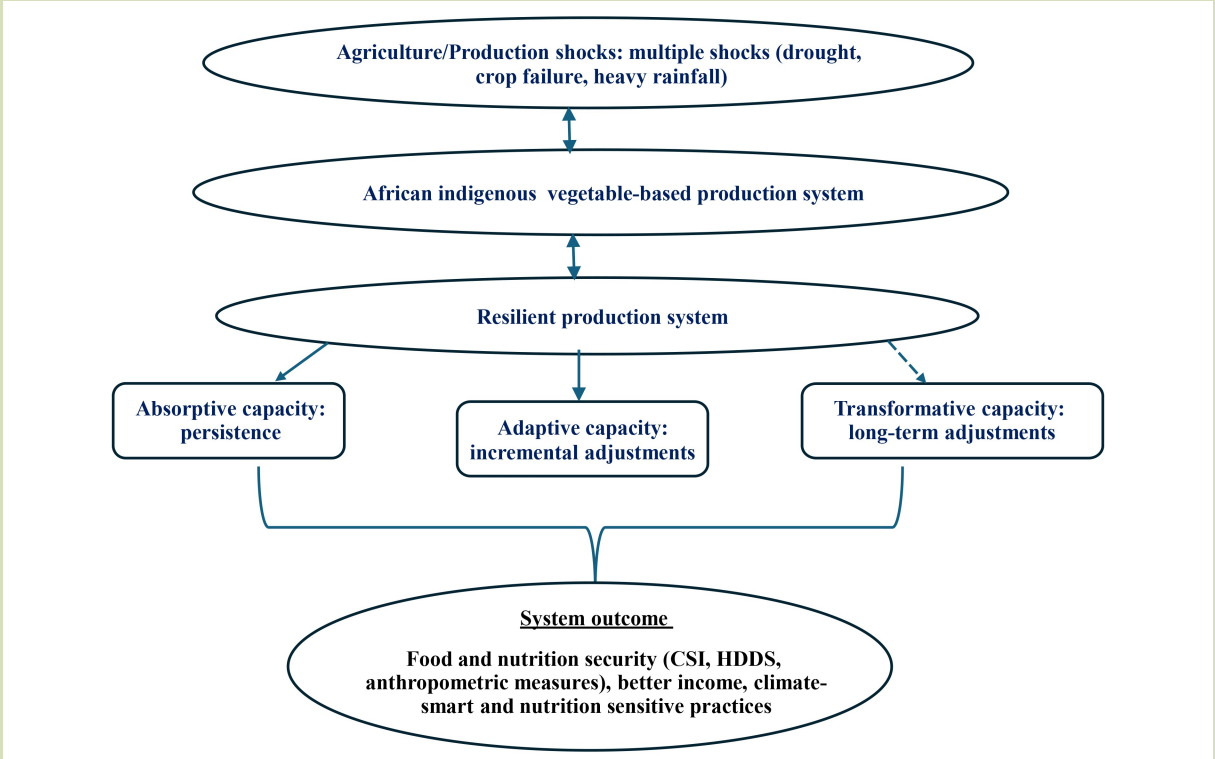


Fig. 1 African indigenous vegetable production systems and a 3D resilience framework.

weaken these capacities. Given the 2-year panel window and household-level focus, this study engages primarily with absorptive and adaptive capacities, while treating transformative capacity as a longer-term contextual backdrop.

3 Materials and methods

3.1 Data

This study draws on data from the Horticultural Innovation and Learning for Nutrition and Livelihoods in East Africa (HORTINLEA) panel survey conducted in rural and peri-urban areas of Kenya in 2015 and 2016. The rural sites were in *Kisii* and *Kakamega* counties in Western Kenya, while the peri-urban sites were in *Kiambu* and *Nakuru* counties. The survey targeted agricultural households, with a particular focus on producers of AIVs.[1] The dataset contains detailed demographic, socioeconomic and agricultural information, with modules on production shocks and food security indicators[25]. Surveyed households were selected using a multistage sampling design. First, counties were purposively chosen based on the prevalence of AIVs production[25]. Intracountry regions and divisions were subsequently identified in consultation with district agricultural offices. Within each division, locations or wards were randomly selected, followed by random sampling of households. Data collection was conducted through face-to-face interviews, resulting in a balanced panel of 683 households used for analysis. Although the HORTINLEA survey is not nationally representative, it offers a comprehensive view of agricultural producers in rural and peri-urban Kenya. Given the randomized sampling and substantial sample size within each county, the results can be considered representative of AIV producers operating in comparable contexts.

[1] This focus aligns with the broader objective of the HORTINLEA project to evaluate the contribution of AIVs to food and nutrition security and to the improvement of rural livelihoods in Kenya.

Fieldwork was conducted in September and October of each survey year. Enumerators and field supervisors were recruited and trained by the HORTINLEA team in collaboration with Egerton University (the project's principal local research partner in Kenya), which provided institutional support for interviewer training prior to deployment. After the questionnaire underwent field piloting with smallholder households in the *Nakuru* area, it was subsequently revised to address the identified ambiguities. Data quality was maintained through a multilayered validation protocol: random back-checks were conducted on a subset of completed interviews to verify enumerator accuracy, while data consistency and cross-validation checks were applied throughout the data collection phase. Panel attrition across the two rounds was minimal, facilitated by the use of geo-coded household records established in the first round, which enabled reliable re-identification and tracking of the same households in the follow-up survey conducted one year later.

The integration of AIVs into Kenyan food systems is a relatively recent development, particularly regarding their emerging presence in urban markets[25]. At the same time, AIV producers are highly exposed to agricultural shocks, such as drought, crop failure, and heavy rainfall, key issues examined in this study. Thus, focusing on this producer group provides an appropriate context for analyzing the impacts of production shocks on household food security in general and specifically highlights the role of AIV-based production systems in enhancing adaptive capacity. Also, the analysis generates policy-relevant insights with dual benefits: (1) reducing farmer vulnerability by improving understanding of shock exposure and its food security implications; and (2) supporting the promotion and commercialization of AIVs as a pathway toward adaptive and resilient food systems in Kenya and other similar contexts.

