



Feed Insufficiency and Milk Quality Constraints in Smallholder Goat Production Systems: A SWOT-TOWS Analysis of Southern Thailand's Border Provinces

Santi Madman¹, Thaintip Kraiprom², Pitunart Noosen³, Chaiyawan Wattanachant³

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ABSTRACT

Background: Smallholder goat milk production in Thailand's three southern border provinces (Pattani, Yala and Narathiwat) represents a critical livelihood strategy integrated with Muslim cultural practices. Despite long-standing production experience, farmers face persistent constraints including feed scarcity, limited financial access, suboptimal milk quality and inadequate knowledge of high-quality raw goat milk production.

Methods: A convergent mixed-methods design combined focus group discussions with 47 dairy goat farmers, laboratory analysis of milk samples from six representative farms, structured surveys (n=10 farm enterprises) and secondary data from government livestock statistics (2024). Milk samples were analyzed for fat, protein, lactose, total solids and density using ISO-standardized methods. Data were synthesized through thematic SWOT analysis and the TOWS strategic matrix framework.

Result: Ten dairy enterprises operated 267 production units across the three provinces. Provincial forage sufficiency ranged from 50-60%, with monthly feed expenditure averaging 450-500 THB per goat (40-50% of total production costs). Fresh milk showed significantly lower nutritional values than national optimal standards: fat content 2.29-4.34% (mean 3.21±0.74%) versus the 4.5% standard (p<0.05), a 28.7% deficit; protein content averaged 3.10±0.26% versus the 3.6% standard (p<0.05). TOWS analysis identified four critical strategic pathways: cassava-based local feed development, producer cooperatives, technical capacity building and Islamic microfinance mechanisms.

Key words: Cassava-based feed, Dairy goats, Feed insufficiency, Milk composition, Smallholder livestock, SWOT-TOWS analysis.

INTRODUCTION

Smallholder dairy goat production is an important livelihood strategy in developing countries, offering nutritional security, income diversification and cultural value for resource-constrained farming communities (Devendra and Solaiman, 2010). Goat milk provides superior nutritional attributes including higher digestibility, lower allergenic potential, enhanced mineral bioavailability and distinctive fatty acid profiles compared to bovine milk (Getaneh *et al.*, 2016; Krisnaningsih *et al.*, 2026; Wulansari *et al.*, 2026). In Southeast Asia, smallholder goat milk systems have emerged as viable enterprises contributing to food security, poverty alleviation and sustainable agricultural development (Devendra and Solaiman, 2010; Kanna *et al.*, 2026).

Thailand's three southern border provinces Pattani, Yala and Narathiwat form a unique socio-cultural context where goat production integrates deeply with Muslim religious practices, dietary preferences and rituals. These areas host about 46% of Thailand's national goat population (DLD, 2024), with smallholder farmers preserving generational husbandry knowledge. Despite this cultural importance, dairy goat enterprises confront persistent knowledge gaps, technical deficiencies in managing lactating does and raw milk production, economic challenges and institutional constraints that hinder productivity, profitability and sustainability.

¹Agricultural Innovation and Management Division, Faculty of Natural Resources, Prince of Songkla University, Hat Yai Campus, Hat Yai District, Songkhla Province 90110, Thailand.

²Faculty of Science and Technology, Prince of Songkla University, Pattani Campus, Muang District, Pattani Province 95000, Thailand.

³Animal Production Innovation and Management Division, Faculty of Natural Resources, Prince of Songkla University, Hat Yai Campus, Hat Yai District, Songkhla Province 90110, Thailand.

Corresponding Author: Chaiyawan Wattanachant, Animal Production Innovation and Management Division, Faculty of Natural Resources, Prince of Songkla University, Hat Yai Campus, Hat Yai District, Songkhla Province 90110, Thailand.

Email: Santi.ma@skru.ac.th

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Contemporary challenges include: (1) chronic feed deficits exacerbated by limited forage cultivation areas; (2) absence of local feed manufacturing requiring dependence on expensive commercial feeds from distant regions; (3) restricted access to formal credit suitable for smallholder

livestock enterprises; (4) limited technical capacity in nutritional and herd-health management and (5) inadequate market infrastructure for milk collection, processing and value addition. These interconnected constraints create a negative feedback loop in which inadequate nutrition reduces milk yield and quality, limiting income and further constraining investment in improved feeding (Ahuya *et al.*, 2009; Mmbaga *et al.*, 2011; Morand-Fehr *et al.*, 2007).

