

Beyond Production: Value Chain Configuration, Livelihood Pathways, and Causal Impacts on Food Security in Hararghe, Ethiopia

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Abstract

This study focused on smallholder Value Chain Configuration, livelihood strategic choices, underlying socio-institutional determinants, and causal impact on multidimensional food security in Hararghe, Ethiopia. The study utilized cross-sectional data from 383 households across six districts. Value chain typologies were constructed by combining Principal Component Factor analysis and K-means clustering. The analysis identified three distinct structural tracks: The of smallholders clustered as spot-market reliance(31.85%), while 42.82% as horizontally integrated, and 25.33% as vertically integrated as distinct strategic pathways". Determinants of livelihood choices were identified using a multinomial average marginal effects model. Extension service access was the strongest determinant of commercialization, increasing participation probability by 50.10 percentage points ($p < 0.01$) and decreasing subsistence retention by 53.19 percentage points ($p < 0.01$). Market information access and male headship significantly increased the likelihood of non-farm diversification by 23.56 and 15.95 percentage points ($p < 0.01$), respectively, while primary education favored agricultural commercialization (+29.83 percentage points, $p < 0.10$). Institutional advisory systems and information access serve as vital triggers for smallholders transitioning from subsistence to commercialized and diversified livelihoods. IPWRA treatment effects for multidimensional food security outcomes revealed, commercialization and off-farm value addition significantly improve multidimensional food security relative to isolated, spot-market baseline households' $p < 0.01$. Compared to the baseline counterfactuals POM: HDDS = 4.15, FCS = 28.40, rCSI = 12.60, "Commercialization" significantly increased dietary diversity ATET = +1.45) and food consumption scores ATET = +8.64, while decreasing food distress ATET= -3.20). " downstream value addition" generated the strongest welfare gains, increasing HDDS and FCS by 2.12 and 14.30 points, respectively, and reducing rCSI by 5.45 points. Policy interventions should prioritize upgrading rural extension to support commercialization while expanding off-farm processing infrastructure, digital market information, and gender-inclusive financial services to enable smallholders to transition into high-welfare, diversified livelihoods.

Keywords: Value Chain configuration, Livelihood pathway, food security; Ethiopia

1. Introductions

Agriculture remains the foundational engine of economic growth across developing nations, providing a direct livelihood for over three billion people globally and employing nearly one in three workers worldwide (FAO, 2020; Gollin, 2010). In Ethiopia, the agricultural sector contributes approximately 34% to 35% of national Gross Domestic Product (GDP) and generates primary employment for over 80% of the population (NBE, 2022, CSA, 2021). Smallholder farming serves as the primary catalyst for rural development, producing nearly 90% of national agricultural output and sustaining rural livelihoods (CSA, 2020; Getahun, 2020). Consequently, structural transformation within smallholder agriculture is widely recognized as a prerequisite for national food security, poverty alleviation, and sustainable economic growth (Awotide *et al.*, 2016; Carletto *et al.*, 2017; Ogutu and Qaim, 2019).

Historically, agricultural development policies and extension strategies in developing nations including Ethiopia have overwhelmingly prioritized supply-side production enhancements, focusing on high-yield crop varieties, chemical fertilizers, and agronomic productivity to step smallholders out of subsistence traps (Gebremedhin and Jaleta, 2019; Kissoly *et al.*, 2017; Dercon and Christiansen, 2011). While boosting yield capacity is necessary, emerging empirical consensus indicates that production-focused paradigms are insufficient on their own to guarantee food security or sustainable welfare gains without concurrent integration into commercial value chain opportunities (Wedekind and Chinigò, 2020). Smallholders face severe systemic market failures, including inadequate transport infrastructure, limited post-harvest technologies, severe credit constraints, and high spatial transaction costs (FAO, 2020; Hillenbrand, 2022; World Bank, 2019).

In Ethiopia, these structural constraints manifest in a persistent "*sell-low, buy-high*" market trap. Faced with urgent post-harvest liquidity needs such as school fees, debt settlement, and immediate household consumption and lacking commercial storage infrastructure, smallholders are routinely forced into distress farm-gate sales precisely when seasonal market supply peaks and commodity prices collapse (Gebremedhin and

Jaleta, 2010; Negassa and Jabbar, 2008). Compounded by severe price information asymmetries and poor road infrastructure, uncoordinated spot-market transactions allow opportunistic local intermediaries to capture midstream value margins, severely depressing farm-gate revenue realization (Abebayehu *et al.*, 2019; Tura *et al.*, 2016).

This systemic erosion of farm-gate income directly compromises household nutritional resilience through interconnected economic and behavioral mechanisms. Deficit net farm revenues restrict purchasing power during the lean season, preventing households from acquiring diverse, nutrient-dense non-farm foods and leading to marked declines in dietary diversity, as measured by the Household Dietary Diversity Score (HDDS), and overall consumption quality, reflected in the Food Consumption Score (FCS). Furthermore, as home-stored food reserves deplete, households are forced to repurchase basic staples from local markets at peak seasonal prices. This seasonal liquidity drain forces families to adopt stressful behavioral coping strategies such as skipping meals, reducing portion sizes, or liquidating productive farm assets as reflected in elevated Reduced Coping Strategies Index (rCSI) scores (Barrett *et al.*, 2020; Sabates-Wheeler *et al.*, 2018). Transforming agricultural policy therefore requires expanding the focus beyond primary crop yields to establish post-harvest storage, localized processing, and synchronized market linkages.

Nowhere are these agricultural structural vulnerabilities more acute than in Hararghe eastern Ethiopia a high-risk, densely populated agro-ecological zone characterized by severe land fragmentation, erratic rainfall patterns, and persistent reliance on emergency safety net programs (Wedekind and Chinigò, 2020). While oilseed commodities, specifically groundnut and soybean, present substantial commercial potential for income generation and nutritional improvement in this region, smallholders remain severely constrained by weak market coordination and high post-harvest losses. Fostering sustainable rural livelihoods in eastern Ethiopia demands a strategic shift beyond primary productivity toward integrating smallholders into midstream oilseed value chains through synchronized input procurement, commercial warehousing, cluster farming, and

horizontal collective marketing organizations that protect farm revenues and enhance household nutritional resilience (Barrett *et al.*, 2020; Reardon *et al.*, 2019).

To evaluate these dynamics, the theoretical foundation of this study integrates the Sustainable Livelihoods Approach (Scoones, 1998) with Dorward's (2009) Livelihood Pathways Framework, Transaction Cost Economics (Williamson, 1981), and Global Value Chain Governance Theory (Gereffi *et al.*, 2005). The Sustainable Livelihoods Approach conceptualizes livelihoods through the interaction between capability sets, capital asset endowments comprising human, natural, physical, financial, and social capital, and the governing institutional context (Adger *et al.*, 2002; Babulo *et al.*, 2008; McLean, 2015). Adapting Dorward *et al.*, (2009), smallholders deploy their capital asset bases across three primary strategic livelihood typologies: defensive survival strategies under extreme vulnerability to preserve baseline assets and protect basic consumption (Mushongah and Scoones, 2012); agricultural intensification and commercialization strategies to boost farming operations and integrate into high-value market channels (Reardon *et al.*, 2019); and capital accumulation strategies to diversify into off-farm micro-enterprises and value-addition processing (Pritchard *et al.*, 2017).