3.2 Methodology

The HORTINLEA household survey included a detailed module on shocks, capturing household experiences over the respective 12 months preceding the 2015 and 2016 survey rounds. The most frequently reported shocks include drought, crop failure, livestock death, household illness and unusually heavy rainfall. The empirical analysis focuses explicitly on these major production shocks. Consistent with evidence emphasizing the methodological challenges of using a single indicator for low food security[26], alternative food security indicators were derived from the comprehensive food security module of the survey. These are the CSI, the HDDS and anthropometric indicators.

Coping strategy index: CSI was constructed following[8]. Households were asked, "What do you do when you do not have enough food or money to buy food?" after which they reported the frequency with which each response was used during the previous week. Focus group discussions were held in each community to identify commonly used coping mechanisms (in response to food shortages) and to assess their relative severity, which provided the weighting scheme. For each household, the frequency of use of specific strategies (captured in the HORTINLEA survey) was weighted by its severity (captured through the group discussions) and aggregated across all strategies to generate a continuous CSI score. A higher CSI value indicates greater reliance on consumption coping strategies, and thus a lower level of food security. Frequently reported coping behaviors include consuming less preferred or cheaper foods, gathering wild foods, eating immature crops or seed stocks, sending children to eat elsewhere, and sending household members to beg. A complete list of reported coping strategies is provided in Fig. S1.

Household dietary diversity score: HDDS reflects the number of food groups consumed by the household during the preceding week, as reported in the HORTINLEA survey. Eleven food groups were considered: staples; roots and tubers; pulses, seeds and nuts; fruits; vegetables; fish; meat; eggs; dairy (milk only); oils; and sugar. While the CSI captures the severity of low food security, dietary diversity is a robust predictor of household and child nutrition, as it indicates dietary quality and micronutrient adequacy[27]. Jointly, CSI and HDDS measure complementary dimensions of food security, household-level coping capacity and diet quality.

Anthropometric indicators: to complement CSI and HDDS, anthropometric indicators of nutritional status were computed for children under five. These include Z-scores for weight-for-age, weight-for-height, and height-for-age, based on the WHO reference population[28,29]. The indicators correspond to three forms of malnutrition: (1) underweight defined as weight-for-age Z-score values are below the WHO reference value by more than two standard deviations; (2) wasting defined as weight-for-height Z-score values are below the WHO reference value by more than two standard deviations; and (3) stunting defined

as height-for-age Z-score values are below the WHO reference value by more than two standard deviations.

Empirical strategy: a panel data approach was used to examine the relationship between agricultural shocks and food security outcomes. Panel models account for unobserved time-invariant heterogeneity that could bias cross-sectional estimates. Both fixed- and random-effects specifications were estimated[30]. Although the fixed-effects model controls for unobserved household-specific characteristics and captures within-household variation over time, the random-effects model exploits both within- and between-household variation. The Hausman test was used to determine the appropriate estimator for inference. The empirical specification is given as:

$$Y_{it} = \beta X_{it} + \gamma Z_{it} + \alpha_i + u_{it} \quad (1)$$

where, Y_{it} is the dependent variable (CSI, HDDS or child anthropometric indicator) for household i at time t, X_{it} is a vector of socioeconomic and demographic characteristics, Z_{it} is the set of shocks experienced, β and γ are vectors of coefficients, a_i is the unobserved household-specific effects (fixed over time), and u_{it} is the idiosyncratic error term. Identification relies on within-household variation over time combined with cross-sectional variation in AIV production status, conditional on observed covariates and time-invariant unobserved heterogeneity captured through the correlated random effects specification.

The use of panel data methods to estimate the effects of agricultural production shocks on food security outcomes is well-established in the empirical literature on smallholder agriculture in sub-Saharan Africa. For example Demeke et al.[31] used a fixed-effects panel regression to identify the effects of rainfall shocks on smallholder food security and vulnerability in rural Ethiopia, demonstrating the necessity of panel approaches for controlling time-invariant household characteristics that confound cross-sectional estimates. Similarly, Hoddinott and Kinsey[32] used a household panel with fixed effects to show that drought shocks significantly reduce child height-for-age in rural Zimbabwe, and this provides a methodological precedent for panel data analysis of anthropometric outcomes following production shocks. More directly, Freudenreich and Kebede[33] applied panel econometric methods to a balanced panel drawn from the HORTINLEA survey in rural and peri-urban Kenya, the same dataset used in the present study, to analyze the effects of shock exposure among AIV-producing smallholder households, supporting the appropriateness of panel methods for this specific context and dataset. To account for potential serial correlation and heteroskedasticity arising from repeated observations on the same households, standard errors were clustered at the household level.

Alternative identification strategies were considered but found unsuitable given the data structure. A purely cross-sectional approach would not account for the time-invariant unobserved household heterogeneity, such as inherent farming ability, land quality and risk preferences, that simultaneously influences both shock exposure and food security outcomes, leading to omitted variable bias. Instrumental variables estimation, while preferable for causal identification, requires instruments that are strongly correlated with production shock occurrence while being excludable from the food security outcome equations. Unfortunately, no such instruments are available in the HORTINLEA dataset.

The analysis used in this study has known limitations, given the nature of data used. First, the two-year panel restricts the ability to capture long-run shock dynamics or assess whether estimated effects persist, attenuate or accumulate beyond the observed survey rounds. Second, the panel specification controls for time-invariant unobserved heterogeneity and unobserved time-varying confounders, such as changes in household preferences, local market conditions, or health status, cannot be fully addressed and may still bias the estimates to some degree. Third, the broader generalizability of the findings is limited because the analytical sample comprises exclusively AIV-producing households. Thus, the study cannot exploit variation between AIV producers and non-producers in a way that attributes resilience outcomes specifically to AIV cultivation. Accordingly, the results should be interpreted as describing patterns and conditional associations rather than causal effects.

