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Research Article

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Camel Milk Commercialization and Its Association with Household Food Insecurity among Pastoralists in the Shebelle Zone, Somali Region, Ethiopia

Abdi Yousuf Muhumed*, Abenet Belete and Michael Akwasi Antwi

Department of Agriculture and Animal Health, School of Agriculture and Life Sciences, College of Agriculture and Environmental Sciences, University of South Africa, Johannesburg, South Africa

*Correspondence to:
Abdi Yousuf Muhumed
Department of Agriculture and Animal Health,
School of Agriculture and Life Sciences,
College of Agriculture and Environmental Sciences,
University of South Africa,
Johannesburg, South Africa
E-mail: 20992793@mylife.unisa.ac.za

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Abstract

Camel milk is central to pastoral diets, income, and livelihood strategies in Ethiopia, yet evidence linking its commercialization to household food insecurity remains limited. This study examined factors associated with camel milk commercialization (CCM) and the direct and indirect associations of milk productivity with household food insecurity among 385 camel milk-producing households in the Shebelle Zone, Somali Region. Cross-sectional survey data collected during the 2024 - 2025 agricultural production season were analyzed using an observed-variable structural path model estimated by maximum likelihood in international business machines (IBM) statistical package for the social sciences (SPSS) analysis of moment structures (AMOS) version 31. Commercialization was measured as the percentage of total camel milk production sold, whereas household food insecurity was measured using the eight-item food insecurity experience scale (FIES) raw score (0 - 8), with higher values indicating greater food-insecurity severity. The model demonstrated good absolute and approximate fit, although incremental fit indices were comparatively weaker: Chi-square (χ^2) (153) = 232.313, $p < 0.001$; Chi-square statistic (CMIN)/degrees of freedom (DF) = 1.518; goodness-of-fit index (GFI) = 0.942; adjusted GFI (AGFI) = 0.920; comparative fit index (CFI) = 0.885; Tucker–Lewis index (TLI) = 0.857; incremental fit index (IFI) = 0.891; and root mean square error of approximation (RMSEA) = 0.037, 90% confidence interval (CI): 0.027, 0.046, p-value for close fit (PCLOSE) = 0.992. The model explained 59.4% of the variance in CCM and 46.2% in FIES. Milk productivity was positively associated with commercialization (B = 0.492 per 100 L/camel/year, $\beta = 0.131$, $p < 0.001$), whereas commercialization was negatively associated with FIES (B = −0.052 per percentage point, $\beta = -0.330$, $p < 0.001$). Milk productivity also had a significant negative direct association with FIES (B = −0.069, $\beta = -0.117$, $p = 0.002$). The standardized indirect productivity–commercialization–FIES association was negative and significant ($\beta \approx -0.043$; bias-corrected 95% CI: −0.069, −0.023, $p < 0.001$), while the standardized total association was −0.160. Institutional, household, and pastoral-context variables were also associated with the two outcomes. Because the study is cross-sectional, all estimates are interpreted as conditional statistical associations rather than causal effects.

Keywords

Camel milk, Commercialization, Food insecurity experience scale, Pastoral households, Structural path model

Introduction

Livestock plays an important role in rural livelihoods and national economies across developing countries. It provides food, income, employment, productive

assets, transport, social status, and protection against livelihood shocks, particularly for pastoralists and other resource-constrained households [1]. Livestock products also account for a substantial share of agricultural output, while demand for meat and milk continues to expand because of population growth, rising incomes, and changing food preference. Food security is commonly understood as a condition in which all people have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life [2]. Household food insecurity is influenced not only by physical food availability but also by purchasing power, market access, livelihood assets, food prices, climatic shocks, and institutional support [3].

Food insecurity remains a major development challenge in Ethiopia, particularly in drought-prone pastoral and agro-pastoral areas [4]. Recurrent drought, land degradation, conflict, livestock disease, water shortages, market disruption, and limited household assets continue to undermine food availability and access [5]. Dairy products in Ethiopia are distributed through both formal and informal marketing systems. Although the formal system has expanded with the entry of private processors, most milk continues to be traded informally through direct sales to consumers, neighbors, itinerant traders, and nearby towns because formal market infrastructure remains underdeveloped [6]. These limitations increase transaction costs, weaken incentives for market participation, and restrict access to more distant and potentially rewarding markets [7].

Access to infrastructure, credit, information, extension services, and reliable markets can facilitate the commercial transformation of smallholder production systems. Smallholder commercialization involves increasing the proportion of agricultural output sold and strengthening producers' engagement with input and output markets [8]. In Ethiopia, agricultural commercialization has been promoted as an important pathway for agricultural growth and agro-industrial development [9]. The Shebelle zone is a major camel-milk production area; pastoral households continue to face weak market linkages, high transaction costs, and limited processing and storage facilities. Improvements in camel milk productivity and management may enhance household welfare, but their benefits depend on whether households can convert output into reliable market sales while retaining sufficient milk for household consumption [10]. Despite the importance of camel milk to pastoral livelihoods, limited empirical evidence explains how milk productivity, institutional and market conditions, commercialization, and household food insecurity are connected within a single analytical framework in Ethiopia's Somali Region. Existing studies have generally examined livestock production, market participation, or food security separately. This separation limits understanding of whether greater productivity creates a marketable surplus, whether that surplus is converted into commercialization under high transaction costs, and whether commercialization is ultimately associated with improved household food access [11].

The commercialization food-security pathway is theoretically ambiguous in pastoral settings. Greater commercialization may increase cash income and purchasing power, but the sale of milk may also reduce the quantity retained for household consumption. The net association therefore depends on milk and food prices, the stability of markets, seasonal production, household consumption needs, the allocation of sales income, and exposure to drought, livestock losses, conflict, and other shocks. Transaction-cost theory explains how weak roads, high transport costs, limited market information, inadequate processing, and unreliable buyers can constrain the conversion of production into market sales. The sustainable livelihoods framework further emphasizes that livelihood outcomes depend on households' assets, institutions and vulnerability context, while an entitlement perspective highlights that food insecurity can persist even when food is produced if households lack stable command over food through own production, income, exchange or transfers. These mechanisms provide the theoretical basis for examining both the direct and indirect associations among productivity, commercialization, and food insecurity. Thus, the study pursued three objectives: (1) to describe the socioeconomic, production, commercialization, and food-insecurity characteristics of pastoral households that produce camel milk; (2) to identify the institutional and market factors linked to CCM; and (3) to investigate the direct relationship between CCM and household food insecurity, and to determine whether commercialization mediates the link between camel milk productivity and household food insecurity.

The following hypotheses were tested:

H_1: Camel milk productivity is positively associated with CCM.

H_2: Market access and infrastructure (MAI), access to credit and finance (ACF), product diversification, access to information (AI), processing infrastructure, and social capital are positively associated with CCM.

H_3: Market demand and price volatility (MDPV) are negatively associated with CCM.

H_4: CCM is negatively associated with household food insecurity.

H_5: Camel milk productivity is negatively associated with household food insecurity.

H_6: CCM mediates the association between camel milk productivity and household food insecurity.