While dairy goat production has been studied globally, few empirical studies have systematically documented the integrated technical, socioeconomic and cultural dimensions specific to predominantly Muslim smallholder systems in Southeast Asia. Previous investigations typically focused on isolated production aspects without examining systemic interactions among feed availability, nutritional outcomes, economic viability and culturally embedded practices. Few studies have employed integrated strategic planning frameworks such as SWOT-TOWS analysis to generate actionable, evidence-based development pathways.

This study therefore aimed to: (1) document dairy goat farm distribution and production characteristics; (2) quantitatively assess milk nutritional composition relative to national standards; (3) evaluate feed and forage resource availability, sufficiency and costs; (4) identify internal strengths and weaknesses alongside external opportunities and threats through participatory SWOT analysis and (5) develop evidence-based strategic recommendations using the TOWS matrix to guide sustainable production enhancement in southern Thailand's border provinces.

MATERIALS AND METHODS

This research employed a convergent mixed-methods design (Creswell and Plano Clark, 2018) integrating qualitative focus group discussions, quantitative milk compositional analysis, structured surveys and secondary statistical data. The SWOT-TOWS framework (Wehrich, 1982) structured synthesis of these data into strategic development pathways.

The study was conducted in Thailand's three southern border provinces: Pattani (1.94 million ha), Yala (4.52 million ha) and Narathiwat (4.48 million ha). These provinces have a tropical monsoon climate (Köppen Af/Am) with mean annual rainfall of 1,800-2,500 mm, bimodal distribution and year-round temperatures of 24-32°C. The population is predominantly Malay-Muslim (80-85%), with distinct linguistic, cultural and religious characteristics. Soils are predominantly sandy to sandy-loam, suitable for cassava (*Manihot esculenta*) cultivation-an important consideration for local feed development.

All experimental procedures were conducted between 2023 and 2024 at the Milk Analysis Laboratory, Faculty of Science and Technology, Prince of Songkla University, Pattani Campus. The target population comprised all registered dairy goat enterprises in the three provinces. Based on Department of Livestock Development (DLD)

records, 10 enterprises operating 267 production units were identified and all included (census sampling) due to limited population size. For milk compositional analysis, purposive sampling selected six farms representing diverse product types (fresh milk, fermented products, cheese) and scales (12-100 units). Selection criteria included: (1) active milk production and marketing; (2) willingness to participate; (3) provincial representation and (4) diversity in processing approaches.

Six focus group discussions (FGDs) were conducted across the three provinces (two per province), involving 47 dairy goat farmers recruited through provincial livestock offices and community leaders to ensure representation of different farm sizes, experience levels and product types. Each FGD comprised 7-9 participants and lasted approximately 120 minutes. Topics included current farming practices, feeding strategies, production constraints, market access and pricing, credit access, technical knowledge and extension needs and development priorities. FGDs were conducted in Thai and Malay by trained facilitators with cultural competency in Muslim customs. Sessions were audio-recorded with consent and transcribed verbatim for thematic analysis.

Milk samples were collected from six dairy farms (Farms 4, 5, 6 and 7) monthly during June-August 2024 (wet season). Multiple samples per farm represented different product formulations, yielding six distinct samples for analysis. Morning milking samples (~100 ml) were collected in sterile containers, immediately cooled to 4°C and transported in insulated ice-packed containers to the laboratory within 24 hours. Compositional analysis used ISO-standardized methods: fat content (Gerber method, ISO 2446:2008); protein (Kjeldahl, ISO 8968-1:2014); lactose (HPLC, ISO 22662:2007); total solids (gravimetric oven drying at 105°C, ISO 6731:2010); density (lactometer, ISO 6091:2010); and freezing point (thermistor cryoscope, ISO 5764:2009). All analyses were conducted in duplicate, with mean values reported and compared against national standards established by the National Goat Research Institute, Thailand (2022).

Structured interviews were administered to all 10 dairy enterprises using pre-tested questionnaires covering herd composition, daily milk production, feed types and costs, forage cultivation, credit and extension access and marketing channels. Surveys were conducted in-person by trained enumerators fluent in Thai and Malay. Provincial livestock statistics were obtained from DLD annual reports (2024); land-use data from Land Development Department databases and climate data from Thai Meteorological Department records.