4 Results

The descriptive analysis provides important context for understanding how AIV-producing smallholder households experience, and respond to, production shocks. The sample largely comprises male-headed (~82%) and married households (83%–85%), with an average household size of six members (Table 1). Mean age of the household head is 53 years, and household heads have an average of 8–9 years of

Table 1 Demographic and socioeconomic characteristics of sample households in 2015 and 2016

Sample household	2015	2016
Male headed households (%)	81.8 (0.39)	81.8 (0.39)
Married households (%)	82.9 (0.37)	85.1 (0.36)
Household size (mean)	5.92 (2.33)	6.10 (2.36)
Age of household head (mean)	51.7 (12.7)	52.7 (12.6)
Years of education of household head (mean)	9.61 (4.56)	8.48 (4.67)
Off farm employment (%)	38.5 (0.63)	33.8 (0.47)
Household owns agricultural land (%)	90.2 (0.30)	96.3 (0.19)
Household perceives agricultural land is fertile (%)	48.9 (0.50)	37.3 (0.48)
Household has access to irrigation (%)	23.4 (0.42)	27.7 (0.45)
Household has access to credit (%)	25.6 (0.44)	23.6 (0.42)
Household has access to extension (%)	46.0 (0.50)	63.7 (0.48)
Number of farm enterprises in household (mean)	7.22 (2.17)	7.43 (2.43)
Household participates in high value market (%)	7.60 (0.27)	30.5 (0.46)
Number of observations	683	683

Note: Numbers in parenthesis are standard deviation.

formal education. Most households cultivate an average of seven crops on their own farmland and over 30% engage in off-farm employment activities. About 48% of households perceived that their plots were fertile in 2015; in just one year this fell to 37%. Access to agricultural services improved between 2015 and 2016, with extension access rising from 46% to 64% and credit access reaching 23% in 2016. Nonetheless, irrigation, an important resilience-enhancing input, remains limited to only one-quarter of households.

Market participation has expanded considerably, with access to high-value markets, such as supermarkets, increasing from 7% in 2015 to 30% in 2016. This drastic increase reflects broader efforts to promote AIVs through awareness campaigns and market linkages[15,34]. The growing integration of AIV producers into formal and urban markets not only enhances income diversification but also strengthens household and food system resilience by embedding traditional crops within modern value chains. Such integration contributes to food system adaptability, as AIVs provide both nutritional diversity and adaptive capacity to withstand production shocks common in smallholder agriculture in Kenya.

Drought emerged as the most prevalent production shock, affecting more than 40% of sample households in both 2015 and 2016, followed by crop failure and unexpected heavy rainfall (Table 2). Although the overall reporting of shock occurrence declined slightly in 2016, exposure remains substantial, underscoring the volatility of the agricultural production environment. In terms of food security indicators, the CSI declined in 2016 relative to 2015, indicating reduced reliance on consumption-based coping strategies, while the HDDS remained relatively stable across the two periods.

On average, households in the sample reported a dietary diversity score of nine, meaning that they consumed nine distinct food groups out of a possible eleven. This relatively high dietary diversity reflects, among other factors, the contribution of AIV production to household nutrition, as AIV producers have direct access to a wide range of nutrient-rich vegetables. Such diversity not only improves dietary quality but also enhances household resilience to production shocks, since AIVs often thrive under variable climatic conditions and provide a reliable food source when other crops fail. The range of dietary diversity in the sample spans from a minimum of four food groups to a maximum of 11, as illustrated in Fig. S2. Also, Z-scores for weight-for-age, weight-for-height, and height-for-age are reported for 2015 and 2016, providing complementary measures of child nutritional status.

Table 2 Description of selected variables

Variable	2015	2016
Production shocks		
Households affected by drought (%)	44.8 (0.50)	40.3 (0.49)
Households affected by crop failure (%)	38.9 (0.49)	28.0 (0.45)
Households affected by heavy rain (%)	26.1 (0.44)	13.0 (0.34)
Number of production shocks (mean)	1.09 (0.90)	0.81 (0.80)
Number of observations	683	682
Food security indicators		
Coping strategy index (mean)	20.7 (25.42)	16.4 (25.0)
Household dietary diversity index (mean)	9.06 (1.39)	9.20 (1.28)
Number of observations	680	681
Weight-for-age Z-score (mean)	0.90 (3.21)	1.33 (3.02)
Weight-for-height Z-score (mean)	–2.27 (5.22)	1.14 (4.52)
Height-for-age Z-score (mean)	0.41 (10.9)	–1.82 (8.23)
Number of observations	208	160

Note: Numbers in parenthesis are standard deviation.

The panel regression results (Tables 3–5) reveal the effect of production shocks on alternative food security indicators. Based on the Hausman test, the random effects model was selected for interpretation (Table S1). Separate regressions were conducted for each production shock type.

Coping strategy index and shock exposure: the CSI, a continuous variable, captures the extent to which households adopt consumption-coping strategies in response to food stress; thus, a higher CSI score indicates lower food security. The findings reveal a positive and significant association between CSI and all types of production shocks (Table 3). Occurrence of drought increases the CSI by 3.9 points, crop failure by 4.3 points, and heavy rainfall by 6.1 points, all significant at the 1% level. These results confirm that production shocks exacerbate acute lack of food security making households adopt severe coping strategies. This shows the sensitivity of consumption behavior to production shocks, reflecting limited absorptive capacity when household food access is constrained.

Several socioeconomic and demographic characteristics moderate these effects. Male-headed households and those with better-educated heads exhibit lower CSI scores, significant at 5% and 1% levels, respectively. This indicates greater absorptive capacity of male-headed and better educated households. In contrast, larger households and married households tend to report higher CSI scores, reflecting greater vulnerability to low food security pressures. Among livelihood-related variables, both perceived soil fertility and use of irrigation significantly reduce CSI, significant at the 1% level, underscoring the role of irrigation not just in enhancing the adaptive capacity of farm households but also mitigating rainfall dependency and buffering households against production shocks. Although market participation and access to services such as credit and extension are not statistically significant in the CSI model, their directional effects hint at longer-term resilience benefits not captured through short-term coping behaviors.