To operationalize market participation within these strategic typologies, this study categorizes integration pathways into three distinct structural value chain tracks grounded in transaction cost economics and value chain governance theory. The Spot Market or Subsistence Track is defined by uncoordinated, arm's-length farm-gate or local village transactions where smallholders act as passive price-takers, absorbing high spatial transaction costs and price volatility without capturing post-harvest value addition. The Horizontal Integration Track fosters peer-to-peer coordination through cooperative-led group aggregation, cluster farming blocks, and collective input procurement, enabling smallholders to pool productive resources, achieve economies of scale, lower unit transaction costs, and enhance bargaining power against commercial buyers (Markelova *et al.*, 2009; Reardon *et al.*, 2019). Meanwhile, the Vertical Integration Track facilitates producer movement into midstream and downstream value chain activities through

individual or collective warehouse storage and value-addition processing such as sorting, drying, and allowing producers to capture temporal price premiums, mitigate post-harvest losses, and smooth liquidity across seasonal marketing windows (Barrett, 2008; Reardon *et al.*, 2019). By directly mapping household capital endowments onto these three structural integration tracks, this analytical framework evaluates how specific asset profiles govern transitions away from isolated spot markets toward organized horizontal aggregation and vertical value addition (Carter and Barrett, 2006).

Despite an emerging body of literature emphasizing the role of institutional services such as agricultural cooperatives (Ma and Abdulai, 2016; Mariyono, 2019), credit access (Matita *et al.*, 2022; Tsige *et al.*, 2020), and off-farm diversification (Adjognon *et al.*, 2017; Oseni and Winters, 2014), a critical knowledge, empirical, and methodological gap persists. Existing literature predominantly evaluates performance through primary yield metrics or binary market participation decisions, largely overlooking how multi-pathway value chain integration strategies, such as individual versus collective storage, cluster farming, and input aggregation, are jointly chosen and how they causally impact multidimensional food security outcomes across availability, access, utilization, and stability (Barrett *et al.*, 2019; Reardon *et al.*, 2019). Furthermore, empirical evidence regarding smallholder oilseed value chain coordination in high-risk, land-constrained environments like Hararghe in eastern Ethiopia remains non-existent. Methodologically, past frameworks frequently fail to account for non-random self-selection bias and potential welfare trade-offs between overall caloric intake and dietary quality.

This study directly addresses these gaps by evaluating the institutional, socioeconomic, and asset-based drivers governing smallholder choices across structural integration tracks and estimating their doubly robust causal impacts on HDDS, FCS, and rCSI. Addressing this problem is critical because treating smallholders merely as primary producers locks them into low-margin, uncoordinated spot markets, exposing them to severe price volatility and post-harvest losses (Mersha and Ayenew, 2018). If this problem remains unaddressed, national investments in agricultural yield technologies will continue to

deliver sub-optimal welfare returns, farm savings will deteriorate, and rural households in eastern Ethiopia will remain structurally trapped in seasonal food deficits and chronic aid dependency (Barrett, 2008; Sabates-Wheeler *et al.*, 2018). Conversely, generating robust empirical evidence on the institutional drivers and welfare returns of value chain participation will enable policymakers and development partners to design targeted interventions such as commercial credit facilities, market-oriented extension programs, and institutional support for cluster farming, and collective storage facilities, empowering smallholders to capture midstream value, buffer seasonal price collapses, and achieve resilient, nutrition-sensitive food security (Dorward *et al.*, 2009; Qaim *et al.*, 2022).

2. Materials and Methods

2.1. Description of the study area

East and west Hararghe are found in Oromia national regional state, Ethiopia, 200km and 400km away from the capital city Addis Ababa respectively. Encompasses topography ranging from 1000 to 3405 meters and temperature ranges lowland 30 - 40%, midland 35 - 45%, and highland 15 - 20% (CSA, 2021). The average household size ranges 6 to 7 members. Agriculture is a backbone of economic activities and major source of smallholders' livelihoods. Beyond direct farming, agriculture serve as the primary engine for the entire off farm and non-farm economy, generating employment including agricultural labor, local commodity aggregation, transport services, primary processing, and trading. Maize, sorghum, sweet potatoes, barley, wheat and pulses are key staple crops, and Khat, potatoes, onions, shallots, and oilseed like soybean and groundnuts are common cash crops cultivated in the area significantly contributes to household incomes (Hailu, and Wako, 2024). Despite the existence of these potentials, smallholder in Hararghe encounter persistent challenges like erratic rainfall , lack of access to seeds, traditional extensions service and fragmented market(Yasin and Woldemariam, 2023). Geographically, West Hararghe is situated around central coordinates of 8°40' N and 40°51' E, while East Hararghe extends between latitudes 7°36' N to 9°41' N and longitudes 41°18' E to 43°00' E . Figure 1. Location map of the study area displaying sample districts in East and West Hararghe zones, Oromia Region, Ethiopia. The top-left panel depicts the administrative location of Oromia within Ethiopia; the bottom-left panel highlights East and West Hararghe zones; the primary panel shows the six target study districts (Babile, Fedis, and Gursum in East Hararghe; Chiro, Mieso, and Tulo in West Hararghe)(See figure 1: map of the study area).

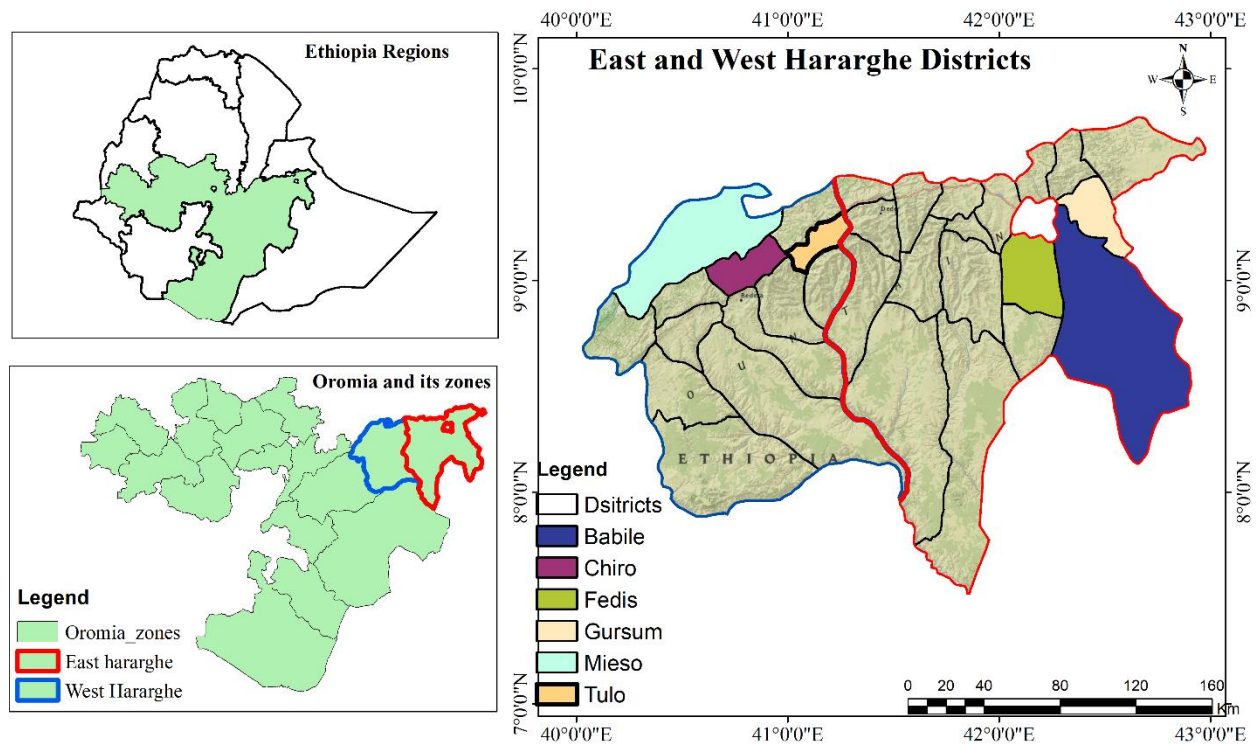


Figure 1: *Map of the study area showing sampled districts across Hararghe zones, Oromia Region, Ethiopia*