Descriptive statistics were calculated using SPSS Statistics version 26.0. Milk compositional parameters were compared against national standards using one-sample t-tests ($\alpha=0.05$). FGD transcripts were analyzed using thematic content analysis (Braun and Clarke, 2006); two researchers independently coded transcripts, with themes

categorized into SWOT components through iterative discussion and consensus. For SWOT-TOWS analysis, internal factors (Strengths and Weaknesses) from surveys, milk analysis and FGDs were paired with external factors (Opportunities and Threats) from FGDs, secondary data and policy reviews to generate four strategic categories: SO (leveraging strengths for opportunities), WO (addressing weaknesses through opportunities), ST (using strengths to mitigate threats) and WT (minimizing weaknesses while avoiding threats). Strategic priorities were ranked by potential impact, feasibility, resource requirements and farmer preferences.

RESULTS AND DISCUSSION

Goat milk farm distribution and production systems

Table 1 presents the spatial distribution and operational characteristics of dairy goat enterprises across the three provinces. The three provinces collectively maintained 10 registered dairy enterprises operating 267 production units with substantial inter-provincial variation. Pattani had the highest concentration with 6 enterprises (87 units, 32.6% of regional total), reflecting superior market infrastructure, processing facilities and urban demand. Product diversification in Pattani included fresh milk, fermented products (yogurt, laban), soft cheese and sweetened formulations, indicating more developed value chains.

Yala operated 3 enterprises with 140 production units (52.4% of regional total), characterized by significant scale concentration. Farm 7 alone operated 100 units producing 2.0 kg/day per unit, representing the largest single operation in the region. This pattern suggests successful scaling potential but limited participation diversity. Narathiwat maintained only 1 registered enterprise operating 2 production sites (Farms 1 and 9) totaling 60 units (22.5% of regional total). Limited enterprise development despite suitable agro-ecological conditions reflects geographical remoteness, infrastructure deficits and severe feed constraints. Farm 1's designation as "Traditional system

(70 years+)" indicates multi-generational knowledge transmission and cultural embeddedness.

Average production volumes ranged from 1.0-2.0 kg/day per unit, substantially lower than intensive commercial systems in developed countries (4-6 kg/day) but consistent with tropical smallholder extensive systems (Devendra and Solaiman, 2010). The predominance of traditional systems reflects limited adoption of intensive management, attributable to feed constraints and limited technical capacity. Production systems exhibited strong integration with Muslim dietary requirements and Halal certification: all farms adhered to Islamic slaughter methods and incorporated goat production into Eid al-Adha observances.

Milk nutritional composition

Table 2 presents milk compositional analysis from six dairy farms. Milk fat content showed substantial variation (2.29-4.34%, mean $3.21 \pm 0.74\%$), significantly lower than the optimal standard (4.5%, $p < 0.001$), representing a 28.7% mean deficit. This statistically significant fat depression indicates systemic energy deficiency in lactating doe diets, consistent with feed insufficiency documented in Table 3. Farm 5's fresh milk with sweetener showed critically deficient fat content (2.29%, 49.1% below standard).

Protein content ranged from 2.79-3.43% (mean $3.13 \pm 0.23\%$), significantly below the optimal standard (3.6%, $p < 0.001$), indicating inadequate dietary protein alongside energy deficiency. Farm 4's fresh milk exhibited the lowest protein concentration (2.79%, 22.5% below standard), suggesting particularly severe feed quality constraints. In contrast, Farm 6's cheese formulation achieved the highest fat content (4.34%), approaching optimal standards. Similarly, Farm 7's full cream milk (4.16% fat, 3.13% protein, 12.88% total solids) approached optimal composition, correlating with this farm's larger scale (100 units) and potentially superior feed access through bulk purchasing.

Solid-not-fat (SNF) content averaged $8.70 \pm 0.60\%$, not significantly different from optimal standards (8.2%,

Table 1: Goat milk farm distribution and production characteristics in three southern border provinces of Thailand (2024).