In combination, the CSI results reveal that production shocks impose immediate pressure on household consumption strategies. However, the presence of AIVs, often cultivated with low external inputs and relatively tolerant to various shocks, may help households maintain some degree of food access even when these shocks occur. This aligns with the resilience-enhancing characteristics of AIV production systems, which reduce dependence on volatile markets and provide fallback food sources during adverse conditions.

Table 3 Coping strategy index (CSI) and production shocks: random effect regression results

Type	CSI (1)	CSI (2)	CSI (3)	CSI (4)	CSI (5)
Household demographic					
Male headed household	−6.79**	−6.73**	−6.834**	−6.79**	−6.75**
	(3.08)	(2.71)	(2.70)	(3.08)	(3.08)
Married household head	5.02*	4.85*	5.14*	5.02*	4.89*
	(2.93)	(2.77)	(2.77)	(2.93)	(2.92)
Age of household head	−0.01***	−0.01	−0.01	−0.01***	−0.01**
	(0.00)	(0.01)	(0.01)	(0.00)	(0.00)
Household size	1.83***	1.90***	1.88***	1.83***	1.83***
	(0.39)	(0.32)	(0.32)	(0.39)	(0.39)
Years of education of head	−0.77***	−0.76***	−0.79***	−0.77***	−0.76***
	(0.14)	(0.14)	(0.14)	(0.14)	(0.14)
Household means of livelihood					
Off-farm employment is main occupation	−6.79**	−0.91	−0.92	−0.81	−0.79
	(1.24)	(1.24)	(1.24)	(1.06)	(1.07)
Head perception on soil fertility	−3.80***	−4.14***	−4.19***	−3.71***	−3.68***
	(1.31)	(1.30)	(1.31)	(1.24)	(1.22)
Household uses irrigation for AIV production	−5.07***	−4.83***	−4.67***	−4.65***	−4.73***
	(1.55)	(1.56)	(1.56)	(1.30)	(1.29)
Household owns gricultural land	−0.11	−0.23	−0.32	−0.31	−0.27
	(2.60)	(2.60)	(2.60)	(2.40)	(2.40)
Access to services and market participation					
Household has access to credit	−0.78	−1.24	−0.88	−1.10	−1.16
	(1.53)	(1.53)	(1.53)	(1.40)	(1.38)
Household has access to extension	−0.66	−0.62	−1.05	−0.97	−0.84
	(1.32)	(1.32)	(1.33)	(1.31)	(1.31)
Number of farm enterprises in household	−0.43	−0.43	−0.44	−0.32	−0.31
	(0.29)	(0.29)	(0.29)	(0.27)	(0.26)
Household participates in high value market	−1.85	−1.88	−1.84	−1.51	−1.53
	(1.68)	(1.68)	(1.68)	(1.59)	(1.59)
Production shocks					
Household faced drought	3.93***			3.58**	
	(1.32)			(1.43)	
Household faced crop failure		4.33***		3.05**	
		(1.36)		(1.46)	
Household faced heavy rain			6.12***	5.86***	
			(1.62)	(1.64)	
Number of shocks faced by household					3.90***
					(0.75)
Constant	20.5***	21.0***	21.5***	19.4***	19.2***
	(5.19)	(5.17)	(5.14)	(4.34)	(4.35)
Observations	1355	1354	1354	1354	1354
Number of households	683	683	683	683	683

Note: Dependent variable: CSI, continuous variable. Regressions coefficient estimates are reported. Standard errors in parentheses. *, ** and *** denote significance at 10%, 5%, and 1% levels, respectively.

Dietary diversity and shock exposure: HDDS results (Table 4) reveal a different pattern. None of the three production shocks show a statistically significant influence on dietary diversity. Although the coefficients for drought and heavy rainfall show the expected negative signs, indicating that these shocks may reduce dietary diversity, their effects are not statistically

Table 4 Household dietary diversity score (HDDS) and production shocks: random effects regression results

Type	HDDS (1)	HDDS (2)	HDDS (3)	HDDS (4)	HDDS (5)
Household demographics					
Male headed household	0.026	0.026	0.026	0.238	0.238
	(0.02)	(0.02)	(0.02)	(0.15)	(0.15)
Married household head	−0.008	−0.008	−0.008	−0.050	−0.054
	(0.02)	(0.02)	(0.02)	(0.15)	(0.15)
Household size	−0.001	−0.001	−0.001	−0.005	−0.006
	(0.00)	(0.00)	(0.00)	(0.02)	(0.02)
Years of education of head	0.002***	0.002***	0.003***	0.020**	0.020**
	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)
Household means of livelihood					
Off-farm employment is main occupation	0.011	0.012	0.012	0.088	0.092
	(0.01)	(0.01)	(0.01)	(0.07)	(0.067)
Household owns agricultural land	0.013	0.013	0.013	0.111	0.114
	(0.02)	(0.02)	(0.02)	(0.14)	(0.14)
Household owns livestock	0.017	0.017	0.016	0.186	0.183
	(0.02)	(0.02)	(0.02)	(0.18)	(0.18)
Access to services and market participation					
Household uses irrigation for AIV production	0.021**	0.022**	0.021**	0.17**	0.17**
	(0.01)	(0.01)	(0.01)	(0.08)	(0.08)
Household has access to credit	0.028***	0.027***	0.028***	0.21**	0.21***
	(0.01)	(0.01)	(0.01)	(0.08)	(0.08)
Household has access to extension	0.003	0.003	0.002	0.016	0.012
	(0.01)	(0.01)	(0.01)	(0.07)	(0.07)
Household participate in high value market	0.023**	0.024**	0.023**	0.170*	0.172*
	(0.01)	(0.01)	(0.01)	(0.09)	(0.09)
Production shocks					
Household faced drought	−0.003			−0.049	
	(0.01)			(0.07)	
Household faced crop failure		0.012		0.105	
		(0.01)		(0.07)	
Household faced heavy rain			−0.005	−0.059	
			(0.01)	(0.09)	
Number of shocks faced by household					0.009
					(0.04)
Constant	2.12***	2.11***	2.12***	2.02***	2.02***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Observations	1365	1364	1364	1364	1364
Number of households	683	683	683	683	683