2.2. Sampling Technique and Sample Size Determination

A four-stage sampling design was deployed to guarantee spatial representativeness, reflect agro-ecological variation, and minimize selection bias (Babbie, 2020). At stage one, the East Hararghe zone (for groundnut production) and West Hararghe zone (for soybean production) were purposively chosen for their established agro-ecological suitability and dominant share of regional commercial oilseed output (CSA, 2021). At stage two, six primary production districts representing major commercial clusters were purposively selected: Babile, Fedis, and Gursum in East Hararghe, alongside Chiro, Tulo, and Mieso in West Hararghe (Creswell and Creswell, 2018). At stage three, three principal oilseed-producing kebeles (the lowest administrative units in Ethiopia) were targeted per district, establishing 18 sampling clusters. At stage four, official kebele household rosters served as the primary sampling frame. The study's target population ($N = 123,230$) comprised all oilseed-producing households across the six study districts. Rather than

calculating a single aggregate sample, the required sample size (n_i) for each individual district was calculated independently using the Krejcie and Morgan (1970) formula:

$$n_i = \frac{X^2 N_i P(1-P)}{d^2 (N_i - 1) + X^2 (P(1-P))} \quad (1)$$

$$n_i = \frac{3.841 \times 123,230 \times 0.50(1 - 0.50)}{(0.05)^2 \times (123,230 - 1) + 3.841 \times 0.5(1 - 0.50)} = 383$$

Where, n_i = sample size for each district; N_i = represents the target population of oilseed-producing households in district i , X^2 = the table value of chi-square for 1 degree of freedom at the confidence level of 95%, p = the population proportion (assumed to be 0.50), d = the degree of accuracy expressed as a proportion (0.05).

Each district's calculated sample size (n_i) was subsequently distributed across its three selected kebeles using Probability Proportional to Size (PPS) allocation (Cochran, 1977):

$$n_{ik} = \frac{N_{ik}}{(N_i)}$$

(2)

Where n_{ik} and N_{ik} represent the sample size and household population of kebele k in district i respectively. Sample sizes for district i (n_i) and kebele k (n_{ik}) were allocated proportionally to their respective populations (N_i , N_{ik}) using PPS, ensuring balanced demographic representation from larger agricultural clusters (Lohr, 2021). Sample households were then selected via simple random sampling from updated kebele rosters.

Table 1: Multi-Stage PPS Sample Allocation across Study Sites

Administrative Zone	District	Target Population (Ni)	District Sample (ni)	Sample Kebele	Kebele Population (Nik)	Kebele Sample (nik)
East Hararghe	Babile	24,774	77	Ifa	8,044	25
				Tula	8,365	26
				Abdulkadir	8,365	26
	Fedis	17,053	53	Riski	5,793	18
				Tuta kenisa	5,467	17
				Muleta	5,793	18
	Gursum	20,914	65	Kasa Oromia	7,400	23
				Ilalam Tokkoffa	7,078	22
				Odaa Oromia	6,436	20
West Hararghe	Chiro	20,271	63	Wacu Gilley	7,076	22
				Wacu Ifabas	5,789	18
				Killiso	7,406	23
	Tulo	18,340	57	Chefe	6,113	19
				Terkanfeta	6,113	19
				Hunde lafto	6,114	19
	Mieso	21,878	67	Tokuma	7,184	22
				Oda Roba	7,184	22
				Oda keneeni	7,510	23
Total	6 Districts	123,230	383	18 Kebeles	123,230	383

Sources: Agriculture office of east and west Hararghe, 2025

2.3. Types and Sources of Data

A cross-sectional survey design was used to capture household, farm, and institutional variables across East and West Hararghe zones. Primary data were collected exclusively from smallholder oilseed producers between January and March 2026 via pre-tested, structured interviews. To cushion against non-response and data-cleaning attrition (De Brauw and Rozelle, 2008; Barrett *et al.*, 2020), 403 households were surveyed, exceeding the calculated minimum sample size ($n = 383$). The questionnaire covered demographics, socioeconomic traits, farm practices, market participation, and institutional access (extension, credit, market intelligence), supplemented by qualitative data for triangulation and empirical validation (Girma Kassie *et al.*, 2013; Worku Legesse *et al.*, 2024). Secondary data were systematically compiled from annual performance reports, administrative records, and policy documents maintained by district agricultural offices, trade and market development agencies, and local input supplier networks.

2.4. Operationalization of Variables

2.4.1. Value Chain Integration (T_i):

To operationalize smallholder value chain integration as a multi-arm categorical treatment variable ($T_i \in \{1, 2, 3\}$), this study applies a sequential, two-step quantitative segmentation approach combining Varimax-rotated Principal Component Analysis (PCA) with a K-means clustering algorithm across nine observed post-harvest behavioral metrics. Including individual input supplying, individual processing, individual storage for selling, collective production, collective input supply, collective processing, collective storage, months stored individually, and months stored collectively). While alternative model-based segmentation techniques such as Latent Class Analysis (LCA) are sometimes used in classification studies, combining orthogonal PCA with K-means clustering over LCA is methodologically superior for this empirical context for three key reasons. First, smallholder post-harvest behaviors exhibit severe multi-collinearity; applying orthogonal Varimax-rotated PCA first extracts uncorrelated latent factor scores, preventing collinear variables from artificially distorting Euclidean distance calculations in cluster algorithms (Kaiser, 1960). Second, unlike LCA, which estimates probabilistic, fuzzy class memberships based on underlying parametric assumptions K-means utilizes a distance-minimizing objective function to construct deterministic, non-overlapping, and mutually exclusive clusters (Hair *et al.*, 2019). Because these typologies serve as discrete treatment arms within the subsequent Multinomial Logit assignment model and Inverse-Probability-Weighted Regression Adjustment (IPWRA) causal framework, deterministic boundaries are mathematically necessary to establish strict, mutually exclusive counterfactual treatment groups. Third, LCA relies on local independence assumptions that are frequently violated by the skewed, zero-inflated transaction data typical of smallholders. By utilizing standardized orthogonal PCA factor scores as segmentation inputs, the distribution-free K-means algorithm generates structurally robust, highly reproducible, and empirically valid value chain typologies without imposing restrictive parametric constraints (Ketchen and Shook, 1996; Punj and Stewart, 1983). The resulting three non-overlapping tracks comprise: (1) the Spot Market Track ($T_i = 1$), representing uncoordinated farm-gate sales; (2) the Horizontal Integration Track ($T_i = 2$), capturing

cooperative aggregation and cluster farming/ commercialization; and (3) the Vertical Integration Track (Ti = 3), value-addition processing.

2.4.2. Multidimensional Food Security Outcomes

To capture the multidimensional nature of household food security spanning availability, access, utilization, and stability (CFS, 2009; FAO *et al.*, 2013) this study operationalizes welfare outcomes through three validated metrics.

Household Dietary Diversity Score (HDDS): Measures nutrient adequacy and economic access by quantifying the consumption of 12 standard food categories over a 24-hour recall period (Swindale and Bilinsky, 2006; FAO, 2010). Higher values reflect superior micronutrient quality and purchasing capability.