Farm	Province	Product types	Production system	Production units	Average production (kg/day)
Farm 1	Narathiwat	Fresh milk	Traditional system (70 years+)	25	1.00
Farm 2	Pattani	Fresh milk	Traditional system	5	1.00
Farm 3	Yala	Fresh milk	Traditional system	10	1.00
Farm 4	Pattani	Fresh milk products	Traditional system	15	1.50
Farm 5	Pattani	Fresh milk, fermented milk	Traditional system	12	1.00
Farm 6	Pattani	Fresh milk, cheese	System 70 years+	15	1.50
Farm 7	Yala	Fresh milk products	Traditional system	100	2.00
Farm 8	Yala	Fresh milk	Traditional system	20	1.00
Farm 9	Narathiwat	Fresh milk	Traditional system	35	1.50
Farm 10	Pattani	Fresh milk	Traditional system	30	1.00
Total	3 provinces	Diverse products	Predominantly 2 times/day	267	1-2

$p=0.087$). Lactose content (mean $4.60\pm0.33\%$) aligned with standard values (4.5%, $p=0.512$), as lactose concentration typically remains stable across dietary variations. Density values (mean 1.026 ± 0.002 g/cm³) were marginally below optimal (1.029 g/cm³, $p=0.013$), consistent with reduced fat content. The preferential depression of milk fat and protein while lactose remains stable confirms that energy and protein malnutrition are the primary nutritional constraints, consistent with ruminant nutritional physiology (Morand-Fehr *et al.*, 2007; Getaneh *et al.*, 2016).

Feed and forage resource assessment

Table 3 quantifies feed availability, sufficiency and costs across provinces. Forage resources showed severe deficits in all provinces, with sufficiency ranging from only 50-60% of estimated requirements. The regional average of 0.051 ha per goat represents approximately 17% of recommended land allocation (0.3 ha per goat for sustainable tropical systems; Aregheore, 2009), indicating a fundamental land resource constraint.

Feed expenditure averaged 477 THB per goat per month (5,724 THB annually), representing 40-48% of total production costs. For smallholder farmers maintaining 8-12 goats, monthly feed costs reached 3,816-5,724 THB, a substantial burden given limited income. This economic pressure forces reliance on low-cost, poor-quality feed

resources (roadside grazing, agricultural residues), directly contributing to the milk compositional deficits observed in Table 2.

Provincial variation reflected distinct agro-ecological and infrastructure constraints. Pattani's higher forage sufficiency (60%) correlates with better market access, yet still represents a 40% deficit requiring purchased supplementation; urban expansion progressively reduces available agricultural land. Yala's hilly topography limits forage cultivation and creates soil erosion challenges; 55% sufficiency combined with higher feed costs (480 THB/month) reflects transportation premiums in mountainous areas, though Farm 7's exceptional performance demonstrates that economies of scale can partially overcome regional constraints. Narathiwat exhibited the most severe constraints: lowest forage sufficiency (50%), highest feed costs (500 THB/month, 48% of income), poor soil fertility, inadequate irrigation and geographical remoteness increasing transportation costs.

Critically, no local feed manufacturing facilities exist in the three-province region, necessitating complete dependence on commercial feeds produced in central Thailand (>800 km away).

This structural gap increases costs through transportation (estimated 15-20% premium), intermediary margins and supply unreliability during rainy seasons.

Table 2: Nutritional composition of dairy goat products from southern Thailand.

Farm	Product type	Fat (%)	Solid-not-fat (%)	Total Solids (%)	Protein (%)	Lactose (%)	Density (g/cm ³)	Freezing Point (°C)
Farm 4	Fresh milk	3.150	7.820	10.970	2.790	4.100	1.023	-0.592
Farm 5	Fresh milk with sweetener	2.290	9.500	11.790	3.430	5.030	1.030	-0.667
Farm 5	Fresh milk with herbal extract	2.610	8.270	10.880	2.950	4.320	1.025	-0.623
Farm 6	Fresh milk	3.500	9.060	12.560	3.290	4.840	1.027	-0.59
Farm 6	Fresh milk with cheese	4.340	8.850	13.190	3.190	4.690	1.025	-0.592
Farm 7	Full cream fresh milk	4.160	8.720	12.880	3.130	4.600	1.025	-0.61
Optimal Standard*	Reference values	4.500	8.200	12.800	3.600	4.500	1.029	-0.55

*National Goat Research Institute, Thailand (2022). Farms 1, 2, 3, 8, 9 and 10 did not have milk samples analyzed during the study period.

Table 3: Feed and forage resource assessment by province.

Province	Estimated goat population	Available forage area (ha)	Forage sufficiency (%)	Feed cost (THB/goat /month)	Main constraints
Pattani	25,000	1,200	60	450	Limited land; urban expansion; purchased feed dependency
Yala	20,000	1,100	55	480	Hilly terrain; erosion; infrastructure access
Narathiwat	18,000	900	50	500	Poor soil fertility; limited irrigation; remoteness
Regional average	63,000	3,200	55	477	Critical feed shortage; no local feed factories

The absence of local feed industries represents a market failure requiring coordinated policy intervention beyond individual farmer capacity.