Conceptual framework

The conceptual framework integrates transaction-cost theory, the sustainable livelihoods framework, agricultural-household consumption–production trade-offs, and an entitlement perspective on food insecurity. Camel milk productivity is expected to increase the quantity potentially available for sale, but the conversion of productive capacity into commercialization depends on the institutional and market environment. MAI, access to finance, product diversification, AI, processing and storage infrastructure, and social capital can reduce transaction costs and strengthen market participation, whereas unstable demand and price volatility can discourage sales. Commercialization is expected to influence food insecurity primarily through income and

purchasing power [12]. However, this relationship is not necessarily unidirectional. Selling a larger share of milk can increase cash income while reducing the amount retained for direct household consumption. The net association between commercialization and food insecurity therefore depends on the relative value of milk sales and food purchases, household consumption requirements, seasonal production, food prices, market reliability, and exposure to climatic and livelihood shocks. Milk productivity may also be directly associated with food insecurity through the availability of milk for household consumption and potential sales income. The empirical model therefore estimates direct pathways from milk productivity to commercialization and food insecurity, a pathway from commercialization to food insecurity, and an indirect productivity–commercialization- food insecurity pathway. Socioeconomic and pastoral vulnerability variables are included as covariates because they may shape households' market participation, resource access, coping capacity, and food entitlement.

The hypothesized relationships among camel milk productivity, institutional and market value chain, CCM, socioeconomic characteristics, and household food insecurity are summarized in figure 1.

Materials and Methods

Description of the study area

Shabelle is one of the eleven zones that comprise the Somali Region. This study was conducted in the Shebelle zone of the Somali Regional State, located in eastern Ethiopia. The zone is bounded by Afdheer to the west, Fiq to the north, Korahe to the northeast, and the country of Somalia to the south. It lies within a lowland agro-ecological zone, with elevations ranging from about 250 to 600 m above sea level. The river traverses the zone and plays a key role in sustaining pastoral and agro-pastoral livelihoods [13]. Two primary rainy seasons occur: the Gu season (April - June) and the Dayr season (October - December). These seasonal rains largely determine livestock production patterns and grazing availability. The study area was deliberately selected because of its large camel population and its status as the main camel-milk production hub in the Somali Regional State. The zone relies heavily on camel-centric production methods; camel milk is a vital source of nutrition and economic benefit for pastoral households. The region also shows varying levels of market access and camel-milk commercialization, which influence the link between production efficiency, value chain, and household wellbeing. The coexistence of traditional and emerging market-focused camel-milk value chains offers a suitable context for studying the factors that affect efficiency and commercialization in pastoral communities. The accessibility of the study sites and the availability of reliable data from local organizations further justified the selection of this area for the research. The study focused on three major pastoral districts: Adadle, Dhanaan, and Godey. Addadle is characterized by extensive camel herds and year-round milk production supported by seasonal grazing and riverine pastures. Godey

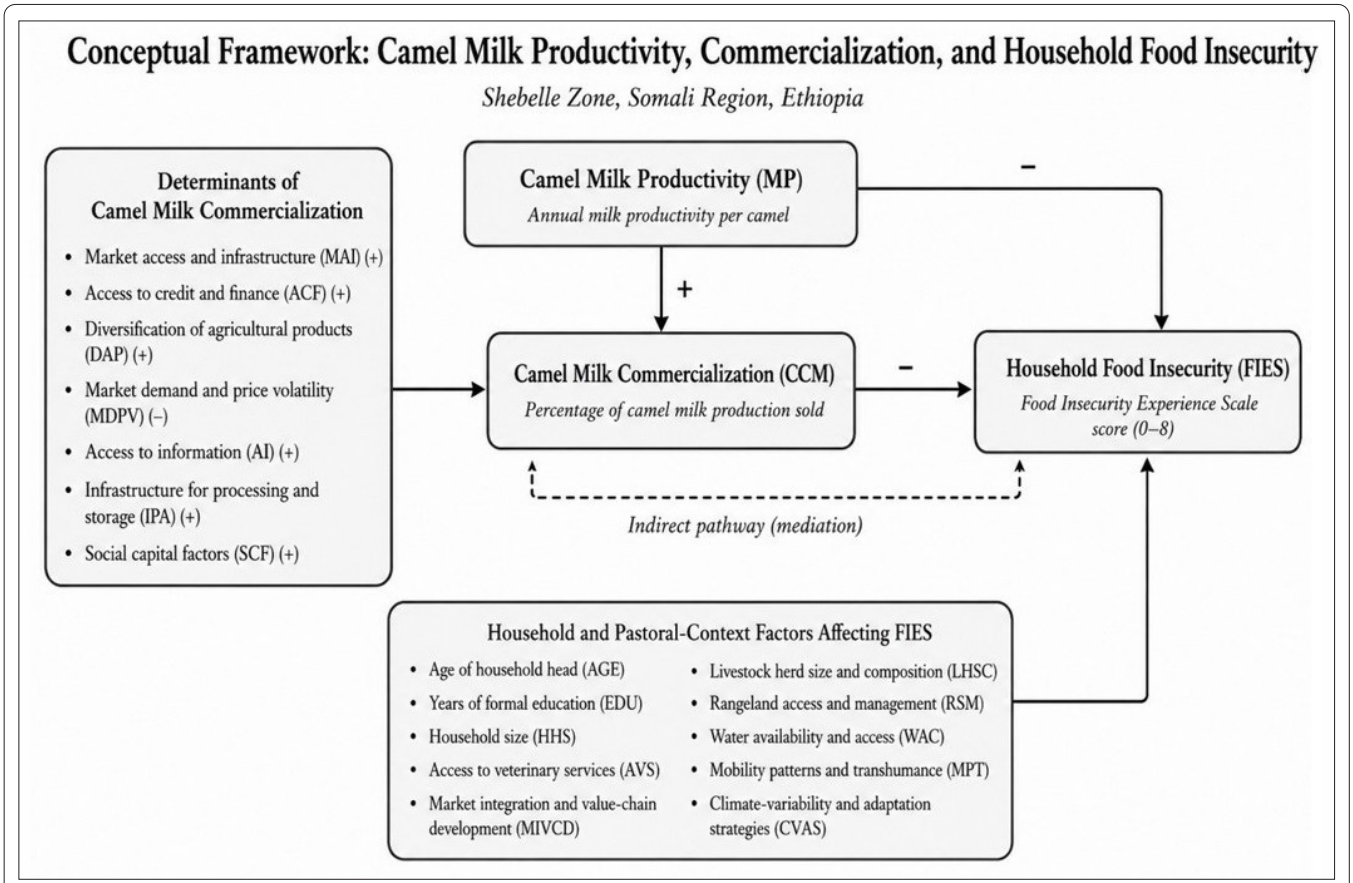


Figure 1: Conceptual framework linking camel milk productivity, commercialization, institutional and market factors, and household food insecurity. Source: Authors' conceptualization based on the sustainable livelihood's framework, transaction cost theory, and entitlement theory.

serves as one of the administrative and commercial centers of the zone, where milk collection points and informal trading networks facilitate camel milk marketing.

The geographical location of the Shebelle zone and the selected study woredas is shown in figure 2

Research design

A quantitative cross-sectional household survey was used. Fieldwork commenced only after ethics approval was granted on 4th July 2024 and was completed during the 2024 - 2025 agricultural production season. The dataset contains one observation per household; it is therefore not a repeated seasonal panel and cannot identify within-household changes between wet and dry seasons.

Study population

The target population for this study comprised camel milk-producing pastoral households in the Shebelle zone of the Somali Regional State, Ethiopia. According to the 2007, population and housing census of Ethiopia, the Shebelle zone had a total population of 464,253 people, of whom 258,558 were male and 205,695 were female. Approximately 89,593 individuals resided in urban areas, while 118,608 were classified as pastoral residents. These figures describe the demographic background of the study area.