Food Consumption Score (FCS): Captures food availability and caloric adequacy by combining the 7-day consumption frequency of eight food groups, weighted by nutrient density (WFP, 2008). FCS classifies household dietary quality into poor, borderline, or acceptable thresholds.

Reduced Coping Strategies Index (rCSI): Gauges household food stress, behavioral adjustments, and shock vulnerability by evaluating the frequency and severity of five standard negative coping mechanisms over a 7-day recall period (Maxwell and Caldwell, 2008; Maxwell et al., 2014). Higher scores denote acute food insecurity and diminished resilience.

2.5. Methods of Data Analysis

Following an asset-based livelihoods framework Scoones (1998) and assuming a utility maximizing framework, a smallholder's welfare outcome (y_i) driven by their structural asset endowments (A_i) and selected post-harvest value chain configuration (T_i) is given as:

$$Y_i = f(A_i, T_i) + \epsilon_i \quad (3)$$

Where

Y_i represents the multi-dimensional food security outcomes, A_i is a vector of household productive assets, T_i represents the distinct value chain configurations, and ϵ_i is the stochastic error term.

To operationalize T_i and capture latent behavioral dimensions without imposing arbitrary structures, an orthogonal Vari-max-rotated principal component analysis was applied to nine distinct value chain pathways. The mathematical model is specified as:

$$PC_m = a_{m1}X_1 + a_{m2}X_2 + \dots + a_{mK}X_K \quad (4)$$

Where, PC_m represents the extracted principal component factor score, a_{mK} denotes the calculated factor loading coefficients, and X_K represents the observed post-harvest behavioral metrics. Factors displaying eigenvalues greater than 1.0 were retained based on Kaiser's criterion. Based on the predicted factor scores generated in principal components analysis as segmentation inputs, a K-means clustering algorithm the 383 households into distinct value chain typologies.

The algorithm minimizes the sum of squared Euclidean distances within each cluster:

$$J = \sum_{i=1}^K \sum_{n \in S_i} \|Z_n - \mu_i\|^2 \quad (5)$$

Where

Z_n is the vector of factor scores for household n , μ_i is the calculated mean centroid of cluster segment S_i , and K is fixed at 3 to yield managerially distinct, robust livelihood typologies.

To analyze determinants of these *livelihood typologies* /value chain segments (T_i), a Multinomial Logit (MNL) model was estimated. Letting Y_i represent the categorical value chain segment ($j = 1, 2, 3$), the probability that household i chooses segment j is written as:

$$P\left(Y_i = \frac{j}{X_i}\right) = \frac{\exp(\beta_j, X_i)}{1 + \sum_{k=3}^3 \exp(\beta_k, X_i)} \quad (6)$$

Segment 2 (the Asset-Constrained Baseline) was designated as the base outcome comparison group. Average Marginal Effects (AMEs) calculated to capture the discrete change in the absolute probability of segment membership.

$$AME_j = \frac{1}{N} \sum_{i=1}^N \frac{\partial P(Y_i=j)}{\partial X_i} \quad (7)$$

To isolate the true causal impacts of livelihood configurations on household food security, Inverse-Probability-Weighted Regression Adjustment (IPWRA) estimator was utilized. IPWRA is a doubly robust framework, meaning that if either the treatment assignment model (*Equation 6*) or the outcome model is correctly specified, the resulting Average Treatment Effect (ATE) estimates is consistent and unconfounded by self-selection bias (Wooldridge, 2007, 2010; Imbens and Wooldridge, 2009). The structural outcome equations for household food security are modeled linearly for each livelihoods configuration as:

$$Y_{ij} = Z_i \gamma_j + \epsilon_{ij} \quad \text{for } j \in \{1, 2, 3\} \quad (8)$$

Y_{ij} = (Multi-Dimensional Food Security Outcomes): This is the observed welfare level for smallholder household i across three distinct dimensions denoted by j in $\{1, 2, 3\}$.

$j = 1$: household dietary diversity score (HDDS), measuring dietary quality, $j = 2$: food consumption score (FCS), measuring nutrient density and frequency, $j = 3$: reduced coping strategies index (rCSI), measuring behavioral food insecurity stress, $Z_i =$ (Vector of Explanatory Covariates): This is a row vector containing the core independent variables for household i . The treatment variable representing the chosen post-harvest value chain configuration. Socioeconomic and institutional controls, such as household asset endowments (human, physical, financial, natural and social capital), $\gamma_j =$ (Vector of Estimated Parameters): This represents the specific regression coefficients to be estimated for the j th outcome model. It measures the direction and magnitude of the causal impact of value chain configurations and asset controls have on specific food security, $\varepsilon_{ij} =$ (Stochastic Error Term): This is the distinctive error component for household i under outcome metric j , capturing random shocks, unobserved heterogeneities, or measurement errors not accounted for in vector Z_i .

To estimate these outcome parameters while correcting for selection bias, the IPWRA framework minimizes the following inverse probability weighted objective function. The outcome equations are modeled as:

$$\min_{\gamma_j} \sum_{i=1}^N \frac{I(Y_i=j)}{\hat{p}(Y_i=j/X_i)} (Y_{ij} - Z_i \gamma_j)^2 \quad (9)$$

Where, $I(y_i = j)$ is an indicator function equal to 1 if household i belongs to configuration j and 0 otherwise, and $\hat{p}(Y_i = j / X_i)$, are the propensity scores predicted from the Multinomial Logistic Regression model, is an indicator function, X_i (like assets, age, or education).

2.6. Variable Definitions, Operationalization, and Theoretical Hypotheses

To analyze the structural determinants of livelihood strategic choices and their subsequent impacts on household food security a robust set of explanatory covariates was established (see table 1). These explanatory covariates are established based on the sustainable livelihoods framework (SLF), and the expected covariate impact sign on value chain are segmented (spot market or subsistence), horizontal integrations (cooperative-led track), and vertical integration (value-added processing track).

Table 1: Operational definition of model covariates and expected sign directions

Variable Code	Operational definition and unit of measurement	Variable Type	Expected horizontal integrations / Value-added processing vs. Subsistence)	Theoretical Sign
Gender	Gender of the household head (1 = Male; 0 = Female)	Dummy		+
Oilseeds productions Experience	Oilseed cultivation (Years)	Continuous		+
Educational level	1 = Formal education; 0 = otherwise	Dummy		+
Oilseeds type	Oilseeds type produced (1 = Groundnut; 0 = Soybean)	Dummy		±
Distance from Main market	Distance from farm-gate to main market (Kilometers)	Continuous		–
Access extensions services	Extension agent interactions (1 = Yes; 0 = No)	Dummy		+
Access to credit	Access to credit (1 = Yes; 0 = No)	Dummy		+
Access to Market information's	Market price and demand information (1 = Yes; 0 = No)	Dummy		+
Family size	Total household members	Continuous		±
Cooperative member	Cooperative member(1= Yes; 0 = No)	Dummy		+
P_NFIGA	Household participation in non-farm income activities (1 = Yes; 0 = No)	Dummy		+

Source: own literature review

3. Results and Discussion

The Results and Discussion section critically evaluates the empirical findings against theoretical models and existing literature, providing the mechanism-driven interpretation of the observed socioeconomic, econometric, and food security outcomes.

3.1. Descriptive statistics

3.1.1. Demographic and Human Capital Dynamics

The gender composition indicates a pronounced structural imbalance, with male-headed households constituting 73.63% of the sample. In rural Ethiopian agricultural systems, this demographic pattern reflects persistent gender disparities in land tenure security, asset ownership, and household decision-making power, where primary productive resources remain heavily controlled by male heads (Mohammed *et al.*, 2019). Regarding human capital, 51.96% of household heads have attained formal education. Human capital acts as a critical determinant of institutional engagement; literate household heads possess a superior capacity to process market information, understand formal financial mechanisms, and adopt post-harvest quality-sorting technologies necessary for commercial market orientation (Dercon and Christiansen, 2011).

