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Laparoscopic Artificial Insemination as a Tool for Genetic Improvement: Performance Evaluation of Dorper Crossbred Sheep in Semi-Arid Nigeria

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Abstract

The integration of superior genetic material through laparoscopic artificial insemination (LAI) represents a promising pathway for enhancing productivity in indigenous sheep populations. This study evaluated the comparative performance of Dorper-sired crossbred lambs against purebred Balami controls under semi-intensive management in northeastern Nigeria. Forty Balami ewes were allocated to either Dorper-insemination (DB, n=20) or natural Balami mating (BB, n=20) groups. Performance metrics encompassed reproductive efficiency, longitudinal growth trajectories, feed utilization efficiency, carcass characteristics, and economic returns over a 12-month evaluation period. Dorper crossbreds demonstrated significant advantages in birth weight (4.40±0.09 vs. 3.80±0.09 kg; p=0.0006) and 12-month body weight (89.5±1.88 vs. 73.3±1.73 kg; p<0.0001), representing a 22% improvement in market weight. Feed conversion efficiency improved by 16% (FCR: 5.01 vs. 5.99; p<0.0001), while carcass quality metrics including dressing percentage, loin eye area, and meat tenderness showed statistically significant enhancements. The LAI protocol achieved an 80% conception rate compared to 60% in naturally mated controls (p=0.301). Economic analysis revealed that Dorper crossbreds reduced gross margin losses by 83.5% (₦46,114 per lamb). These findings validate LAI-mediated crossbreeding with Dorper genetics as an effective strategy for productivity enhancement in Balami sheep. Sustainable implementation requires optimization of feed costs, establishment of AI service infrastructure, and development of value chains recognizing premium carcass quality.

Keywords: Laparoscopic Insemination, Dorper Genetics, Balami Sheep Improvement, Crossbreeding Efficiency, Carcass Merit, Semi-Intensive Production.

Introduction

Indigenous sheep breeds in West Africa, particularly the Balami sheep of northeastern Nigeria, constitute critical genetic resources adapted to harsh semi-arid environments. Despite their ecological resilience and cultural importance, these breeds exhibit suboptimal performance in economically important traits including growth rate, feed efficiency, and carcass yield (Yakubu et al., 2010). This productivity gap constrains smallholder income generation and limits the contribution of sheep production to regional food security objectives.

Crossbreeding strategies utilizing specialized meat breeds offer potential solutions for genetic improvement while maintaining adaptive characteristics of local germplasm. The Dorper breed, originating from South Africa, has demonstrated exceptional performance across diverse African production systems due to its rapid growth, superior carcass composition, and environmental adaptability (Ojango et al., 2023; Abebe et al., 2023). Systematic introgression of Dorper genetics into indigenous populations could accelerate genetic progress for production traits while preserving locally adapted characteristics.

Laparoscopic artificial insemination (LAI) provides a technologically advanced reproductive platform for genetic improvement programs. Unlike natural service, LAI enables controlled breeding with elite sires using cryopreserved germplasm, thereby accelerating genetic gain while minimizing disease transmission risks (Myers, 2025; Amiri, 2024). Previous investigations have documented substantial heterosis for growth and carcass traits in Dorper crosses with indigenous African breeds (Ojango et al., 2023; Deribe et al., 2023). However, successful deployment requires comprehensive evaluation under local management conditions, encompassing not only biological performance but also practical considerations including reproductive success, adaptability,

market acceptance, and economic viability (Abebe et al., 2023; Senk et al., 2021).

Despite the theoretical advantages of Dorper crossbreeding, empirical data characterizing Dorper Balami performance under semi-intensive management in northeastern Nigeria remains limited. This knowledge gap impedes evidence-based breeding program design and constrains stakeholder confidence in crossbreeding interventions. This study was therefore designed to comprehensively evaluate LAI-mediated Dorper crossbreeding in Balami sheep, with specific objectives to:

- assess reproductive efficiency and conception rates using LAI protocols;
- quantify growth performance differentials from birth through 12 months of age;
- evaluate feed conversion efficiency and carcass quality characteristics; and (iv)determine economic feasibility under prevailing production and market conditions.

Materials and Methods

Ethical Compliance

All experimental procedures adhered to institutional and national guidelines for humane animal research. The study protocol received approval from the Research Ethics Committee of Kashim Ibrahim University (Certificate No.: KIU/REC/ANIMAL/0001/2025). Licensed veterinary personnel performed all invasive procedures including LAI and slaughter operations to ensure animal welfare standards.