Note: Dependent variable: HDDS, continuous variable. Standard errors in parentheses. *, ** and *** denote significance at 10%, 5%, and 1% levels, respectively.

significant and are economically negligible. These findings suggest that household dietary diversity remains relatively stable even under adverse production conditions, highlighting the nutritional buffering role of AIVs within production systems. AIVs offer a consistent and culturally embedded source of micronutrients that can be harvested even under challenging conditions. Their incorporation into diversified production portfolios likely contributes to the absorptive and adaptive capacity of households, allowing them to preserve dietary diversity without substantial shifts in consumption behavior.

Of the socioeconomic and demographic characteristics, years of education of the household head gave a statistically

Table 5 Anthropometric measures and production shocks: random effects regression results

Type	Weight-for-age (underweight)	Weight-for-height (wasting)	Height-for-age (stunting)
Household demographics			
Male headed household	1.25	1.18	0.192
	(0.804)	(1.61)	(2.56)
Married household head	−0.303	−2.01	1.37
	(0.794)	(1.58)	(2.53)
Age of household head	0.021	0.027	0.008
	(0.015)	(0.029)	(0.049)
Household size	−0.042	0.066	−0.413
	(0.081)	(0.150)	(0.259)
Years of education of head	0.051	−0.031	0.243**
	(0.035)	(0.064)	(0.112)
Household means of livelihood			
Off-farm employment is main occupation	0.062	−0.395	0.380
	(0.228)	(0.402)	(0.725)
Household owns agricultural land	−0.854	−1.08	−1.36
	(0.626)	(1.17)	(1.99)
Household owns livestock	0.440	0.563	1.88
	(0.795)	(1.57)	(2.52)
Access to services and market participation			
Household uses fertilizer	−0.352	−0.342	−0.311
	(0.324)	(0.620)	(1.03)
Household uses irrigation	0.081	0.354	-0.603
	(0.396)	(0.757)	(1.26)
Household has access to credit	0.463	−0.113	0.894
	(0.364)	(0.698)	(1.16)
Household has access to extension	0.226	2.58***	−3.55***
	(0.328)	(0.632)	(1.04)
Number of farm enterprises in household	−0.15**	−0.299**	0.080
	(0.076)	(0.150)	(0.244)
Household participate in high value market	−0.063	0.064	1.08
	(0.427)	(0.815)	(1.35)
Production shocks			
Household faced drought	−0.849***	−1.78***	1.56
	(0.321)	(0.611)	(1.02)
Household faced heavy rain	−0.113	0.280	−0.393
	(0.421)	(0.817)	(1.33)
Household faced crop failure	−0.764**	−0.949	1.37
	(0.333)	(0.641)	(1.06)
Number of shocks faced by household	−0.564***	−0.899**	0.885
	(0.187)	(0.365)	(0.598)
Constant	0.822	0.935	−1.97
	(1.45)	(2.77)	(4.59)
Observations	396	290	396
Number of households	271	229	271

Note: Robust standard errors in parentheses. *, ** and *** denote significance at 10%, 5%, and 1% levels, respectively. Sample size is small because only households with children younger than five are considered.

significant, albeit economically modest, positive association with dietary diversity scores. Thus, education may enhance household awareness of nutritional diversity, even if the magnitude of its effect is limited in our sample estimation. For

access to services and markets, use of irrigation for AIV production, participation in high-value markets and access to credit each increase dietary diversity by about two food groups, with effects significant at 5%, and at 1% levels, respectively. This further reinforces the importance of investments in market linkages and institutional support in enhancing the adaptive capacity of AIV-producing households.

Overall, the findings highlight the potential role of AIV production and market integration in sustaining dietary diversity and nutritional quality, even when households face production shocks. The availability of AIVs, often cultivated under small-scale irrigation and traded in emerging markets, appears to provide a buffering effect that supports food system adaptability, helping households maintain diverse diets despite production-related shocks.

Child anthropometry and shock exposure: the regression results for anthropometric measures (Table 5) reveal differentiated sensitivity to production shocks. Both weight-for-age (underweight) and weight-for-height (wasting) decline significantly in response to drought and to the cumulative number of shocks, with significant effects at the 1% level. Similarly, crop failure shows a significant negative effect on weight-for-age, reducing the corresponding Z-scores at the 5% significance level. These patterns indicate that short-term nutritional outcomes among children are particularly vulnerable to fluctuations in household food availability during shock periods.

In contrast, no statistically significant relationship was found between any of the production shocks and height-for-age (stunting), a measure of long-term chronic malnutrition. This finding is consistent with resilience literature suggesting that long-term indicators are less responsive to short-term shocks and reflect deeper structural conditions, such as maternal nutrition, sanitation and overall deprivation.

The mixed results across anthropometric indicators mirror the differentiated response patterns observed for CSI and HDDS. While acute shocks undermine short-term nutritional status, the persistence of dietary diversity among AIV-producing households may help mitigate deeper nutritional deterioration. This reflects not only household coping behaviors but also the underlying robustness of AIV-based production systems: their short growth cycles, agroecological suitability, and nutrient density contribute to nutritional resilience even when production shocks occur.

5 Discussion

This study examined the relationship between production shocks and alternative food security measures among AIV producers in rural and peri-urban Kenya. The analysis focused on the most prevalent production shocks, drought, crop failure and heavy rainfall, and used alternative indicators of food security, namely the CSI, the HDDS and anthropometric measures for children under 5 years of age. The panel data collected in 2015 and 2016 by HORTINLEA provides a unique opportunity to account for unobserved household-level heterogeneity in assessing these relationships. As such, the study provides empirical insights into how traditional, agroecologically grounded vegetable production systems enhance the resilience of smallholder production systems. Interpreted through the conceptual lens of absorptive, adaptive and transformative resilience capacities, the results offer a nuanced picture of resilience pathways within AIV-based agricultural production systems.