In terms of farming experience, respondents demonstrate substantial generational knowledge, averaging 19.04 years of oilseed cultivation (SD = 10.68, ranging from 5 to 44 years). While extensive farming experience fosters familiarization with local agro-ecological risks and crop management practices, it can also induce path-dependency and risk-aversion toward adopting novel post-harvest processing models unless backed by strong institutional incentives (Gebremedhin and Jaleta, 2019). Household family size averages 7 members (SD = 2, ranging from 3 to 12). In labor-intensive agricultural systems, larger family size represents a dual socio-economic indicator: it provides vital family labor required for labor-intensive post-harvest activities such as harvesting, drying, and hand-sorting, yet simultaneously elevates baseline household subsistence food

demand, which can force distress sales to meet immediate cash needs (Carletto *et al.*, 2017).

Table 2: Demographic characteristics of household head (Dummy Variables)

	Variables	Frequency	Percent
Sex of household head	Female	101	26.37
	Male	282	73.63
Education level	Formal	199	51.96
	No-formal	184	48.04
Cooperative membership	None	218	56.92
	Member	165	43.08
Market information	No access	105	27.42
	Access	278	72.58
Access to credit	No access	286	74.67
	Access	97	25.33
Access to extension services	No access	107	27.94
	Access	276	72.06
Edible oilseeds type	Groundnuts	204	53.26
	Soybean	179	46.74

Table 3. Demographic characteristics of household (continues variables)

Variable	Observations	Mean	Std. dev.	Min	Max
Productions experience	383	19.044	10.677	5	44
Family size	383	7.402	1.741	3	12
Distance from the market (Km)	383	15.005	5.869	3	35
Land allocated to oilseeds	383	.642	.412	.15	2
Quantity produced in(kg)	383	679.707	313.520	150	1780
Quantity sold (Kg)	383	571.279	281.474	0	1600

Source: Survey result, 2026

3.1.2. Institutional Service Coverage and Financial Inclusion

Substantial heterogeneity exists across institutional service access variables in the study area. While public agricultural extension services (72.06%) and market price information channels (72.58%) achieve relatively broad coverage, financial inclusion remains severely restricted. Nearly three-quarters of the respondents (74.67%) lack access to formal credit services. This acute credit bottleneck severely constrains smallholders' working capital, preventing them from acquiring post-harvest storage facilities, hiring transport, or purchasing localized processing equipment. Consequently, liquidity-constrained smallholders are frequently forced into immediate, post-harvest farm-gate sales at depressed prices (Hillenbrand, 2022).

Formal cooperative membership stands at 43.08%, leaving 56.92% of smallholders operating outside collective action organizations. Membership in agricultural cooperatives provides economies of scale, lowers unit spatial transaction costs, and strengthens bargaining power against commercial buyers (Markelova *et al.*, 2009). The high proportion of non-members highlights a structural gap in horizontal aggregation, leaving the majority of farmers to interact independently with unorganized spot markets.

3.1.3. Land Allocation, Spatial Friction, and Commercial Intensity

Land allocation data reflect extreme land fragmentation in the Hararghe highlands, with smallholders allocating an average of only 0.64 hectares (SD = 0.41) to edible oilseeds, ranging from 0.15 to 2.00 hectares. Despite severe land pressure, oilseed cultivation remains a primary commercial cash enterprise, producing an average of 679.71kg (SD = 313.52) per household. Crucially, smallholders market an average of 571.28 kg, (SD = 281.47), demonstrating a high commercialization intensity of 84.05 % of total production output. Crop distribution reflects distinct agro-ecological specialization across zones, with groundnut production from East Hararghe (53.26%) and soybean cultivation in West Hararghe (46.74%).

However, commercialization gains are heavily constrained by spatial friction. Sampled households are located an average of 15.01 km (SD = 5.87, reaching up to (35km) from main terminal markets. High spatial distance combined with inadequate rural transport infrastructure generates prohibitive transportation costs and physical post-harvest losses during transit. These spatial transaction costs act as a major structural barrier that deters isolated producers from directly accessing urban market hubs, locking them into low-margin, farm-gate spot-market transactions (Barrett *et al.*, 2019; Williamson, 1981).

3.1.4. Exploratory Factor Analysis

To map how smallholder integration into value chains an exploratory factor analysis (EFA) was applied to nine behavioral post-harvest management indicators. Principal Component Factor (PCF) extraction was paired with an orthogonal Vari-max rotation (see table 4, rotated factor loadings, variances, and uniqueness values).

Table 4: Rotated factor loadings, variances, and uniqueness values

Behavioral Indicator Variable	Factor 1 (Collective Engagement)	Factor 2 (Individual Storage)	Factor 3 (Processing Intensity)	Uniqueness values
Individual Input Supplying	0.9480	0.1252	0.0738	0.0802
Individual Processing	0.0353	0.0310	0.8742	0.2336
Individual Storage for Selling	0.3693	0.8679	0.0312	0.1094
Collective Production	0.1291	-0.1975	0.8414	0.2365
Collective Input Supply	0.8923	0.1972	0.0030	0.1649
Collective Processing	0.9361	0.1782	0.1096	0.0799
Collective Storage	0.5486	0.6783	0.1530	0.2156
Months Stored Individually	0.0408	-0.9080	0.2443	0.1143
Months Stored Collectively	0.8578	0.0850	0.0553	0.2540
Post-Rotation Eigenvalue	3.7637	2.1712	1.5766	—
Proportion of Variance (%)	41.82%	24.12%	17.52%	—
Cumulative Variance (%)	41.82%	65.94%	83.46%	—

Likelihood Ratio(LR) χ^2 (36) = 2917.46, $p < 0.01$, eigenvalues (Factor 1 = 4.42, Factor 2 = 1.94, Factor 3 = 1.16), over all KMO=.7139

Source: Survey result, 2026

Factor 1, capture value chain collective engagement with 41.82% of Variance. Cooperative-driven institutional integration and features with high positive loadings on individual input supplying 0.9480, collective processing 0.9361, collective input supply 0.8923, and months stored collectively 0.8578. Factor 1 also reflects strong horizontal and vertical integrations through institutional value chain pathways. Factor 2 individual storage and local spot market interactivity with 24.12% of Variance and shows high positive loadings on individual storage for immediate

selling 0.8679 and collective storage 0.6783, paired with a sharp negative loading on months stored individually -0.9080 . This negative duration confirms characteristic of distress selling patterns, where smallholders store for a short period before immediate selling in isolated local spot markets due to cash needs pressures. Factor 3, shows processing and production intensity with 17.52% of variance, where it is dominated by strong positive loadings on individual processing activities 0.8742 and collective production configurations 0.8414. Smallholders, who actively transform oilseed into higher-value additions than marketing raw commodities to the isolated spot market.

3.1.5. Smallholder Segmentation and Behavioral Typologies

K-means clustering algorithm was run using the regression-scored factor coordinates to group the 383 smallholders into mutually exclusive behavioral segments (see table 5). sample distribution and livelihood typologies of developed clusters) . A segment represents the actual household by their profile that is vulnerable spot market reliant, cooperative commercialization track/ horizontal integration and value-added processing track. Segment 2 forms the largest share at 42.82%, showing that horizontal coordination via cooperatives is the primary path for smallholder commercialization. Segment 1 represents 31.85% of the sample, capturing highly vulnerable, market-isolated households stuck in survivalist spot-market cycles. Segment 3 accounts for 25.33% of the sample, representing an entrepreneurial cohort shifting toward processing and income diversification.