However, the total zonal population was not used as the sampling frame for this study. Since the unit of analysis was the camel milk-producing household, the sampling frame consisted only of eligible households actively engaged in camel milk production. Based on records obtained from woreda livestock offices, kebele administrative records, cooperatives, and pastoral development structures, approximately 9,600 eligible camel milk-producing households were identified in the selected kebeles of Godey, Dhanaan, and Adadle woredas.

Sample size and sampling approach

The sample size for the household survey was determined using Cochran's formula at a 95% confidence level, a 5% margin of error, and a conservative population proportion of 0.5. The minimum required sample size was 384.16, which was rounded to 385 camel milk-producing households. The initial sample size was calculated as follows:

$$n_0 = Z^2 p(1-p)/e^2 = 1.96^2 \times 0.5 \times 0.5/0.05^2 = 384.16 \quad (1)$$

Where, Z = 1.96 is the standard normal value for a 95% confidence level, p = 0.5 is the assumed population proportion, and e = 0.05 is the margin of error.

Because the eligible household sampling frame was approximately 9,600, the finite-population correction was also considered:

$$n = n_0/1 + (n_0 - 1)/N \quad (2)$$

The finite-population correction gives a sample slightly below 385; however, the larger Cochran sample of 385 households was retained to preserve precision and allow for possible incomplete responses. A multistage sampling design was employed. Godey, Dhanaan, and Adadle woredas were purposively selected because of their importance in camel-milk

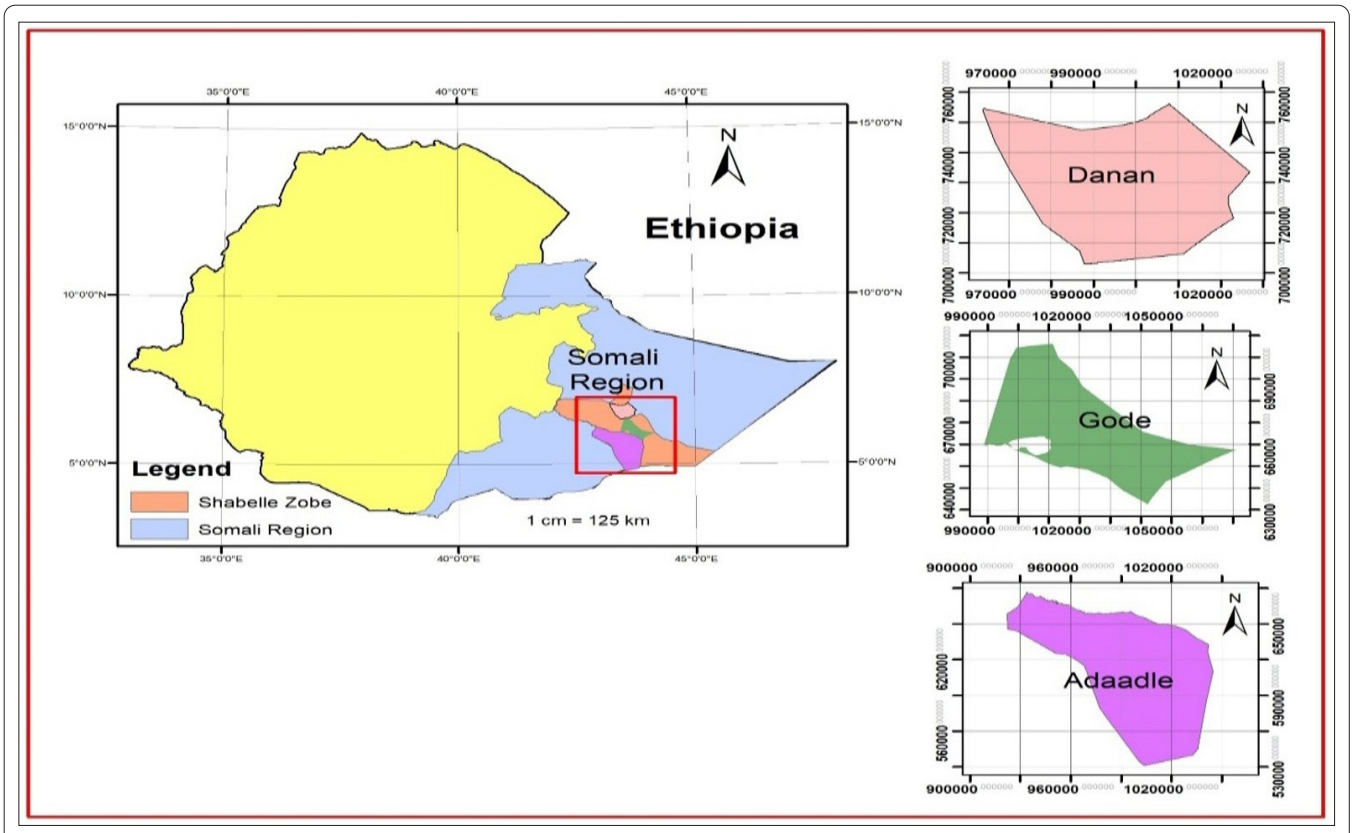


Figure 2: Map of the study area.
Source: Central statistic Ethiopia [14].

production and marketing. Kebeles were then selected within each woreda, after which camel milk-producing households were chosen through systematic random sampling from lists compiled by woreda livestock offices, kebele administrations, cooperatives, and pastoral development structures (Table 1).

Data collection

Table 1: Sample allocation by woreda.

No.	Woreda	Allocated sample	Percentage (%)
1	Godey	156	40.5
2	Adadle	125	32.5
3	Dhanaan	104	27.0
Total		385	100

Source: Authors' field survey data 2025.

The primary data were collected from camel milk-producing households using a structured questionnaire that covered milk production, input use, commercialization, socioeconomic characteristics, and household food insecurity. The questionnaire was reviewed by agricultural economics experts and pre-tested before the main survey. Secondary information was obtained from government reports and the Somali Region relevant office. Ethical clearance was obtained from the University of South Africa College of Agriculture and Environmental Sciences Health Research Ethics Committee (reference 2024/CAES_HREC/2691). All respondents were informed about the purpose of the study, participated voluntarily, and could withdraw at any time without penalty.

Measurement of variables

Household food insecurity was measured using the eight-item FIES. Each item was coded as X_{ij} = 1 when household i responded "Yes" to item j and X_{ij} = 0 when the response was "No." The raw household FIES score was calculated as:

$$FIES_i = \Sigma_{j=1}^{8} X_{ij} \quad (3)$$

Where, $FIES_i$ is the food-insecurity score of households i and X_{ij} represents the response of household i to FIES item j. The resulting score ranged from 0 to 8, with higher values indicating greater severity of household food insecurity. The continuous 0 - 8 FIES score was used as the primary outcome in the structural path analysis. For descriptive purposes only, households were grouped into food-secure, mildly food-insecure, moderately food-insecure, and severely food-insecure categories.

CCM was measured using the household commercialization index:

$$CCM_i = QMS_i/QMP_i \times 100 \quad (4)$$

Where, CCM_i is the camel milk commercialized by household i, QMS_i is the quantity of camel milk sold during the 2024 - 2025 crop season, and QMP_i is the total quantity of camel milk produced during the same period. The index theoretically ranges from 0 to 100, with higher values indicating greater market orientation (Sales). Camel milk productivity was measured as annual milk output per camel in liters. Age was measured in completed years, education as formal schooling, and household size as the number of household members. The institutional and market variables predicting commercialization were MAI, ACF, diversification of agricultural products (DAP), MDPV, AI, infrastructure for processing and storage (IPA), and social capital factors (SCF).