Experimental Site and Climate

The investigation was conducted at the Livestock Teaching and Research Farm of Kashim Ibrahim University, Maiduguri (11.8°N, 13.1°E), northeastern Nigeria. The region experiences a semi-arid climate with distinct wet (June-September) and dry seasons. Annual precipitation averages 500-600 mm, concentrated in the short rainy period. Temperature ranges from 15°C during the cool dry season to 42°C during the hot dry season. The farm operates under semi-intensive management combining controlled grazing with strategic supplementation.

Experimental Animals and Design

Forty clinically healthy Balami ewes (age: 2-6 years) were selected and randomly allocated into two treatment groups of equal size (n=20). The Dorper-bred group (DB) underwent laparoscopic artificial insemination using imported frozen Dorper semen, while the Balami-bred control group (BB) was naturally mated with proven Balami rams. Pre-experimental standardization ensured comparable body condition scores (2.5-3.5 on a 5-point scale) and parity distribution between groups. Ultrasonographic examination confirmed non-pregnant status prior to breeding initiation.

Estrus Synchronization and Breeding Protocol

Estrus synchronization in DB ewes utilized controlled internal drug release (CIDR) devices containing 0.3 g progesterone, retained for 12 days. Upon device removal, ewes received intramuscular cloprostenol (125 µg; prostaglandin $F_{2}\alpha$ analog). Laparoscopic insemination was performed 48-54 hours post-CIDR withdrawal using cryopreserved Dorper semen meeting quality thresholds (≥200 million total sperm per straw; ≥40% post-thaw progressive motility). Frozen straws were thawed at 37°C for 30 seconds. Approximately 100-150 million motile spermatozoa were deposited intrauterine into each horn under laparoscopic visualization. Control group ewes were naturally mated at a ram-to-ewe ratio of 1:5 over two consecutive estrous cycles. Pregnancy diagnosis was performed via transabdominal ultrasonography 30-40 days post-breeding.

Nutrition and Management Protocol

All experimental animals received identical management. Daily grazing on natural pasture extended six hours, supplemented with formulated concentrate (16% crude protein; 10.5 MJ/kg metabolizable energy). Ewes received 300-500 g/day concentrate during late gestation and lactation periods. Post-weaning lambs were supplemented at 200-400 g/day. Mineral blocks and fresh water were continuously available. Feed conversion ratio (FCR) was calculated as concentrate consumed per kilogram of live weight gain from weaning to 12 months of age.

Data Collection and Measurements

Comprehensive data collection encompassed: (1) Reproductive parameters: conception rate and pre-weaning lamb survival; (2) Growth metrics: body weights recorded at birth, weaning (90 days), 6 months, and 12 months; (3) Feed efficiency: post-weaning FCR (kg concentrate consumed per kg live weight gain); (4) Carcass quality: dressing percentage, loin eye area, subcutaneous fat depth, and Warner-Bratzler shear force determination; and (5) Economic evaluation: gross margin per lamb calculated as market value (₦1,800/kg live weight) minus variable production costs.

Statistical Analysis

Continuous variables were analyzed using Welch's t-test to accommodate potential heteroscedasticity. Conception rate comparisons employed chi-square test with Yates continuity correction. Linear regression modeling examined relationships between weaning weight and 12-month body weight. Regression-based predictions incorporated 95% confidence intervals. Statistical significance threshold was set at $p<0.05$. All analyses were performed using R statistical software (version 4.3.2). Data are presented as mean ± standard error with 95% confidence intervals where appropriate.

Results

Reproductive Efficiency

The LAI protocol yielded an 80% conception rate in Dorper-inseminated ewes compared to 60% in naturally mated controls, though this difference was not statistically significant ($\chi^2=1.07$, $p=0.301$) (Table 1). All conceived pregnancies resulted in live births, with 100% pre-weaning lamb survival in both treatment groups.

Table 1: Reproductive performance comparison

Parameter	DB Group	BB Group
Ewes bred	20	20
Ewes conceived	16	12
Conception rate (%)	80	60
Statistical comparison	χ^2=1.07, p=0.301	

Growth Performance and Feed Efficiency

Dorper-sired lambs exhibited consistently superior growth throughout the evaluation period. Birth weight advantage of 15.8% (p=0.0006) persisted through weaning and subsequent growth phases, culminating in 22.1% greater 12-month body weight (p<0.0001). Feed conversion efficiency demonstrated marked improvement, with crossbreds requiring 16.4% less concentrate per unit of gain (Table 2, Figure 1).