Table 5: Sample distribution and livelihood typologies of developed clusters

Cluster Segment	Sample Frequency (n)	Percentage Share	Dominant Latent Factor Coordinates	Empirical Livelihood Typology
Segment 1	122	31.85%	Low collective engagement, negative storage durations, high spot reliance	Vulnerable Spot Market Reliant
Segment 2	164	42.82%	High collective input and marketing coordinates prolonged cooperative storage	Cooperative Commercialization Track
Segment 3	97	25.33%	High processing intensity coordinates high off-farm activity diversification	Value-Added Processing Track

Sources: own computation of data 2026

3.2. Multinomial Logit Analysis

To identify the forces driving smallholders into these distinct Livelihood typologies, a Multinomial Logit (MNL) model was used. Segment 2 (Cooperative Commercialization Track) was designated as the baseline comparison group because it represents the largest market share (see table 6 multinomial logit average marginal effects (AME) for segment membership) . To ensure clear economic interpretation, analysis focuses on Average Marginal Effects (AME).

Table 6: Multinomial Logit Average Marginal Effects (AME) for Segment Membership

Explanatory Variables	Segment 1: " Vulnerable Spot Market Reliant "	Segment 2: " Cooperative Commercialization Track " (Base Group)	Segment 3: " Value-Added /Processing "
Gender (1 = Male)	-0.1555*** (0.0494)	-0.0040 (0.0371)	0.1595*** (0.0403)
Edible oilseeds Production Experience	0.0005 (0.0026)	-0.0043* (0.0022)	0.0038* (0.0021)
Education Level (1 = Primary)	0.0845 (1.1274)	0.2983* (0.1575)	-0.3828*** (1.1095)
Edible Oilseed Type (1 = Groundnut)	0.0489 (0.0635)	0.0382 (0.0433)	-0.0872 (0.0558)
Distance from Main Market (in Km)	-0.0034 (0.0030)	-0.0005 (0.0027)	0.0039 (0.0025)
Extension Service Access (1 = Yes)	-0.5319*** (0.0501)	0.5010*** (0.0273)	0.0309 (0.0423)
Access to Credit (1 = Yes)	0.0617 (0.0502)	-0.0888* (0.0462)	0.0270 (0.0294)
Access to Market Information (1 = Yes)	-0.2226*** (0.0578)	-0.0129 (0.0451)	0.2356*** (0.0445)
Family Size	-0.0111 (0.0100)	0.0006 (0.0079)	0.0105 (0.0090)
Cooperative Membership (1 = Yes)	-0.0593* (0.0335)	-0.0057 (0.0281)	0.0650** (0.0292)
Participations in Non-Farm Income (P_NFIGA)(1=yes)	0.0370 (0.1397)	-0.1822 (0.1553)	0.1452† (0.1025)

Log likelihood = -139.85913. LR χ^2 (22) = 544.05, $p = 0.0000$. Pseudo $R^2 = 0.6604$, $n = 383$.

*Note: Delta-method standard errors are reported in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. † denotes a strong directional trend validated by a statistically significant baseline Relative Risk Ratio (RRR = 16.26, $p = 0.047$).*

3.2.1. Determinants of the Vulnerable Spot Market Reliant Pathway

Smallholders in Vulnerable Spot Market are isolated from cooperative and remain in informal market exploitation. Predatory market players with high-unstructured market dominate them. In areas where population density, land fragmentation, and recurring weather shocks restrict smallholder to risk-mitigating practices and defensive livelihoods strategies. No access to credit, low educational attainment and absence of cooperative membership are their major characteristics' (Barrera, 2025). Specific factors that conditioned smallholder into '*Vulnerable Spot Market Reliant' Pathway* are:-

Access to agricultural Extension services: Access to extension services dramatically reduces the probability of a household falling into *Spot Market* pathway by 53.19 %, at 1% significant level. Access to agricultural extension is most prominent institutional determinants, to escape route away from subsistence, isolated and distress selling. Tailored agricultural extension are the most vital to prevent resource constrained from remaining trapped in survivalist pathways (Belay and Ayalew, 2020; Matita *et al.*, 2022).

Access to Market Information: Access market information significantly reduces the likelihood of remaining in high immediate spot market reliance by 22.26 %, at 1% significance level. Without market information's smallholders are enslaved into isolated market outlets and vulnerable to asymmetric price manipulation. Absence of market information platform forced smallholder to accept the lowest price. Access to market information significantly generate higher marginal profit compared to their counterparts by reducing the risk of accepting low prices (Belay and Ayalew 2020). Smallholder with market information access increased bargaining power and increase marginal benefit while its counterparts severely weakens their negotiations power and forced to sales their produces with least possible price (Gabremadhin, 2001). Access to market information create an opportunity to bypass the isolated spot market and reduces the likelihood of remaining in high immediate spot market reliance (Matita *et al.*, 2022).

Gender of Household Head: Male-headed households are 15.55% less likely at 1% significant level to be confined to hanging in pathway than female-headed households. Gender of household head are primary factors to remain in *Spot Market* livelihood typologies (Matita *et al.* 2022). Female-headed are more under economic mobility and access to asset restrictions compared to their counterpart'. Females face access to credit, land and market information force them to

remain trapped in low-profit margin, isolated transactions (Tavenner *et al.*, 2022). Female-headed household are mainly suffering from access to agricultural extension service, cooperative membership, and land ownership systematically confine them in survivalist, spot-market (Tsige *et al.*, 2020).

Cooperative Membership: Agricultural cooperatives are approximately 5.9 %, at 10% significant level less likely to be confined to *Spot Market* than compared to their non-member counterparts. Cooperative membership significantly reduces the probability of smallholder remained trapped in subsistence and vulnerable pathway's (Matita et al., 2022). Cooperative membership significantly increase smallholder incomes to asset accumulation, shield against falling into subsistence distress selling (Mojo *et al.*, 2017). It also significantly reduce transaction costs and plays escaping route out of trapping in the *Spot Market* in livelihood pathways (Ma and Abdulai, 2016).

3.2.2. Determinants of the Cooperative Commercialization pathway

Smallholder with Cooperative Commercialization pathway are demand-based producers. They are market-oriented characterized as active transition from simple market orientations towards intensification (Leavy and Poulton, 2008; Matita et al., 2022). High transaction costs, price volatility, and post-harvest loss are the prominent challenges for smallholder with Cooperative Commercialization pathway. Social capital is the primary structural mechanism used to manage these challenges (Mariyono, 2019). Collective actions are power to overcome the diseconomies of scale to bypass informal market outlets (Mariyono, 2019). Specific factors that determine *Cooperative Commercialization* pathway.

Access to Agricultural Extension services: Extension services transits smallholders from subsistence into Cooperative Commercialization pathway. Access to extensions services increases the probability of *Stepping Up* by 50.10 %, at 1% significance level. Extension service increases input adoption and volume produced to increase likelihood of escaping out from a subsistence focus to intensive market participation. It is also powerful determinants of livelihood transitions from subsistence to Commercialization by enhancing capacity required to expanding cooperative commercialization pathways (Matita *et al.*, 2022). Increasing access to extension services increase the probability of horizontal value chain integrations (Gebremedhin *et al.*, 2009, Dorward *et al.*, 2009).