The extended household food-insecurity equation additionally included access to veterinary services (AVS), market integration and value-chain development (MIVCD), livestock herd size and composition (LHSC_TLU_index), rangeland access and management (RSM), water availability and access (WAC), mobility patterns and transhumance (MPT), and climate variability and adaptation strategies (CVAS). AVS and MIVCD were measured on five-point scales ranging from 1 = very poor access/integration to 5 = very good access/integration.

Model specification

To examine the direct and indirect associations among milk productivity, commercialization, institutional and market factors, socioeconomic characteristics, pastoral livelihood conditions, and household food insecurity, an observed-variable structural path model was specified. The commercialization equation modeled CCM_percent as a function of milk productivity, MAI, ACF, DAP, MDPV, AI, IPA, and SCF. The household food-insecurity equation modeled FIES_score_0 to 8 as a function of CCM_percent, milk productivity, age, education, household size, AVS, MIVCD, LHSC_TLU_index, RSM, WAC, MPT, and CVAS. The indirect association of milk productivity with FIES through commercialization was defined as the product of the milk-productivity → commercialization and commercialization → FIES paths, while the total association combined the direct and indirect components. Selected covariances among substantively related exogenous predictors were estimated to represent plausible interdependence among market, household, and pastoral-context conditions; these covariances were treated as nuisance associations rather than substantive causal hypotheses. The data were cross-sectional; all structural coefficients were interpreted as conditional statistical associations rather than causal effects.

Commercialization equation

$$CCM_i = \alpha_0 + \alpha_1 MP_i + \alpha_2 MAI_i + \alpha_3 ACF_i + \alpha_4 AI_i + \alpha_5 IPA_i + \alpha_6 DAP_i + \alpha_7 MDPV_i + \alpha_8 SCF_i + \varepsilon_{1i}. \quad (5)$$

Where, CCM_i = camel milk commercialization; MP_i = annual milk productivity per camel; α_0 = intercept; α_1–α_8 = structural coefficients; and ε_{1i} = commercialization disturbance term.

For the selected substantively related exogenous predictors were allowed to covary in the AMOS specification. These covariance parameters were estimated separately from the structural regression equations and were treated as nuisance associations reflecting plausible interdependence among market, household, and pastoral-context conditions rather than as directional causal relationships.

Household food-insecurity equation

$$FIES_i = \beta_0 + \beta_1 CCM_i + \beta_2 MP_i + \beta_3 AGE_i + \beta_4 EDU_i + \beta_5 HHS_i + \beta_6 AVS_i + \beta_7 MIVCD_i + \beta_8 LHSC_i + \beta_9 RSM_i + \beta_{10} WAC_i + \beta_{11} MPT_i + \beta_{12} CVAS_i + \varepsilon_{2i} \quad (6)$$

Where, $FIES_i$ = household FIES score; CCM_i = camel milk commercialization percentage; MP_i = annual milk productivity per camel; AGE_i = age of household head; EDU_i = years of formal education; HHS_i = household size; β_0 = intercept; β_1–β_{12} = structural coefficients; and ε_{2i} = food-insecurity disturbance term.

Mediation effect

The indirect association of camel milk productivity with household food insecurity through commercialization was specified as

$$IE = \alpha_1\beta_1 \quad (7)$$

The total association of camel milk productivity with household food insecurity was specified as

$$TE = \beta_2 + \alpha_1\beta_1 \quad (8)$$

Where, β_2 represents the direct association of milk productivity with household food insecurity, and $\alpha_1\beta_1$ represents the indirect association operating through CCM.

The study used cross-sectional data; all structural coefficients were interpreted as conditional statistical associations rather than causal effects. Since the model was estimated from cross-sectional data, we interpret all direct, indirect, and total paths as conditional statistical associations. The indirect productivity–commercialization–FIES pathway therefore represents statistical mediation and does not establish causal mediation or temporal ordering.

Methods of data analysis

Descriptive statistics and observed-variable structural path analysis were conducted using IBM SPSS statistics and IBM SPSS AMOS version 31. The analytical sample consisted of 385 camel milk-producing households. The structural model was estimated using maximum-likelihood estimation, and milk productivity was rescaled to units of 100 liters per camel per year to facilitate interpretation of unstandardized coefficients. Model adequacy was assessed using chi-square (CMIN), CMIN/DF, GFI, AGFI, CFI, TLI, IFI, normed fit index (NFI), RMSEA with its 90% CI and PCLOSE, parsimony-adjusted indices, information criteria, and Hoelter's critical N. The non-centrality parameter (NCP) and minimum fit function were treated as supplementary discrepancy measures. Regression results are reported as unstandardized coefficients (B), standard errors (S.E.), critical ratios (C.R.), p-values, and standardized coefficients (β). Squared multiple correlations summarize the explained variance in commercialization and FIES. Distributional diagnostics were reviewed before estimation, and 5,000 bootstrap samples were used to assess parameter stability and to obtain CI for indirect and total effects. All 5,000 bootstrap samples were usable. Because the survey was cross-sectional, estimated paths are interpreted as associations rather than causal effects. Model-fit CI generated (Analyzed) by IBM SPSS AMOS version 31 are reported at the 90% level for RMSEA and other non-centrality-based fit statistics, whereas bias-corrected bootstrap CI for indirect and total effects are reported at the 95% level.

Results

Household, demographics, and production characteristics

Age of household heads

Most household heads were of working age. Respondents aged 30 - 59 years accounted for 311 households (80.8%), with the largest share in the 40 - 49-year group (29.4%). Respondents younger than 30 years and those aged 60 years or older represented 9.9% and 9.4%, respectively (Table 2).

Table 2: Distribution of household heads by age.

Age category (years)	Frequency (n)	Percentage (%)
Below 30	38	9.9
30 - 39	101	26.2
40 - 49	113	29.4
50 - 59	97	25.2
60 and above	36	9.3
Total	385	100

Source: Field survey data from 2024 - 2025.

Sex of respondents

Table 3 shows that 260 households (67.5%) were male-headed and 125 (32.5%) were female-headed. The distribution supports reporting gender-disaggregated descriptive information, while future multi-group analyses should examine whether structural associations differ by the household head's sex.

Table 3: Sex of the household head.

Variable	Category	Frequency (n)	Percentage (%)
Sex of household head	Male	260	67.5
Sex of household head	Female	125	32.5

Source: Field survey data from 2024 - 2025.

Education of household heads

Educational attainment was concentrated at the primary level. A total of 214 household heads (55.6%) had completed 1 - 6 years of schooling, 122 (31.7%) had 7 - 12 years, 42 (10.9%) had no formal education, and 7 (1.8%) had at least 13 years of education (Table 4).

Table 4: Education level of the household head.

Variable	Category	Frequency (n)	Percentage (%)
Education level	No formal education	42	10.9
Education level	Primary (1 - 6 years)	214	55.6
Education level	Secondary (7 - 12 years)	122	31.7
Education level	Tertiary (≥13 years)	7	1.8

Source: Field survey data 2024 - 2025.

Place of residence

Most households resided in pastoral (52.5%) or agro-pastoral (29.9%) areas; together, these settings accounted for 82.3% of the sample. Peri-urban households constituted the remaining 17.6% (Table 5), confirming that the sample was

predominantly rural and pastoral.

Table 5: Place of residence of respondents.

Variable	Category	Frequency (n)	Percentage (%)
Place of residence	Pastoral	202	52.5
	Agro-pastoral	115	29.9
	Peri-urban	68	17.6

Source: Field survey data 2024 - 2025.