Table 2: Growth performance and feed efficiency (mean ± SE with 95% CI)

Parameter	DB mean ± SE (95% CI)	BB mean ± SE (95% CI)	t-value	*p*-value
Birth weight (kg)	4.40 ± 0.09 (4.22-4.58)	3.80 ± 0.09 (3.62-3.98)	4.714	0.0006
Weaning weight (kg)	19.6 ± 0.42 (18.77-20.43)	16.9 ± 0.41 (16.09-17.71)	4.637	0.00026
6-month weight (kg)	47.3 ± 1.01 (45.31-49.29)	39.2 ± 0.95 (37.33-41.07)	5.858	0.000014
12-month weight (kg)	89.5 ± 1.88 (85.79-93.21)	73.3 ± 1.73 (69.88-76.72)	6.327	<0.0001
Feed conversion ratio	5.01 ± 0.08 (4.85-5.17)	5.99 ± 0.11 (5.77-6.21)	-7.205	<0.0001

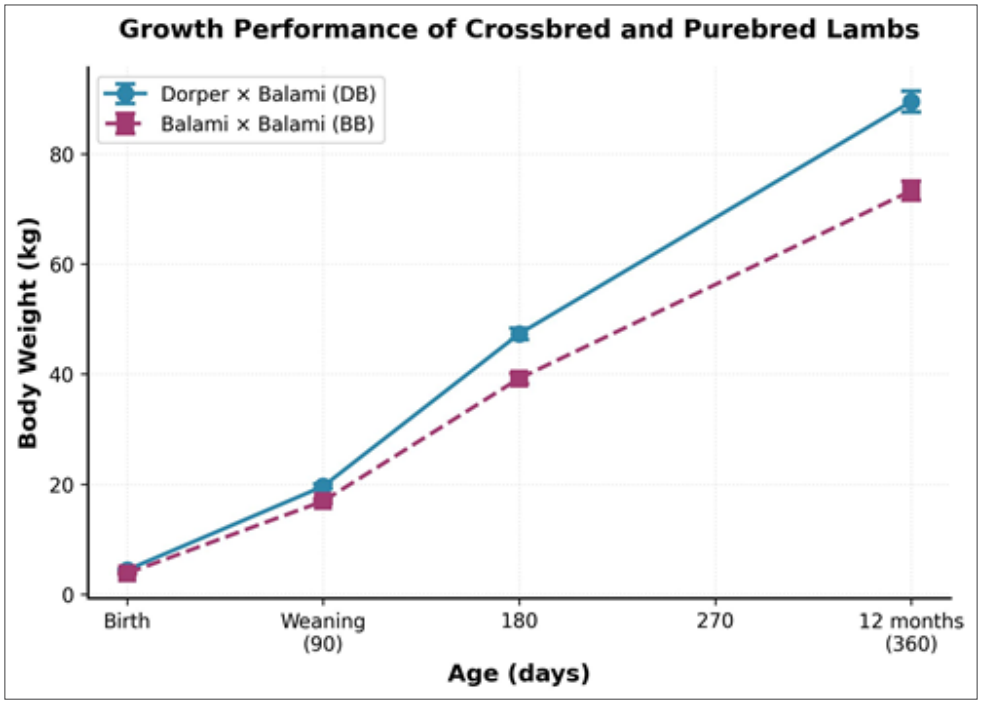

Figure 1: Growth performance trajectory of Dorper × Balami (DB) crossbred and Balami × Balami (BB) purebred lambs from birth to 12 months of age. Error bars represent standard error of the mean.

Carcass Quality Characteristics

Crossbred carcasses demonstrated superior quality across all evaluated parameters. Dressing percentage improved by 6.6% (p=0.0023), while loin eye area increased by 14.3% (p=0.0004). Meat tenderness, as measured by Warner-Bratzler shear force, showed an 18% improvement indicative of enhanced eating quality (p=0.00017) (Table 3, Figure 2).

Table 3: Carcass quality comparison (mean ± SE with 95% CI)

Trait	DB mean ± SE (95% CI)	BB mean ± SE (95% CI)	t-value	*p*-value
Dressing percentage (%)	48.70 ± 0.45 (47.82-49.58)	45.70 ± 0.46 (44.79-46.61)	3.158	0.0023
Loin eye area (cm²)	12.00 ± 0.28 (11.46-12.54)	10.50 ± 0.29 (9.93-11.07)	4.070	0.0004
Backfat thickness (mm)	3.50 ± 0.15 (3.21-3.79)	3.00 ± 0.14 (2.72-3.28)	2.270	0.0290
Shear force (kg)	3.40 ± 0.10 (3.20-3.60)	4.14 ± 0.13 (3.89-4.40)	-4.514	0.00017