Education level: Education increases the probability of choosing collective commercial pathway by 29.83%, at 5% significance level. Because, it enhance collective financial records keeping, group logistics co-ordination, and shared inputs management (Geffersa and Islam, 2024). Smallholder with primary formal education level are far better to understand supply and demand dynamics to overcome opportunistic middlemen(Masara *et al.* , 2024).Educated smallholder can increase their horizontal integrations pathway as compared to their counterpart smallholder. It enhances smallholder ability to choose high market value where it can generate the maximum benefit. Smallholder with no educations expected to face challenges to understand extension services and value chain interventions (Matita *et al.*, 2022).

Production Experience: Specialized production experience significantly increases the relative likelihood to be in the Stepping Up track at the 10% significance level. It raises the relative probability of farm-level intensification by 0.43%, anchoring long-term experienced to value chain integration. Accumulated experience is a vital driver of Cooperative Commercialization. Experience in production plays a significant role in the transition of semi-commercial to market-oriented (Anteneh and Endalew, 2023). Smallholder, with long-term productions experience anchors households to successful value chain intensification (Jaleta *et al.*, 2009).

Access to credit services: Access to credit increases relative likelihood of smallholders choosing the Cooperative Commercialization pathway over diversification at 10% significance level and reduces the relative probability of moving into alternative value chain pathways by 8.88%. It heavily tied to agricultural intensifications and shifting role away from survivalist strategies toward agricultural intensification (Matita *et al.*, 2022). Access to credit boost output per unit of existing land (Carranza and Niles, 2019).It enable households to self-finance on-farm intensification rather than exiting agriculture (Falconnier *et al.*, 2015).

3.2.3. Determinants of the Value-Added /Processing Pathway

Asset-wealthy smallholders diversify into non-farm income streams and value-added processing track. Value-Added /Processing manifests as entrepreneurial diversification process where smallholder sufficient accumulations of asset to vertical value additions. These is transitional bridge between primary production and processing (Hazell *et al.*, 2022; Islam *et al.*, 2021). Transforming agricultural commodities to capture maximum benefit margins (Caulfield *et al.*, 2021). The finance generated from the vertical value added actively reinvested into other

agribusiness to create a resilient. Understanding determinants that enables transition into the *Value-Added /Processing pathway* is very important for smallholder livelihoods improvement (Melembe *et al.*, 2021). *Specific factors that affects value-added processing track pathway.*

Access to Market Information: Market information increases the probability of entering in stepping out livelihood pathway by 23.56 %, at 1% significance level. It gives smallholder the confidence to invest in value addition. It is a significant resource to stepping out from subsistence traps. It empower the transition from passive price-takers to active participants in high value market (Andaregie *et al.*, 2021). Market information enables smallholder to engage into post-harvest processing to escape price volatility (Gizachew, 2025). Lack of reliable market information is the primary bottleneck to invest in post-harvest processing and reduce smallholder confidence to move beyond isolated spot market (Mhazo *et al.*, 2012).

Gender of Household Head: Male heads increase 15.95 %, at at 1% significance level , the probability of reaching specialized processing pathway. Female-headed are systemically cutoff from advanced processing intensity and faces systemic challenges like, unequal access to land, access to financial credit, and access to agricultural technologies (Tsige *et al.*, 2020). Whereas, male headed has a superior control over liquid capital and investment (Gichunge *et al.*, 2023), leaving female-led households structurally constrained from scaling up to *Value-Added /Processing* pathways. Gender asset gap trapped female-headed household in low, survivalist, isolated spot market than participating in high-value chains (Quisumbing *et al.*, 2015). Female-headed households hardly access the available resources.

Cooperative Membership: Cooperatives raises the likelihood of joining Value-Added /Processing by 6.50 %, at 5% significance level indicating that horizontal social networks provide an essential risk-pooling foundation. Cooperatives membership reduces transaction costs and increase bargaining power (Cazzuffi and Moradi, 2012). It has risk-pooling foundation providing smallholders with the financial security needed to diversify beyond production (Mojo *et al.*, 2017). It enhanced confidence from basic raw marketing to vertical value-added processing (Shiferaw *et al.*, 2011). Cooperative membership allows members to accumulate wealth to invest in high-value income generating than trapped in survivalist, isolated spot market pathways.

Production Experience: Production experience increases the relative likelihood of smallholders choosing the stepping out track over the stepping up at the 10% significance level. Each additional

year of production helps step out of isolated spot market pathways to vertically integration. Specialized production's experience dictates whether a household has the capability to Value-Added /Processing or not. Smallholder with specialized experience possess the risk tolerance and capability required to step out into value additions (Matita, *et al.*, 2022). It lowers transaction costs, and drives the capacity of smallholder into highly profitable value additions (Islam *et al.*, 2021). Production experiences build managerial capacity and financial surplus for smallholders to step out into high return agro-processing rather than remaining locked in labor-intensive productions (Rahut and Micevska Scharf, 2012).

Non-Farm Income Streams: Non-farm income participations increases the relative odds of entering the processing track over the cooperative baseline, RRR = 16.26, $p = 0.047$. The corresponding marginal effect shows a positive 14.52 % point shift at $p=0.156$. This strong directional trend proves that liquid cash from non-farm income serve as vital working capital. Non-farm income provides essential liquidity that smallholders reinvest in upgrading and processing than diverting resources away from agriculture (Barrett *et al.*, 2001). Non-farm income overcomes credit market failures and serves as a critical substitute for missing formal credit markets access (Reardon *et al.*, 2007, Oseni and winters, 2014). Smallholder engagement in non-farm income generating activities demonstrate that instead of pulling focus away from value chain activities actively used to purchase inputs (Oseni and winters, 2009, Stampini and Davis, 2009). Non-farm income is the primary source of cash used to self-finance capital-intensive farm upgrades and value-addition where there is no credit access (Adjognon *et al.*, 2017).

4. Causal Impact of Value Chain Typologies on Multidimensional Food Security

Smallholder face persistent structural and institutional barriers, including high transaction costs, informational asymmetries, and low farm-gate bargaining power to mentions some (Gabre-Madhin, 2001; Piabuo *et al.*, 2020). To overcome the persistent challenges up-to-dated agricultural policies are needed (Reardon *et al.*, 2019; Barrett *et al.*, 2020). Cooperative aggregation and vertically integration are proposed to improve smallholder livelihood position. (Ma and Abdulai, 2016; Gheri and Reardon, 2020). Smallholder livelihood position depends on resources and livelihood strategic choices. Distinct livelihood typologies impact on smallholder welfare remains mixed and subjected to self-selection attribution challenges (Barrett *et al.*, 2020; Maziya *et al.*, 2022). Resource-constrained smallholder frequently lack assets required to enter into high-value chains, giving rise to potential structural exclusion (Dorward *et al.*, 2009; Matita

et al., 2022). To evaluate these dynamics and rigorously estimate the causal impacts of value chain configuration on household food security IPWRA model was utilized (Imbens and Wooldridge, 2009; Wooldridge, 2010). This quasi-experimental framework handles double-robust selection bias by modeling both treatment assignment and outcome processes simultaneously (Linden *et al.*, 2016; Slocumb and Dong, 2019), thereby isolating the true treatment effects on food security using marginalized isolated spot market survivalist as the baseline counterfactual comparison group (Dorward *et al.*, 2009; Kassie *et al.*, 2018; Tambo and Mockshell, 2018). The doubly robust Inverse Probability Weighted Regression Adjustment (IPWRA) estimates for multidimensional food security outcomes are presented in Table 7.