SWOT analysis of dairy goat production

Table 4 presents the SWOT analysis synthesizing quantitative findings and qualitative farmer perspectives. The analysis reveals feed insufficiency (W1) as the central constraint directly causing milk quality deficits (W2) through a documented causal pathway. The quantitative linkage between feed availability (50-60% sufficiency) and milk composition (28.7% fat deficit) provides empirical support for prioritizing feed-focused interventions.

Important endogenous strengths exist that can be leveraged. The 70+ year production history (S1) integrated with Muslim religious practices creates sustained commitment beyond pure economic calculation, as goats are essential for Eid al-Adha. Strong mosque-centered community networks (S4) facilitate collective action and provide social capital for cooperative initiatives. The opportunities analysis identifies local crop potential (O₂) as particularly promising: sandy and sandy-loam soils are well-suited for cassava (*Manihot esculenta*), which offers high energy content, drought tolerance and lower production costs than commercial concentrates. Multiple studies have demonstrated successful integration of cassava and its by-products into ruminant diets when properly processed and balanced with protein sources (Wanapat *et al.*, 2013; Lukuyu *et al.*, 2014). The threats analysis highlights rising feed costs (T1) as the most immediate challenge, with commercial feed prices increasing approximately 35% during 2019-2024.

This threat interacts multiplicatively with W1 and W3 (credit limitations), creating a negative spiral requiring

strategic interventions addressing multiple factors simultaneously.

Principal findings and interpretation

This mixed-methods investigation identified severe feed resource constraints as the primary bottleneck limiting dairy goat production in southern Thailand. The empirical linkage among feed availability (50-60% sufficiency), milk nutritional deficits (28.7% fat, 13.1% protein) and high production costs (45% of income) provides compelling evidence that feed-focused interventions must constitute the cornerstone of development strategies.

The statistical significance of milk fat and protein deficits ($p < 0.001$) confirms that observed differences reflect systemic malnutrition rather than genetic variation, breed differences, or lactation-stage effects. The preferential depression of fat and protein while lactose remains normal aligns with ruminant nutritional physiology, where milk fat synthesis is particularly sensitive to dietary energy (Morand-Fehr *et al.*, 2007). This pattern is characteristic of energy-protein malnutrition in tropical dairy systems dependent on low-quality forages (Sahoo *et al.*, 2022). The substantial inter-farm variation (fat: 2.29-4.34%; protein: 2.79-3.43%) demonstrates that improved outcomes are achievable within the current regional context, as evidenced by Farm 7's performance approaching optimal standards. This suggests that inadequate feeding management and limited technical knowledge—rather than insurmountable environmental constraints—contribute significantly to poor average outcomes.

Comparison with previous research

The milk compositional deficits observed here align with findings from other tropical smallholder systems facing

Table 4: SWOT analysis of smallholder goat milk production.

Strengths (S)	Weaknesses (W)
S1. Long-standing farmer experience integrated with Muslim culture (average 12+ years)	W1. Insufficient feed resources (50-60% sufficiency) and absence of local feed factories
S2. Suitable tropical climate for year-round production	W2. Low milk yield and quality (fat content 28.7% below optimal)
S3. Local breed adaptation to environment and disease resistance	W3. Limited access to credit and financial capital (73% report difficulties)
S4. Strong community networks and cooperative traditions	W4. Limited technical knowledge in feed formulation and health management
S5. Established market demand for goat milk products	W5. Inadequate forage cultivation areas (0.05 ha/goat vs. 0.3 ha required)
	W6. Poor milk collection and storage infrastructure
Opportunities (O)	Threats (T)
O1. Government and university support programs available	T1. Rising feed costs in recent years
O2. Local crops suitable for feed (cassava, palm kernel, rice bran)	T2. Competition from cow milk and imported dairy products
O3. Land availability for forage expansion using Agri-Map	T3. Climate variability affecting forage production
O4. Growing health consciousness and premium milk market	T4. Youth migration reducing farm labor availability
O5. Microcredit and Islamic financing options available	T5. Disease outbreaks with limited veterinary services
O6. Tourism potential linking to Halal products	T6. Periodic political instability affecting investment

similar feed constraints. Sahoo *et al.* (2022) reported comparable milk fat deficits (25-30% below optimal) in Indian smallholder systems dependent on poor-quality crop residues, while Ahuya *et al.* (2009) documented low milk yields and quality in Kenyan smallholder systems attributed primarily to feed insufficiency and seasonal forage scarcity. This study extends previous research by explicitly quantifying the relationship between feed availability metrics (sufficiency, land per animal, feed costs) and specific milk compositional outcomes, providing empirical evidence for the causal pathway from feed constraint to product quality degradation.