Socioeconomic characteristics

Household income sources

Table 6 shows that camel milk sales were the principal source of income for 174 households (45.2%). Sales of other livestock were the second-most-frequently reported source (96 households; 24.9%). Non-livestock income sources were less common: petty trade and self-employment accounted for 10.9%, crop production for 9.9%, wage employment for 5.5%, and remittances for 3.6%. These findings underscore the central economic role of camel milk and livestock in pastoral livelihoods.

Table 6: Main sources of household income.

Income source	Households (n)	Percentage (%)
Camel milk sales	174	45.2
Livestock sales (camels, goats, and sheep)	96	24.9
Crop production	38	9.9
Petty trade/self-employment	42	10.9
Wage employment	21	5.5
Remittances	14	3.6
Total	385	100.0

Source: Field survey data 2024 - 2025.

Asset ownership and livelihood diversification

Asset ownership patterns reinforce the dominance of livestock-based livelihoods. All sampled households owned at least one camel, and 72.2% owned goats or sheep. Cattle ownership was less common (24.9%). Only 21.6% cultivated crops, 15.1% operated a small business, 10.6% owned a transport asset, and 9.4% engaged in non-farm wage employment. Limited diversification beyond livestock may constrain income stability and adaptive capacity (Table 7).

Table 7: Asset ownership and livelihood diversification.

Asset/Livelihood activity	Households (n)	Percentage (%)
Camels	385	100.0
Goats and sheep	278	72.2
Cattle	96	24.9
Crop farming	83	21.6
Small business/trade	58	15.1
Transport assets (motorcycles/carts)	41	10.6
Non-farm wage activity	36	9.4

Source: Field survey data 2024 - 2025.

Access to credit, extension, and veterinary services

Access to essential support services varied across households. Only 168 households (43.6%) reported ACF, while 149 (38.7%) had received extension support. Veterinary services were relatively more accessible, with 228 households (59.2%) reporting access; nevertheless, 40.8% still lacked regular veterinary support. Limited access to these services may constrain investment, delay animal treatment, and weaken the adoption of improved production and marketing practices (Table 8).

Table 8: Access to credit, extension, and veterinary services.

Service type	Access (Yes) n (%)	No access n (%)
Credit services	168 (43.6)	217 (56.4)
Extension services	149 (38.7)	236 (61.3)
Veterinary services	228 (59.2)	157 (40.8)

Source: Field survey data 2024 - 2025.

Camel milk production characteristics

Households owned an average of 2.33 lactating camels (standard deviation (SD) = 0.96; range = 1 - 5), indicating that most milk-producing households operated with relatively small lactating herds. Annual milk productivity averaged 2,176.59 liters per camel (SD = 344.91; range = 1,200.00 - 3,143.68). The broad range indicates meaningful heterogeneity in productive performance and supports modelling productivity as a continuous predictor rather than dividing it into arbitrary categories.

Milking occurred an average of 1.97 times per day. Supplementary feeding, pasture access, labor input, and animal-health expenditure also varied considerably across households. These differences reflect unequal resource endowments and management conditions that may shape both production and the capacity to bring milk to market.

CCM characteristics

Table 9 indicates substantial variation in herd size, total household milk output, supplementary feeding, pasture access, labor use, and animal-health expenditure. In the AMOS analysis data, annual milk productivity averaged 2,176.59 liters per camel. Households were located, on average, 10.61 km from a market and 12.22 km from a livestock clinic, indicating spatial barriers that may increase transaction costs and delay access to services.

Table 9: Camel milk production characteristics of sample households.

Variable	Mean	SD	Minimum	Maximum
Herd size (lactating camels)	2.33	0.96	1.00	5.00
Milk yield per camel per year	2,176.59	344.91	1,200.00	3,143.68
Total household milk output	16,932.13	6,349.43	1,935.30	47,910.10
Milking frequency	1.97	0.66	1.00	3.06
Supplementary feed provided	376.89	60.03	240.00	551.40
Pasture area accessed	12.66	6.14	1.00	31.25
Labor input	179.57	61.78	14.65	361.10
Health expenditure per camel	746.08	297.40	100.00	1,722.00

Source: Field survey data 2024 - 2025.

Household food-insecurity status

Each of the eight FIES items was coded as 1 for an affirmative response and 0 for a negative response. Item responses were summed up to produce a household raw score ranging from 0 to 8, with higher scores indicating more severe food-insecurity experiences. The continuous 0 - 8 raw score was used as the outcome in the structural path model. This use should be distinguished from Rasch-based respondent-severity parameters and from globally comparable prevalence estimates. Accordingly, the score intervals in table 10 are descriptive groupings for this study sample. Of the 385 households, 16 (4.2%) recorded a raw score of 0, 129 (33.5%) scored 1 - 3, 186 (48.3%) scored 4 - 6, and 54 (14.0%) scored 7 - 8. Thus, 62.3% of households fell within the study-defined 4 - 8 range, indicating substantial food insecurity during the 2024 - 2025 survey period.

Table 10: Descriptive grouping of FIES raw scores.

FIES category (score)	Frequency (n)	Percentage (%)
Food security (0)	16	4.2
Mild (1 - 3)	129	33.5
Moderate (4 - 6)	186	48.3
Severe (7 - 8)	54	14.0
Total	385	100.0

Source: Field survey data 2024 - 2025.

Determinants of CCM

Table 11 presents the structural equation modeling (SEM) AMOS commercialization equation. Holding the remaining predictors constant, milk productivity and the six enabling institutional and market factors were positively and statistically significantly associated with CCM, whereas MDPV were negatively associated with commercialization. ACF showed the strongest positive standardized association with commercialization (B = 8.026, S.E. = 0.694, C.R. = 11.567, β = 0.393, p < 0.001). DAP was also positively associated with commercialization (B = 5.168, S.E. = 0.670, C.R. = 7.717, β = 0.263, p < 0.001), followed by MAI (B = 4.637, S.E. = 0.670, C.R. = 6.920, β = 0.236, p < 0.001), IPA (B = 4.587, S.E. = 0.688, C.R. = 6.663, β = 0.223, p < 0.001), AI (B = 4.374, S.E. = 0.707, C.R. = 6.185, β = 0.209, p < 0.001), and SCF (B = 3.186, S.E. = 0.682, C.R. = 4.670, β = 0.158, p < 0.001). MDPV exhibited a significant negative association with commercialization (B = −6.565, S.E. = 0.689, C.R. = −9.533, β = −0.328, p < 0.001). Milk productivity remained positively associated with commercialization after adjustment for the complete set of predictors (B = 0.492 per 100 L/camel/year, S.E. = 0.122, C.R. = 4.023, β = 0.131, p < 0.001). Overall, the commercialization equation explained 59.4% of the variance in CCM (R^2 = 0.594), indicating substantial explanatory power.

Table 11: AMOS path coefficients for the CCM.

Predictor	B	S.E.	C.R.	β	p
Milk productivity (per /100 L)	0.492	0.122	4.023	0.131	< 0.001
MAI	4.637	0.670	6.920	0.236	< 0.001
ACF	8.026	0.694	11.567	0.393	< 0.001
DAP	5.168	0.670	7.717	0.263	< 0.001
AI	4.374	0.707	6.185	0.209	< 0.001
IPA	4.587	0.688	6.663	0.223	< 0.001
SCF	3.186	0.682	4.670	0.158	< 0.001
MDPV	−6.565	0.689	−9.533	−0.328	< 0.001

Source: Authors' structural path analysis in IBM SPSS AMOS version 31 using field survey data 2024 - 2025.