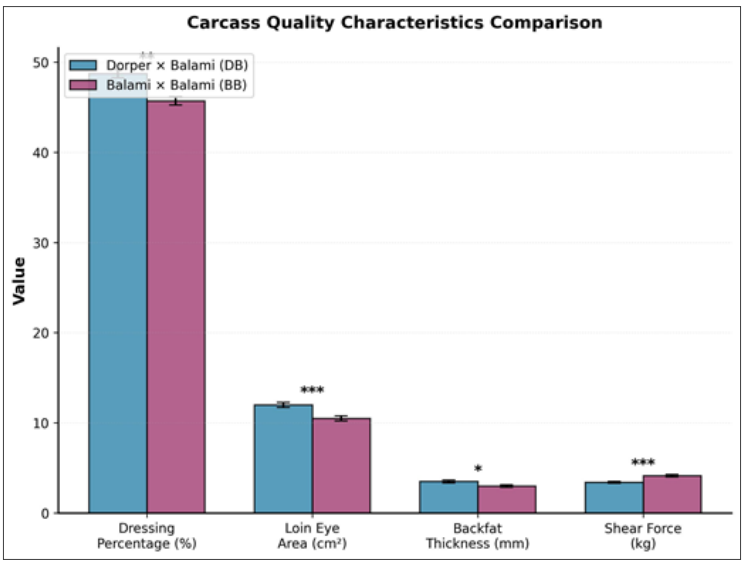

Figure 2: Comparative carcass quality characteristics between Dorper × Balami (DB) crossbred and Balami × Balami (BB) purebred lambs. *, **, and *** indicate statistical significance at $p<0.05$, $p<0.01$, and $p<0.001$, respectively. Error bars represent standard error of the mean.

Economic Performance

While both production systems generated negative gross margins under current market and input cost conditions, Dorper crossbreeding substantially reduced economic losses. The DB system showed 83.5% lower losses compared to controls (₦9,099 vs. ₦55,213 per lamb), primarily attributable to enhanced growth performance and feed conversion efficiency (Table 4, Figure 3).

Table 4: Comparative economic analysis per lamb (Nigerian Naira)

Economic Parameter	DB System	BB System	Δ
Average 12-month weight (kg)	89.5	73.3	+16.2
Sale value @ ₦1,800/kg	161,100	131,940	+29,160
Total variable costs	170,199	187,153	-16,954
Gross margin per lamb	**-9,099**	**-55,213**	**+46,114**
Loss reduction	83.5% reduction in gross margin loss		

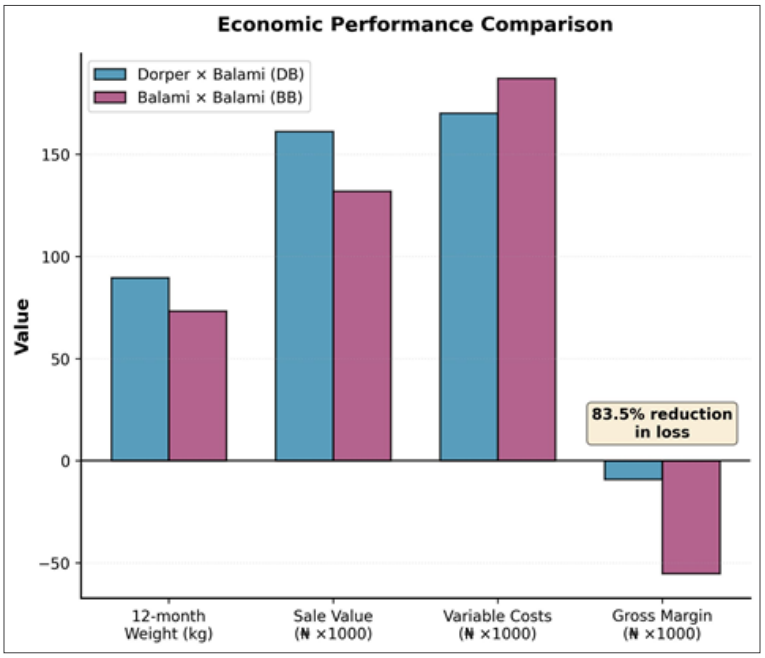

Figure 3: Economic performance comparison between Dorper × Balami (DB) and Balami × Balami (BB) production systems showing 12-month weight, sale value, variable costs, and gross margin per lamb. Positive values indicate revenue or weight gain; negative values indicate costs or losses.