Table 7: IPWRA Treatment Effects for Multidimensional Food Security Outcomes

Multidimensional Food Security Outcome Metrics	ATET: (Cooperative Track vs. Baseline)	ATET: (Processing Track vs. Baseline)	Potential Outcome Mean (POM) (isolated, spot market household Baseline Counterfactual)
Household Dietary Diversity Score (HDDS)	+1.45*** (0.31)	+2.12*** (0.42)	4.15 (0.22)
Food Consumption Score (FCS)	+8.64*** (1.98)	+14.30*** (2.65)	28.40 (1.50)
Reduced Coping Strategies Index (rCSI)	-3.20*** (0.85)	-5.45*** (1.10)	12.60 (0.95)

*Source: own survey 2026, Note: Estimation via Inverse Probability Weighted with Regression Adjustment (IPWRA). The comparison baseline counterfactual group is isolated, spot market. Robust standard errors are presented in parentheses. Significance levels: *** $p < 0.01$.*

The causal Average Treatment Effects on the Treated (ATET) reveal that escaping spot-market vulnerabilities triggers substantial, positive shifts in household nutrition and food security:

4.1. Impact of Cooperative Track

Horizontally coordinated pathway brings immediate, significant improvement over isolated spot market and resource constrained. Household dietary diversity (HDDS) increases by 1.45 point, $p < 1\%$ significance level, food consumption score (FCS) improves by 8.64 points, at 1% significance level and exposure to acute food scarcity drops significantly by a 3.20-point. Institutional coordination capabilities through cooperative membership serves as a primary

determinant for improving multidimensional food security. Cooperative structures has direct and positive transitions on household food consumption and reduce household vulnerability to seasonal food shortage (Shumiye and Tolossa, 2025). Horizontal configuration pathway provides technical support, and market coordination to transitioning out from structural food deficits into higher quality and diversified diets (Ng'ombe *et al.*, 2024).Horizontal pathways significantly increase household consumption expenditures by reducing transaction costs. Aggregating market power yield positive dietary shifts and shield households against acute food scarcity (Bidari, 2024). Institutional coordination are highly effective in reducing food consumptions stress (Shumiye, 2025). Resource pooling mitigate the severity of seasonal food shortages and preventing households from resorting to dietary reduction (Mati, 2020).

4.2. Impact of Value-Added/ Processing tracks

Smallholder integration into processing achieve an average increase by 2.12 points in household dietary diversity and a major jump of 14.30 points in total food consumption relative to the baseline at 1% significance level. Food consumptions stress dropped by 5.45-point at 1% significance level. Vertical value chain converts raw product into stable health-sustaining household food security (Tilore *et al.*, 2025). Smallholder engagement in agro-processing significantly reduces post-harvest losses and stabilizes food prices. It also enables nutrition smoothing by ensuring a stable supply of food throughout off-season generating steady incomes, .smallholder integrations directly improve dietary diversity and lowers dependence on negative coping strategies (Othieno, and Csonka, 2025). Value-addition increase net income compared to raw-commodity sellers. This net income allows purchasing diverse food groups and protects from adopting restrictive food-consumption coping strategies (Shumiye and Tolossa, 2025; Adio *et al* 2025)

5. Conclusion, Policy Implications, and Future Research Directions

5.1. Conclusion

This study evaluated the structural determinants and multidimensional food security impacts of post-harvest value chain integration pathways among smallholder oilseed producers in the Hararghe, Ethiopia. Grounded in the Sustainable Livelihoods Framework and Transaction Cost Economics, the analysis demonstrates that smallholder value chain integration is not a homogenous process, but rather a strategic selection across distinct post-harvest pathways. Using an orthogonal Varimax-rotated Principal Component Analysis combined with K-means clustering, three distinct smallholder typologies were identified: the Vulnerable Spot Market (Survivalist Pathway (31.85%), the Cooperative Commercialization / Horizontal Pathway (42.82%), and the Value-Added / Vertical Processing Pathway (25.33%).

The empirical findings reveal that nearly three-quarters of smallholders remain trapped in asset-constrained, low-margin market pathways, forced into immediate post-harvest distress sales due to severe seasonal liquidity pressures and uncoordinated spot market transactions. The structural drivers governing transitions out of distress sales are highly gendered; male-headed households exhibit a significant competitive advantage in accessing capital and productive assets necessary to enter vertical processing channels. Econometric estimations via doubly robust Inverse-Probability-Weighted Regression Adjustment (IPWRA) confirm that transitioning from isolated spot markets into localized agro-processing and commercial storage structurally upgrades smallholder livelihoods. Capturing midstream value margins and stabilizing year-round cash flows drives substantial gains in household food security specifically increasing the Household Dietary Diversity Score (HDDS = +2.12) and Food Consumption Score (FCS= +14.30), while significantly mitigating reliance on adverse behavioral coping mechanisms ($rCSI = -5.45$). Ultimately, these empirical results affirm that smallholder development strategies must transcend primary productivity enhancements and actively foster midstream value-addition and processing capacities.

5.2. Policy Implications

To transition smallholders away from survivalist spot-market reliance toward high-value horizontal aggregation and vertical processing, targeted institutional and policy interventions are required across regional and national governance levels:

1. **Reorienting Agricultural Extension Services Beyond Primary Production:** The Ministry of Agriculture, the Oromia Agricultural Bureau, and District Agricultural Offices should systematically modernize extension curricula. Agricultural extension advice must expand beyond traditional agronomic yield practices to incorporate specialized training on post-harvest handling, commercial storage management, cooperative marketing, and localized agro-processing techniques.
2. **Addressing Gender Disparities in Asset and Value Chain Access:** Given the pronounced gender gap in vertical integration, gender-targeted policy frameworks must be institutionalized. Public interventions should channel dedicated agricultural credit lines, micro-processing technologies (such as mechanized oil extraction units), and commercial transport access directly through women-led cooperative subsets and self-help groups to dismantle structural entry barriers facing female-headed households.
3. **Mobilizing Working Capital through Off-Farm Synergies and Credit Access:** Because non-farm income and formal credit serve as crucial working capital for post-harvest investments, rural development policies should promote off-farm enterprise development. Financial institutions and rural credit cooperatives should deploy tailored pre-harvest and post-harvest credit lines that relieve immediate liquidity constraints, preventing premature distress selling at farm-gate prices.
4. **Institutionalizing Digital Market Information Systems:** Federal and regional agricultural authorities should invest heavily in open-access digital market information infrastructure. Broadcasting real-time, localized commodity price data via mobile networks and digital platforms will reduce spatial information asymmetries, strengthen smallholder bargaining power against opportunistic intermediaries, and encourage entry into value-added processing.

5.3. Directions for Future Research

While this study offers robust doubly robust causal estimates of post-harvest value chain integration in eastern Ethiopia, several avenues remain for future empirical inquiry:

1. **Longitudinal and Panel Data Dynamics:** This study relied on cross-sectional survey data. Future research should utilize multi-year panel datasets to trace the temporal stability of value chain typologies and model how smallholders transition dynamically across integration tracks over time in response to market and climate shocks.
2. **Spatial and Commodity Generalizability:** Expanding this analytical framework to other major agricultural regions and non-oilseed food crop value chains (such as cereals, pulses, and high-value horticulture) would evaluate the generalizability of these post-harvest pathway dynamics across diverse agro-ecological zones.
3. **Value-Chain-Wide Margin Analysis:** Future studies should examine the full midstream and downstream market structure including commercial processors, wholesalers, and urban retailers to quantify marketing margins, transaction costs, and price transmission mechanisms across the broader agrifood system.

Declaration of Use of Generative AI and AI-Assisted Technologies

During the preparation of this work, the authors used Gemini solely to edit the text for language accuracy and improve overall readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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