The results of all hypothesized commercialization predictors were statistically significant. ACF showed the largest positive standardized association with commercialization (β = 0.393, p < 0.001), followed by product diversification (β = 0.263), MAI (β = 0.236), processing and storage infrastructure (β = 0.223), AI (β = 0.209), social capital (β = 0.158), and milk productivity (β = 0.131); all p < 0.001. MDPV were negatively associated with commercialization (β = −0.328, p < 0.001). The equation explained 59.4% of the variance in commercialization (= 0.594).

Structural path analysis of camel milk productivity, commercialization, and household FIES

The observed-variable structural path model converged successfully. The chi-square statistic was significant, $\chi^2(153) = 232.313$, p < 0.001, while the normed chi-square indicated good fit (CMIN/DF = 1.518). Absolute fit indices were satisfactory (GFI = 0.942; AGFI = 0.920), and approximate fit was strong (RMSEA = 0.037, 90% CI: 0.027, 0.046, PCLOSE = 0.992). Incremental fit indices were comparatively weaker (CFI = 0.885; IFI = 0.891; TLI = 0.857; NFI = 0.736; relative fit index = 0.672). The NCP was 79.313 (90% CI: 42.183, 124.406), substantially lower than that of the independence model, although its CI did not include zero. Parsimony-adjusted indices were parsimony goodness-of-fit index = 0.686, parsimony NFI = 0.593, and parsimony CFI = 0.713. Taking together, the results indicate good absolute and approximate fit with moderate incremental fit; therefore, the AMOS model is interpreted as an acceptable mixed-fit structural model solution rather than a uniformly excellent-fitting model (Figure 3 and table 12).

Commercialization was negatively associated with FIES (B = −0.052, β = −0.330, p < 0.001), indicating that

Table 12: AMOS path coefficients for the household food insecurity equation.

Predictor	B	S.E.	C.R.	β	p
CCM percentage	−0.052	0.006	−8.671	−0.330	< 0.001
Milk productivity (per 100 L)	−0.069	0.023	−3.041	−0.117	0.002
Age	−0.010	0.007	−1.554	−0.059	0.120
Education (years)	−0.071	0.023	−3.072	−0.116	0.002
Household size	0.194	0.038	5.039	0.192	< 0.001
AVS	−0.391	0.107	−3.657	−0.138	< 0.001
MIVCD	−0.421	0.104	−4.042	−0.153	< 0.001
LHSC_TLU_index	−0.048	0.017	−2.906	−0.111	0.004
RSM	0.759	0.093	8.208	0.310	< 0.001
WAC	0.482	0.093	5.195	0.196	< 0.001
MPT	−0.294	0.109	−2.692	−0.102	0.007
CVAS	0.714	0.092	7.801	0.294	< 0.001

Source: Authors' structural path analysis in IBM SPSS AMOS version 31 using field survey data 2024 - 2025.

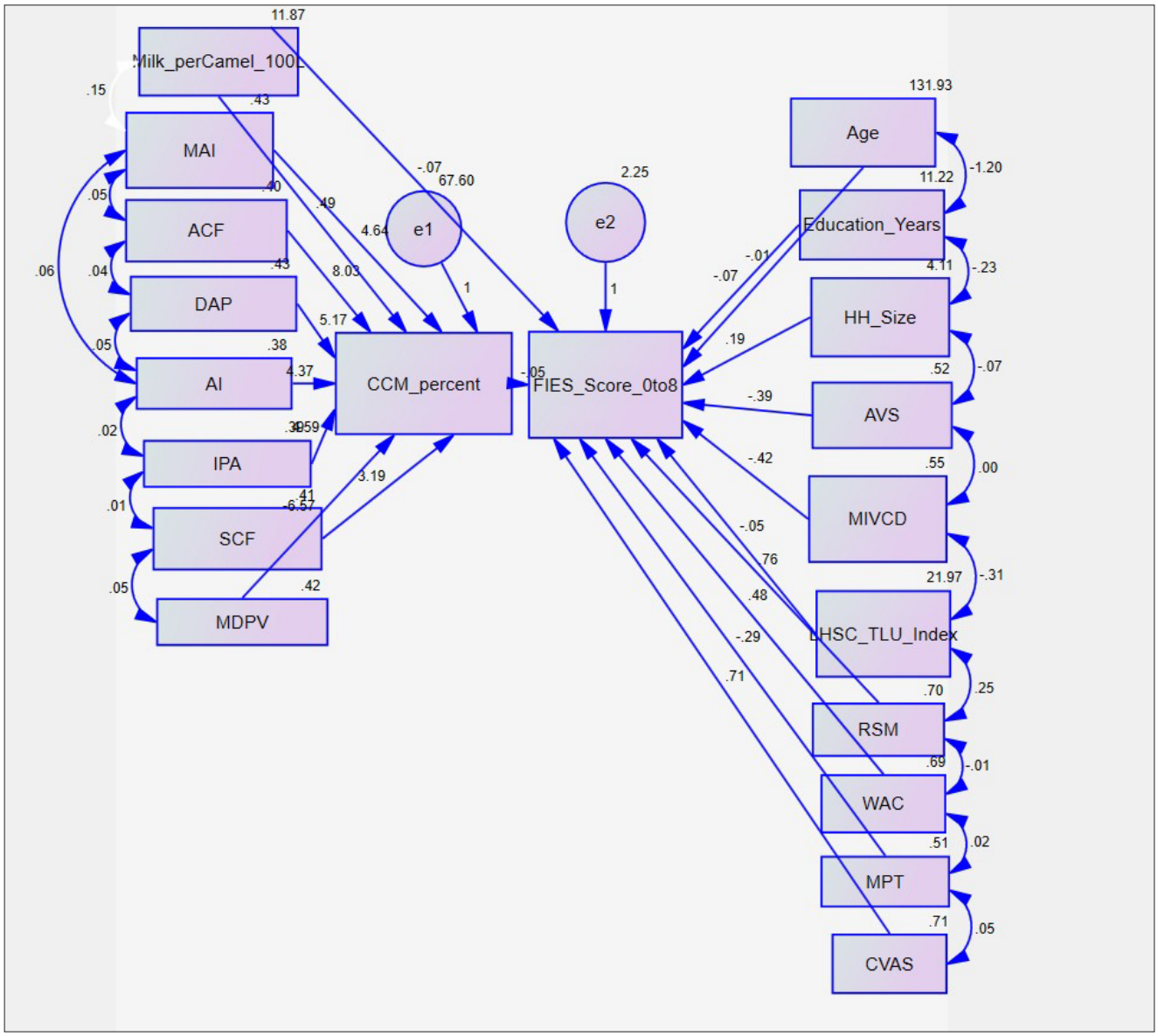


Figure 3: Analysis of AMOS observed-variable structural path model. Coefficients shown in the diagram are unstandardized estimates; path statistics are reported in table 11 and table 12.
Source: Authors' analysis of field survey data 2024 - 2025.

greater commercialization was associated with lower food-insecurity severity after adjustment for the other variables. Milk productivity also had a significant negative direct association with FIES (B = −0.069, β = −0.117, p = 0.002). Education, AVS, MIVCD, LHSC_TLU_index, and MPT were negatively associated with FIES, whereas household size, RSM, WAC, and CVAS were positively associated with FIES (Table 13). Age was not statistically significant (β = −0.059, p = 0.120). The FIES equation explained 46.2% of the variance in household food insecurity (0.462) .