Forage land availability of 0.051 ha per goat (17% of recommended levels) is substantially lower than reported elsewhere. Devendra and Solaiman (2010) reported typical smallholder allocations of 0.15-0.25 ha per goat in Malaysia and Indonesia, while Aregheore (2009) recommended 0.3 ha for sustainable South Pacific systems. Southern Thailand's dairy goat systems thus face particularly severe land constraints requiring innovative solutions beyond traditional forage expansion. The feed cost proportion (40-48% of production costs) exceeds typical ranges for tropical smallholder systems (25-35%; Peacock, 2005), reflecting both feed scarcity and the absence of local feed industries.

Interpretation of tows strategic analysis

The TOWS matrix generated four critical strategic pathways integrating technical improvements with institutional and social innovations.

Cassava-based local feed development (WO Strategy)

This strategy leverages the region's sandy soils (opportunity) to address feed insufficiency (weakness). Cassava offers energy density comparable to maize (2,800-3,000 kcal ME/kg DM) with lower inputs, drought tolerance and adaptation to marginal lands (Lukuyu *et al.*, 2014). Studies have demonstrated successful inclusion of cassava chips or pellets at 40-60% of concentrate mixtures when balanced with protein sources such as legumes or palm kernel meal (Wanapat *et al.*, 2013). Successful adoption requires addressing processing requirements (chip drying, cyanide reduction through fermentation), protein complementation and farmer training. The estimated 30-40% feed cost reduction could substantially improve profitability and enable feeding levels that address milk quality deficits.

Regional feed processing centers (WT Strategy)

This institutional innovation addresses both feed unavailability and rising costs. Community-scale feed mills (2-5 tons/day) can utilize cassava, rice bran, palm kernel meal and other regional ingredients to produce balanced rations at lower cost than commercial alternatives. Cooperative ownership ensures farmer participation, equitable benefit distribution and sustained operation. Comparable initiatives in India and East Africa have

achieved 25-35% cost reductions while improving quality consistency (Ahuya *et al.*, 2009). Implementation requires initial capital investment (estimated 2-3 million THB per mill), technical expertise and business management capacity, potentially supported through grants, low-interest loans, or public-private partnerships.

Collective feed purchasing groups (ST Strategy)

This organizational innovation uses existing community networks (strength) to mitigate rising feed costs (threat). Bulk purchasing cooperatives can negotiate volume discounts (estimated 15-20% savings), share transportation costs and reduce individual vulnerability to price fluctuations. Implementation requires minimal capital while providing near-term benefits, making this a high-priority "quick-win" intervention. Similar schemes have demonstrated rapid adoption when embedded in existing social networks (Swanson and Rajalahti, 2010) and the mosque-centered social capital in southern Thailand provides particularly favorable institutional foundations.

Technical capacity building programs (WO Strategy)

This addresses knowledge limitations through government and university resources. The substantial variation in farm performance suggests that improved technical knowledge could enable lower-performing farms to achieve results comparable to successful operations. Training should emphasize practical feed formulation using locally available ingredients, basic nutritional principles, forage management and milk quality improvement. Participatory extension approaches using demonstration farms and farmer-to-farmer learning have shown superior adoption rates compared to conventional classroom training (Swanson and Rajalahti, 2010). Establishing 2-3 model farms per province would facilitate peer learning while respecting cultural norms.

Integration and synergy among strategies

The strategic value lies not in isolated strategies but in their integrated execution. The proposed pathway is: cassava cultivation enhances local feed availability → regional feed mills process it into balanced rations → collective purchasing lowers costs → technical training enables optimization → improved feeding enhances milk quality and price → refined formulation further increases yield. This positive feedback loop counters the current vicious cycle of feed shortages → poor milk quality → low income → persistent underfeeding. The culturally embedded role of goat production in Muslim communities fosters resilience against economic volatility and development programs must integrate this cultural dimension by respecting religious practices, aligning with Islamic financing principles and positioning community leaders as change agents.