The significant increase in CSI in response to most reported shocks, including drought, crop failure and heavy rainfall, underscores the sensitivity of short-term consumption behaviors to production shocks. This finding is consistent with studies reporting that acute production shocks can often undermine household absorptive capacity, leading to reliance on stress-coping strategies[9]. Given that all households in the sample are AIV producers, the observed levels of coping may reflect a moderated response compared to producers of less resilient crops. Owing to their short growth cycles, low input requirements and ability to withstand variable shocks, AIVs likely contribute to buffering food availability, even when households must adjust their consumption strategies. These attributes illustrate the role of indigenous crops in supporting absorptive capacity, helping households maintain at least minimal food access under adverse conditions.

In contrast to CSI, dietary diversity remained stable in the face of shocks, suggesting a form of nutritional resilience within AIV-producing households. This stability is consistent with resilience theory and recent findings, which posits that diversified production, particularly of nutrient-dense and climate-adapted crops, supports dietary quality during shocks by providing accessible sources of essential micronutrients[35,36]. The ability of households to maintain dietary diversity despite experiencing major production shocks implies that AIV-based systems help preserve dietary quality,

potentially through continuous access to vegetables that are culturally embedded, rapidly harvested and agronomically suited to shock-prone environments. Irrigation, participation in high-value markets and access to credit further strengthen this adaptive capacity, enabling households to supplement home-produced foods with purchased food items even under conditions of production shortfall. It should be noted, however, that HDDS measures dietary variety, the number of food groups consumed, rather than caloric adequacy or total nutrient intake. Households may therefore sustain food group diversity by shifting toward AIVs and lower-cost staples while overall energy and micronutrient intake falls below thresholds sufficient to protect child nutritional status, a distinction that helps account for the apparent divergence between stable dietary diversity and the deterioration in short-term anthropometric outcomes.

The anthropometric results reveal a mixed picture. Short-term nutritional indicators such as underweight and wasting deteriorate significantly in response to drought and occurrence of multiple shocks, highlighting the vulnerability of young children to acute fluctuations in food availability during shocks. These findings reflect the immediate biological and behavioral pathways through which shocks influence child nutrition[37]. However, height-for-age (stunting), the indicator of chronic malnutrition, shows no significant association with production shocks in our sample households. Thus, distinction between short- and long-term food security indicators is important. Chronic nutritional deprivation reflects long-term structural vulnerabilities rather than short-term shocks, and improvements in stunting require sustained changes in diet, health and livelihood security[38]. The lack of responsiveness of stunting to short-term shocks aligns with resilience concepts that emphasize the temporal differentiation between immediate absorptive responses and deeper structural conditions that shape transformative outcomes.

Overall, the differentiated responses across food security indicators demonstrate the value of analyzing multiple dimensions of food and nutritional resilience. The stability of dietary diversity alongside heightened coping strategies indicates that AIV-based production systems help households preserve nutritional quality even when food quantity is compromised. This duality, reliance on coping mechanisms while maintaining diverse diets, reflects the complex ways in which households manage shocks. It also highlights the potential of AIVs to serve as resilience-enhancing components of production systems, contributing to both food access and dietary adequacy in shock-prone environments. It should also be noted that since the analytical sample comprises exclusively AIV-producing households, the study cannot establish whether these patterns are specifically attributable to AIV cultivation or are common to smallholder agricultural households more broadly, a constraint that limits attribution and underscores the need for future research incorporating non-AIV producer comparison groups.

These findings contribute to emerging evidence on the role of traditional crops in building resilient agricultural systems. By integrating AIVs into production portfolios, households not only reduce their exposure to climate-sensitive production patterns while strengthening food and income buffers, they also enhance the ecological stability of their farming systems. Such diversification is not only central to household adaptive strategies but also forms part of broader transformations toward climate-resilient, sustainable and nutrition-sensitive agricultural systems.

Although this study is grounded in the specific context of rural and peri-urban Kenya, the underlying principle has broader relevance. In smallholder systems across sub-Saharan Africa and beyond, locally adapted, nutrient-dense indigenous crops represent an underutilized asset for buffering dietary quality and food access during production shocks. As climate volatility intensifies and agrobiodiversity continues to erode globally, evidence on the resilience-enhancing properties of such crops holds relevance for agricultural development strategies in other regions, including South and Southeast Asia, Central America and parts of the Pacific, where comparable agro-ecological conditions and food security challenges prevail.

6 Policy implications

The findings of this study carry several policy implications for building resilient, nutrition-sensitive agricultural systems in smallholder contexts.

First, the significant increase in coping strategy scores in response to drought, crop failure and heavy rainfall signals that households are regularly pushed beyond their absorptive capacity at the farm level. This points to an urgent need for investments in shock-mitigation infrastructure, particularly small-scale irrigation systems, weather-resilient crop cultivars

and accessible climate information services that reduce household exposure to production losses in the first place. Such investments would directly strengthen the productive buffers that households currently lack, reducing their reliance on stress-coping behaviors when shocks occur.

Second, the stability of dietary diversity in the face of production shocks is partly attributable to the inherent agronomic and nutritional properties of AIVs, their short growth cycles, low input requirements and nutritional density, that make them accessible food sources even under adverse conditions. This resilience can be deepened further. Policies that strengthen AIV value chains, including improved market access, targeted extension services, and access to credit, would amplify household adaptive capacity by enabling them to substitute purchased food for production losses and expand the market viability of AIV cultivation as a livelihood strategy.