Taken together, the fit indices indicate good absolute and approximate fit with moderate incremental fit. The normed chi-square (CMIN/DF = 1.518), GFI (0.942), AGFI (0.920), and RMSEA (0.037, 90% CI: 0.027, 0.046, PCLOSE = 0.992) supported model adequacy, while CFI (0.885) and IFI (0.891) approached the conventional 0.90 benchmark and TLI (0.857) remained below it. The model explained 59.4% of the variance in CCM and 46.2% in household food insecurity. Accordingly, the model specification is interpreted as an acceptable mixed-fit structural model (Table 14).

The indirect productivity → commercialization → FIES association was negative and statistically significant (standardized indirect effect β ≈ −0.043; bias-corrected 95% CI: −0.069, −0.023, p < 0.001). Because the direct productivity → FIES path remained significant (β = −0.117, p = 0.002), the pattern is consistent with partial statistical mediation. The total standardized association was −0.160 (bias-corrected 95% CI: −0.240, −0.072, p < 0.001). Given the cross-sectional design, this is statistical mediation and should not be described as causal mediation (Table 15).

The result of the AMOS model supported hypotheses H_1 – H_6. Milk productivity and favorable institutional and market conditions were positively associated with commercialization, whereas MDPV were negatively

Table 13: Overall fit and explained variance of the AMOS structural path model.

Fit index	SEM AMOS value	Interpretation
χ^2 (df), p	232.313 (153), < 0.001	Significant exact-fit test
CMIN/DF	1.518	Good
GFI	0.942	Good
AGFI	0.920	Good
CFI	0.885	Approaches 0.90
TLI	0.857	Below preferred 0.90
IFI	0.891	Approaches 0.90
RMSEA (90% CI)	0.037 (0.027, 0.046)	Close approximate fit
PCLOSE	0.992	Supports close fit
CCM	0.594	59.4% explained; substantial
FIES	0.462	46.2% explained; moderate-to-substantial

Note: RMSEA confidence limits are the 90% intervals reported by IBM SPSS AMOS version 31. PCLOSE tests the close-fit hypothesis that RMSEA ≤ 0.05. Higher FIES scores indicate greater household food-insecurity severity.
Source: Authors' structural path analysis in IBM SPSS AMOS version 31 using field survey data 2024 - 2025.

associated with commercialization. Both commercialization and milk productivity were negatively associated with FIES. The significant indirect productivity → commercialization → FIES association supported H_6 and was consistent with partial statistical mediation because the direct productivity → FIES path remained significant. These relationships are interpreted as statistical associations rather than causal effects because the study is cross-sectional.

Discussion

This study examined the relationships among camel milk productivity, institutional and market conditions, commercialization, pastoral vulnerability, and household food insecurity in Ethiopia's zone. The findings show that CCM is embedded within a broader livelihood system: productivity and institutional-market conditions were associated with commercialization, while commercialization, productivity, household characteristics, and pastoral-context factors were associated with household food insecurity. These relationships should be interpreted as conditional statistical associations because the study used cross-sectional data.

Camel milk production characteristics and productivity

Households owned an average of 2.33 lactating camels, while annual milk productivity averaged approximately 2,177 liters per camel. The considerable variation observed in milk productivity, supplementary feeding, pasture access, labor input, veterinary expenditure, and total milk output reflects heterogeneity in household resource endowments and pastoral production conditions.

For households with relatively few lactating camels, disease, reproductive failure, drought, feed shortages, and water scarcity may rapidly reduce both milk available for household consumption and the surplus available for sale. This vulnerability is particularly important in pastoral systems where livestock simultaneously provide food, income, savings, and protection against livelihood shocks. The observed production conditions therefore reinforce the importance of interventions that combine animal-health services, improved feeding, sustainable pasture and water management, and climate-risk preparedness rather than focusing on milk output alone.

These findings are consistent with evidence that pastoral and agro-pastoral livelihoods in Ethiopia remain highly exposed to recurrent climatic and production shocks [15]. However, given the cross-sectional nature of the data, the descriptive production differences reported here should not be interpreted as causal determinants of productivity.

Determinants of CCM

The commercialization equation supports transaction costs and institutional explanations of market participation. ACF, product diversification, MAI, processing and storage infrastructure, AI, and social capital were each positively and significantly associated with commercialization. These

Table 14: Direct and implied indirect productivity associations with FIES.

Association	B	β	p	Bootstrap interpretation
Direct: productivity → FIES	−0.069	−0.117	0.002	Direct path significant
Indirect: productivity → CCM → FIES	≈ −0.026	≈ −0.043	< 0.001	BC 95% CI β: −0.069, −0.023; significant
Total productivity association	≈ −0.095	−0.160	< 0.001	BC 95% CI β: −0.240, −0.072; significant

Source: Authors' structural path analysis in IBM SPSS AMOS version 31 using field survey data 2024 - 2025.

Table 15: Hypothesis decisions from the AMOS structural path model.

Hypothesis	Tested association	AMOS evidence	Decision
H_1	Milk productivity → CCM (+)	β = 0.131; p < 0.001	Supported
H_2	MAI, ACF, DAP, AI, IPA, SCF → CCM (+)	β = 0.158 to 0.393; all p < 0.001	Supported
H_3	MDPV → CCM (−)	β = −0.328; p < 0.001	Supported
H_4	CCM → FIES (−)	β = −0.330; p < 0.001	Supported
H_5	Milk productivity → FIES (−)	β = −0.117; p = 0.002	Supported
H_6	Milk productivity → CCM → FIES (indirect)	β ≈ −0.043; BC 95% CI: −0.069, −0.023; p < 0.001	Supported

resources may help households finance transport and handling, locate buyers, reduce spoilage, coordinate sales, and absorb short-term shocks. MDPV showed a strong negative association, consistent with the disincentive created by uncertain buyers and prices for a highly perishable product [16].

Milk productivity was positively associated with commercialization after institutional and market conditions were controlled, supporting the expected marketed-surplus pathway: greater output per camel may enlarge the quantity potentially available for sale. The result also indicates that productive capacity operates alongside institutional and market conditions; productivity alone does not remove transaction-cost, finance, information, processing, and market-stability constraints [17, 18].

Household food-insecurity outcomes

Household food insecurity remained widespread in the study sample. Only 4.2% of households recorded a FIES raw score of zero, while 33.5%, 48.3%, and 14.0% fell within the study-defined mild, moderate, and severe food-insecurity categories, respectively. The predominance of moderate and severe food-insecurity experiences demonstrates that ownership of camels and participation in milk production do not, by themselves, ensure stable household food access. This result is consistent with the multidimensional nature of food insecurity in pastoral settings. Household access to food depends not only on livestock production but also on purchasing power, household size, market integration, animal-health services, herd resources, rangeland and water conditions, mobility, climatic stress, food prices, and the capacity to respond to shocks. The sustainable livelihoods framework is particularly relevant: productive assets can contribute to welfare, since their benefits depend on the institutional environment and the vulnerability context in which households operate.

The SEM AMOS model reinforces this interpretation. Education, veterinary access, MIVCD, livestock herd resources, and mobility/transhumance were negatively associated with FIES, whereas household size, rangeland-related constraints, water-access constraints, and climate-related stress were positively associated with food-insecurity severity. These findings indicate that pastoral food insecurity cannot be understood through commercialization alone and should instead be interpreted within the broader interaction of household resources, service access, market conditions, and environmental vulnerability.