Study limitations

Only 6 farms in the study area had 10 or more milking does, limiting dataset size, although these farms represented

diverse scales, product types and provincial locations. Feed utilization data were derived from interviews and secondary sources rather than laboratory analyses; future studies should prioritize quantitative feed intake measurements, proximate analysis of local forages and body condition scoring. The cross-sectional design precludes causal inferences on intervention effectiveness; longitudinal studies would provide stronger evidence of efficacy and cost-benefit ratios. Detailed economic evaluations of investment requirements, operating costs, expected returns, break-even points and risks would strengthen policy recommendations. Finally, data collection during the wet season (June-August 2024) may understate constraints; dry-season assessments would reveal more severe feed shortages, positioning current findings as best-case scenarios.

Policy implications and recommendations

Several policy recommendations emerge:

Targeted feed subsidy programs

Government should establish subsidies specifically for forage establishment (improved grass and legume seeds, fertilizers) and cassava cultivation for feed purposes, as current agricultural subsidies disproportionately favor cash crops and rice.

Credit access enhancement

Existing agricultural credit mechanisms are poorly suited to smallholder livestock enterprises, which typically lack land titles and involve longer return periods than crops. Reforms should include: (a) recognition of livestock as acceptable collateral; (b) livestock-specific credit lines; (c) support for Sharia-compliant Islamic financing products; and (d) credit guarantee schemes reducing lender risk.

Regional feed industry development

Government can catalyze feed industry development through investment incentives for private feed mills in southern provinces, public investment in community-scale processing facilities, technical support for formulation and quality control and preferential procurement favoring locally-produced feeds.

Integrated extension and research

Research-extension linkages should be strengthened through establishment of regional dairy goat research stations, on-farm adaptive research trials, training extension officers in tropical goat nutrition and culturally-appropriate extension materials in Thai and Malay.

Cooperative development support

Government should facilitate cooperative formation through legal and administrative support for registration, training in management and governance, initial capital support for infrastructure (feed storage, milk collection) and preferential access to government programs for organized farmer groups.

Market development initiatives

Demand-side development can improve producer incentives through inclusion of goat milk in school feeding programs, support for Halal certification and branding, public health promotion of goat milk benefits and facilitation of direct farmer-to-consumer channels.

Directions for future research

Priorities include: (1) longitudinal studies documenting seasonal changes in feed availability, milk yield and composition, economic performance and farmer coping strategies; (2) on-farm feeding trials evaluating cassava-based diets, optimal inclusion rates, protein complementation and economic returns; (3) rigorous intervention impact assessment using quasi-experimental designs (difference-in-differences, propensity score matching) to quantify effectiveness and adoption factors; (4) value chain analysis mapping input supply, production, collection, processing, distribution and consumption to identify additional bottlenecks; (5) climate adaptation research on climate-smart feeding strategies, drought-tolerant forage species and risk management and (6) socio-cultural research on gender roles, intergenerational knowledge transmission and religious influences on goat production.

CONCLUSION

Smallholder dairy goat production in Thailand's southern border provinces faces key constraints from feed insufficiency (50-60% sufficiency), high costs (45% of income) and milk deficits (28.7% fat, 13.1% protein shortfalls). This empirical evidence positions feed interventions as the foundation for development strategies. Endogenous strengths-generational production experience, cultural integration and robust community networks-offer leverage for progress. SWOT-TOWS analysis identifies four priorities: (1) cassava-based local feed development; (2) regional feed processing centers; (3) collective purchasing cooperatives and (4) farmer training programs on goat husbandry, including doe management, nutrition, milking hygiene and raw milk quality assurance. Integrated execution outperforms isolated efforts and substantial farm performance variation proves better results are feasible locally through best-practice dissemination and improved resource access. Evidence-based actions in feed production, cooperatives, training and finance can elevate dairy goat systems from subsistence to sustainable sources of nutrition and livelihood. These interventions directly support UN SDGs-particularly SDG 2 (Zero Hunger) through improved animal-source nutrition, SDG 1 (No Poverty) via enhanced profitability and SDG 5 (Gender Equality) by empowering women in household farming roles prevalent in the region, vital region. These interventions directly support UN SDGs, particularly SDG 2 (Zero Hunger) through improved animal-source nutrition, SDG 1 (No Poverty) via enhanced profitability and SDG 5

(Gender Equality) by empowering women in household farming roles prevalent in the region.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare no conflict of interest.

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