Third, the significant deterioration of short-term child nutritional indicators, underweight and wasting, in response to drought and multiple concurrent shocks underscores the vulnerability of young children to acute production failures. This calls for integrating AIV-producing households into nutrition-sensitive social protection programs, including school feeding schemes, community-based nutrition interventions, and maternal and child health programs that explicitly recognize AIV production as a household food security asset. The evidence that child nutritional status responds to short-term shocks, but not to chronic structural deprivation in the same way, indicates that timely, shock-responsive social assistance can meaningfully protect children during high-risk periods.

Finally, the differentiated resilience response documented across all three food security indicators demonstrates the multi-dimensional value of AIV-based production systems, value that extends beyond any single indicator or policy domain. Translating this evidence into durable impact requires mainstreaming AIVs into national agricultural policies, food and nutrition security plans, and climate adaptation strategies in Kenya and comparable contexts. This means moving beyond project-level interventions toward institutional integration: including AIVs in agricultural extension curricula, national seed system programs and climate-smart agriculture frameworks.

7 Conclusions

This study provides empirical evidence, first, that production shocks affect multiple dimensions of household food security in distinct ways and, second, that AIVs are associated with resilience patterns within smallholder agricultural systems. Although drought, crop failure, and heavy rainfall significantly increase the use of coping strategies and negatively affect short-term nutritional outcomes among children, dietary diversity remains stable. Given that all households in this study produce AIVs, their responses to drought, crop failure and heavy rainfall offer insights into the resilience-enhancing potential of AIV-based systems. Thus, the observed stability in dietary diversity and the differentiated sensitivity of food security indicators can be understood not only as household coping outcomes, but also as reflections of the underlying properties of these production systems. Also, this stability reflects the agroecological robustness and nutritional value of AIVs, which offer reliable food sources during occurrence of production shocks. The findings highlight the importance of AIVs in supporting the absorptive and adaptive capacities of smallholder production systems.

Finally, it is acknowledged that some limitations of this study could be improved in future research, particularly the short 2-year panel window and the absence of a comparison group of non-AIV producers. Future research needs to explore longer-term resilience trajectories, examine cumulative exposure to shocks over longer period and compare the relative resilience capacity of AIV producers with non-AIV producers. Nevertheless, this study demonstrates that AIV-based production systems have several resilience-enhancing characteristics that enable households to maintain key dimensions of food and nutrition security under conditions of shocks. These insights should be valuable for designing interventions and policies aimed at building resilient agricultural production systems in Kenya and similar contexts.

Supplementary materials

The online version of this article at https://doi.org/10.15302/J-FASE-2026702 contains supplementary materials (Figs. S1–S2; Table S1).

Acknowledgements

This research was conducted within the HORTINLEA project and was supported by the German Federal Ministry of Education and Research and the German Federal Ministry of Economic Cooperation and Development. The authors thank HORTINLEA project researchers for constructive comments on earlier versions of the manuscript and are grateful to participants at international conferences for valuable feedback that helped refine the paper. During the preparation of this manuscript, the authors used Claude Sonnet 5 (Anthropic) to assist with language polishing, organizing the literature review and formatting the reference list. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Compliance with ethics guidelines

Sindu W. Kebede, Mary Abukutsa-Onyango, and Wolfgang Bokelmann declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human, or animal subjects by any of the authors.

REFERENCES

1. FAO, IFAD, UNICEF, WFP, WHO. The State of Food Security and Nutrition in the World 2025: Addressing High Food Price Inflation for Food Security and Nutrition. Rome: *Food and Agriculture Organization of the United Nations* (*FAO*), 2025
2. Ngongolo K, Gayo L. Synergistic impact of COVID-19 and climate change on agricultural resilience and food security in Sub-Saharan Africa. *Discover Agriculture*, 2024, **2**(1): 41
3. Ben Hassen T, El Bilali H, Daher B, Burkart S. Editorial: sustainable and resilient food systems in times of crises. *Frontiers in Nutrition*, 2025, **12**: 1564950
4. Favas C, Cresta C, Whelan E, Smith K, Manger M S, Chandrasenage D, Singhkumarwong A, Kawasaki J, Moreno S, Goudet S. Exploring food system resilience to the global polycrisis in six Asian countries. *Frontiers in Nutrition*, 2024, **11**: 1347186
5. Maxwell D, Vaitla B, Coates J. How do indicators of household food insecurity measure up? An empirical comparison from Ethiopia. *Food Policy*, 2014, **47**: 107–116
6. Coates J. Build it back better: deconstructing food security for improved measurement and action. *Global Food Security*, 2013, **2**(3): 188–194
7. Pérez-Escamilla R, Gubert M B, Rogers B, Hromi-Fiedler A. Food security measurement and governance: assessment of the usefulness of diverse food insecurity indicators for policy makers. *Global Food Security*, 2017, **14**: 96–104
8. Maxwell D, Caldwell R. The Coping Strategies Index: A Tool for Rapid Measurement of Household Food Security and the Impact of Food Aid Programs in Humanitarian Emergencies. 2nd ed. Nairobi: *CARE*, 2008
9. Ansah I G K, Gardebroek C, Ihle R. Resilience and household food security: a review of concepts, methodological approaches and empirical evidence. *Food Security*, 2019, **11**(6): 1187–1203
10. Niles M T, Salerno J D. A cross-country analysis of climate shocks and smallholder food insecurity. *PLoS One*, 2018, **13**(2): e0192928
11. Ngigi P B, Termote C, Pallet D, Amiot M J. Mainstreaming traditional fruits, vegetables and pulses for nutrition, income, and sustainability in sub-Saharan Africa: the case for Kenya and Ethiopia. *Frontiers in Nutrition*, 2023, **10**: 1197703
12. Bokelmann W, Huyskens-Keil S, Ferenczi Z, Stöber S. The role of indigenous vegetables to improve food and nutrition security: experiences from the project HORTINLEA in Kenya (2014–2018). *Frontiers in Sustainable Food Systems*, 2022, **6**: 806420
13. van Jaarsveld P, Faber M, van Heerden I, Wenhold F, Jansen van Rensburg W, van Averbeke W. Nutrient content of eight African leafy vegetables and their potential contribution to dietary reference intakes. *Journal of Food Composition and Analysis*, 2014, **33**(1): 77–84
14. Lugumira R, Tafiire H, Vancoillie F, Ssepuuya G, Van Loey A. Nutrient and phytochemical composition of nine African leafy vegetables: a comparative study. *Foods*, 2025, **14**(8): 1304
15. Muhanji G, Roothaert R L, Webo C, Stanley M. African indigenous vegetable enterprises and market access for small-scale farmers in East Africa. *International Journal of Agricultural Sustainability*, 2011, **9**(1): 194–202
16. Ndlovu M, Scheelbeek P, Ngidi M, Mabhaudhi T. Underutilized crops for diverse, resilient and healthy agri-food systems: a systematic review of sub-Saharan Africa. *Frontiers in Sustainable Food Systems*, 2024, **8**: 1498402
17. Mgwenya L I, Agholor I A, Ludidi N, Morepje M T, Sithole M Z, Msweli N S, Thabane V N. Unpacking the multifaceted benefits of indigenous crops for food security: a review of nutritional, economic and environmental impacts in southern Africa. *World*, 2025, **6**(1): 16
18. van Zonneveld M, Castañeda-Álvarez N P, Achigan-Dako E G, Almekinders C, de Haan S, Hugo W, Otieno G, Ortiz R, Raneri J E, Roa C, Sperling L, Spielman D, von Wettberg E. Enhancing