Structural relationships among productivity, commercialization, and food insecurity

The AMOS structural path model demonstrated good absolute and approximate fit, although incremental fit indices were comparatively weaker. The normed chi-square was achieved (CMIN/DF = 1.518), while GFI = 0.942, AGFI = 0.920, and RMSEA = 0.037, 90% CI: 0.027, 0.046, PCLOSE = 0.992 supported close approximate fit. CFI (0.885) and IFI (0.891) approached the commonly referenced 0.90 benchmark, whereas TLI (0.857), NFI (0.736), and relative fit index (0.672) remained below preferred levels. The NCP = 79.313, 90% CI: 42.183, 124.406 was substantially lower than that of the independence model, providing supplementary evidence of reduced model discrepancy. Overall, the SEM model is best characterized as showing good absolute and approximate fit with moderate incremental fit rather than uniformly excellent fit.

Commercialization was negatively associated with household food insecurity ($\beta = -0.330$, $p < 0.001$), indicating that greater CCM was associated with lower FIES severity after adjustment for the other variables in the model. Milk productivity was positively associated with commercialization ($\beta = 0.131$, $p < 0.001$) and also showed a significant negative direct association with FIES ($\beta = -0.117$, $p = 0.002$). The indirect productivity → commercialization → FIES association was negative and statistically significant ($\beta \approx -0.043$; bias-corrected 95% bootstrap CI: −0.069, −0.023, $p < 0.001$). Because both the direct and indirect associations remained statistically significant, the pattern is consistent with partial statistical mediation. However, because productivity, commercialization, and FIES were measured within the same cross-sectional survey, the mediation result represents a statistical decomposition of associations and does not establish temporal ordering or causal mediation.

Explanatory power and broader food-security determinants

The model explained 59.4% of the variance in CCM and 46.2% of the variance in household food insecurity. These findings indicate substantial explanatory power for commercialization and moderate-to-substantial explanatory power for household food insecurity. These findings indicate substantial explanatory power for commercialization and moderate-to-substantial explanatory power for FIES. These findings indicate substantial explanatory power for commercialization and moderate-to-substantial explanatory power for household food insecurity. The remaining unexplained variation may reflect food prices, remittances, conflict, livestock mortality, humanitarian assistance, intra-household allocation, and other factors not measured in the analysis of the study.

Seasonality and gender remain important areas for further investigation. Because the study used a single-round cross-sectional survey, the analysis cannot distinguish between dry- and wet-season relationships among milk productivity, commercialization, food prices, household consumption, and FIES. Similarly, although descriptive statistics provide useful insights, several limitations should be considered when interpreting the findings. These limitations relate primarily to cross-sectional design, sampling strategy, seasonality, unmeasured dimensions of food insecurity, potential gender heterogeneity, self-reported information, and the refinement of the AMOS structural model (Table 16).

Disaggregated by sex of household head, the structural model did not test whether path coefficients differed between male- and female-headed households. Future research should therefore use repeated seasonal observations and adequately powered multi-group models to assess temporal variation and gender heterogeneity.

Table 16: Study limitations.

Limitation	Implication
Cross-sectional design	Associations cannot establish causality, temporal ordering, or causal mediation
Purposive first-stage selection of study areas	Generalization should be limited primarily to comparable camel-producing pastoral and agro-pastoral settings
Single survey period	Wet- and dry-season dynamics in productivity, commercialization, prices, consumption, and food insecurity cannot be separated
Multidimensional nature of food insecurity	Economic, climatic, conflict-related, humanitarian, and household-level determinants not included in the model may explain additional FIES variation
No gender-specific structural model	Potential differences in structural relationships between male- and female-headed households remain untested
Self-reported household information	Some measures may be affected by recall error or reporting bias
Post-estimation model refinement	Selected covariance refinements should be interpreted as theoretically plausible nuisance associations rather than causal relationships

Conclusion

CCM in Ethiopia's zone was positively associated with milk productivity and with access to finance, markets, information, processing and storage infrastructure, product diversification, and social capital, while MDPV were negatively associated with commercialization. Greater commercialization was associated with lower household food-insecurity severity after adjustment for socioeconomic, institutional, and pastoral-context conditions. Milk productivity was also directly associated with lower FIES and indirectly associated with FIES through commercialization. The AMOS model explained 59.4% of the variance in CCM and 46.2% in FIES.

The indirect productivity → commercialization → FIES association was negative and statistically significant ($\beta \approx -0.043$; bias-corrected 95% CI: −0.069, −0.023, $p < 0.001$), while the direct productivity → FIES association remained significant ($\beta = -0.117$, $p = 0.002$). This pattern is consistent with partial statistical mediation. Because all variables were measured in the same cross-sectional survey, this finding should not be interpreted as evidence of causal mediation or temporal sequencing.

Overall, the findings support an integrated approach to pastoral food security in which productivity enhancement and value-chain development are combined with improved veterinary services, pastoral-adapted finance, market information, processing and cold-chain infrastructure, water and rangeland management, climate resilience, household livelihood support, and food-access interventions. Commercialization should therefore be treated as one component of a broader pastoral food-security strategy rather than as a stand-alone solution.

Policy implementation should be tailored to the mobility, seasonality, and market conditions of pastoral households in the Somali Region. In the short term (0 - 2 years), the Somali Regional Bureau of Livestock and Pastoral Development, woreda livestock offices, pastoral cooperatives, microfinance institutions, and humanitarian and development partners should prioritize mobile veterinary and extension services, regular dissemination of camel-milk price and buyer information, provision of food-grade milk containers, and flexible working-capital products adapted to irregular pastoral cash flows. Milk collection schedules and service delivery should be coordinated with seasonal livestock mobility rather than relying exclusively on fixed service points. Progress during this phase could be monitored through the proportion of camel-producing households reached by mobile veterinary services, the number of producers receiving regular market information, access to pastoral-adapted credit, reported milk losses, and changes in the volume and share of milk marketed.

In the medium term (3 - 5 years), the Somali Regional Government, in collaboration with woreda administrations, relevant water and rangeland authorities, producer organizations, private milk traders and processors, financial institutions, and development partners, should invest in strategically located milk aggregation and solar-powered cooling facilities, strengthen producer cooperatives and quality-control systems, rehabilitate priority pastoral water and grazing infrastructure, and improve feeder-road and transport links connecting major camel-milk production areas with markets such as Godey and other trading centers. These investments should be located along pastoral production and marketing corridors and should be designed so that mobile households can access them during both dry- and wet-season movements. Key indicators should include the number of functioning collection/cooling points, reductions in milk spoilage and transport time, producer participation in organized marketing, stability of farm-gate prices, veterinary-service coverage, and improvements in market access.

Food-security policy should not treat commercialization as a stand-alone intervention. The AMOS model indicates that household food insecurity is also associated with veterinary access, value-chain integration, herd resources, household size, mobility, water and rangeland conditions, and climate-related stress. The Somali Regional Government should therefore link CCM programs with drought-responsive livestock services, strategic water and grazing management, pastoral social protection, livelihood diversification, and household food-access support. Implementation should be reviewed annually and, where feasible, before and after the major dry and rainy seasons using indicators that capture both market performance and household welfare, including milk productivity, commercialization share, milk losses, prices received by producers, household dietary access, and FIES scores. Because the present study is cross-sectional, these recommendations should be implemented with monitoring and evaluation systems capable of testing whether improvements in market and pastoral-service conditions are followed by sustained

reductions in food insecurity over time.

Implementation should also be gender responsive. Women's important roles in milking, handling, local marketing, and household food allocation require that finance, training, producer-organization membership, milk-collection infrastructure, and market-information services be designed to ensure women's practical access and participation. Monitoring should therefore disaggregate participation, access to finance, control over milk-sale income, and food-security outcomes by sex of household head and, where data permit, by women's participation in milk marketing.

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Conflict of Interest

None.

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