farmers' access to neglected crop seeds for healthy diets in a changing climate: six recommendations for policy action. *Food Security*, 2026, **18**(4): 839–852

19. Korir L, Hannaford M, Fuller T. Science for Africa's future food security: reimagining the histories and futures of underutilised crops. *Food Security*, 2026, **18**(3): 649–653
20. Béné C. Resilience of local food systems and links to food security–A review of some important concepts in the context of COVID-19 and other shocks. *Food Security*, 2020, **12**(4): 805–822
21. Béné C, Headey D, Haddad L, von Grebmer K. Is resilience a useful concept in the context of food security and nutrition programmes? Some conceptual and practical considerations. *Food Security*, 2016, **8**(1): 123–138
22. Béné C. Why the Great Food Transformation may not happen–A deep-dive into our food systems' political economy, controversies and politics of evidence. *World Development*, 2022, **154**: 105881
23. Béné C, Frankenberger T R, Nelson S, Constas M A, Collins G, Langworthy M, Fox K. Food system resilience measurement: principles, framework and caveats. *Food Security*, 2023, **15**(6): 1437–1458
24. Abukutsa-Onyango M O. African Indigenous Vegetables in Kenya: Strategic Repositioning in the Horticultural Sector. In: Proceedings of the 2nd Inaugural Lecture of Jomo Kenyatta University of Agriculture and Technology. Nairobi, Kenya: *Jomo Kenyatta University of Agriculture and Technology*, 2010
25. Kebede S W, Bokelmann W. African indigenous vegetables and their production practices: evidence from the HORTINLEA survey in Kenya. *Agrotechnology*, 2017, **6**(3): 1000170
26. Carletto C, Zezza A, Banerjee R. Towards better measurement of household food security: harmonizing indicators and the role of household surveys. *Global Food Security*, 2013, **2**(1): 30–40
27. Arimond M, Ruel M T. Dietary diversity is associated with child nutritional status: evidence from 11 demographic and health surveys. *The Journal of Nutrition*, 2004, **134**(10): 2579–2585
28. World Health Organization, Multicentre Growth Reference Study Group. WHO Child Growth Standards: Methods and Development: Length/Height-for-Age, Weight-for-Age, Weight-for-Length, Weight-for-Height and Body Mass Index-for-Age. Geneva: *WHO*, 2006
29. World Health Organization (WHO), United Nations Children's Fund (UNICEF). WHO Child Growth Standards and the Identification of Severe Acute Malnutrition in Infants and Children. Geneva, Switzerland: *World Health Organization*, 2009
30. Wooldridge J M. Econometric Analysis of Cross Section and Panel Data. Cambridge, MA: *MIT Press*, 2002
31. Demeke A B, Keil A, Zeller M. Using panel data to estimate the effect of rainfall shocks on smallholders food security and vulnerability in rural Ethiopia. *Climatic Change*, 2011, **108**(1): 185–206
32. Hoddinott J, Kinsey B. Child growth in the time of drought. *Oxford Bulletin of Economics and Statistics*, 2001, **63**(4): 409–436
33. Freudenreich H, Kebede S W. Experience of shocks, household wealth and expectation formation: evidence from smallholder farmers in Kenya. *Agricultural Economics*, 2022, **53**(5): 756–774
34. Kurgat B K, Ngenoh E, Bett H K, Stöber S, Mwonga S, Lotze-Campen H, Rosenstock T S. Drivers of sustainable intensification in Kenyan rural and peri-urban vegetable production. *International Journal of Agricultural Sustainability*, 2018, **16**(4–5): 385–398
35. Jones A D, Creed-Kanashiro H, Zimmerer K S, de Haan S, Carrasco M, Meza K, Cruz-Garcia G S, Tello M, Plasencia Amaya F, Marin R M, Ganoza L. Farm-level agricultural biodiversity in the Peruvian Andes is associated with greater odds of women achieving a minimally diverse and micronutrient adequate diet. *The Journal of Nutrition*, 2018, **148**(10): 1625–1637
36. Koppmair S, Kassie M, Qaim M. Farm production, market access and dietary diversity in Malawi. *Public Health Nutrition*, 2017, **20**(2): 325–335
37. Arndt C, Hussain M A, Salvucci V, Østerdal L P. Effects of food price shocks on child malnutrition: the Mozambican experience 2008/2009. *Economics & Human Biology*, 2016, **22**: 1–13
38. Brown M E, Backer D, Billing T, White P, Grace K, Doocy S, Huth P. Empirical studies of factors associated with child malnutrition: highlighting the evidence about climate and conflict shocks. *Food Security*, 2020, **12**(6): 1241–1252