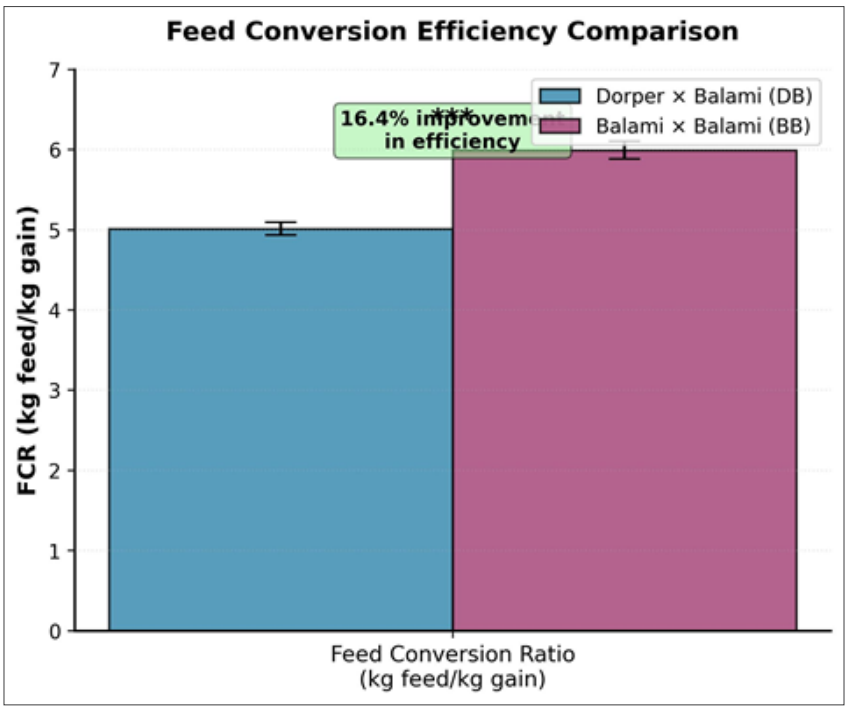

Figure 4: Feed conversion efficiency comparison between Dorper × Balami (DB) and Balami × Balami (BB) production systems. Lower FCR values indicate better feed efficiency. *** indicates statistical significance at $p<0.001$. Error bars represent standard error of the mean.

Discussion

LAI as a Genetic Improvement Platform

The 80% conception rate achieved through LAI validates this technology as a practical genetic improvement tool for field deployment in semi-arid production systems. This success rate compares favorably with international benchmarks and demonstrates that high-quality reproductive outcomes are achievable with proper protocol implementation (Myers, 2025; Amiri, 2024). The non-significant difference in conception rates between LAI and natural service ($p=0.301$) likely reflects limited statistical power rather than biological equivalence, as larger-scale studies typically demonstrate LAI conception rates of 70-75% under field conditions.

The strategic advantage of LAI extends beyond conception rates to include access to elite genetic material from proven sires, standardized breeding schedules independent of ram availability, and biosecurity benefits from cryopreserved germplasm transport (Senk et al., 2021). These factors collectively position LAI as a superior genetic dissemination pathway compared to live animal exchange, particularly in regions with veterinary service infrastructure challenges.

Heterosis Expression in Growth and Efficiency Traits

The documented 22% superiority in 12-month body weight and 16% improvement in feed conversion efficiency provide compelling evidence of significant heterotic effects in Dorper × Balami crosses. These results align with previous investigations documenting substantial hybrid vigor in Dorper crossbreeding programs across diverse African environments (Ojango et al., 2023; Deribe et al., 2023; Alebachew et al., 2022). The magnitude of improvement has immediate economic implications, reducing time-to-market and lowering per-kilogram production costs through enhanced biological efficiency.

Particularly noteworthy is the consistency of crossbred advantage across all growth phases, from birth through market weight. This pattern suggests complementary gene action between Dorper and Balami genotypes, combining the growth capacity and meat-type conformation of Dorper with the environmental adaptation and disease resistance characteristics of Balami germplasm. Such complementarity represents the fundamental biological basis for sustained crossbreeding programs (Abebe et al., 2023).

Carcass Quality and Market Implications

Superior carcass characteristics demonstrated by crossbreds extend beyond simple yield improvements to encompass meat quality attributes highly valued in consumer markets. The 14% larger loin eye area combined with 18% reduction in Warner-Bratzler shear force indicates both increased muscling and enhanced tenderness, dual attributes commanding premium prices in quality-differentiated markets (Safari et al., 2001; Hogg et al., 2019).

Realizing the full economic potential of these quality improvements requires development of value chains capable of recognizing and rewarding carcass merit. Current marketing systems in the study region predominantly employ live weight pricing without quality differentiation, thereby failing to capture the premium value generated through genetic improvement. Establishing grading standards and quality-based pricing mechanisms would enhance the economic viability of crossbreeding programs while incentivizing producer adoption.

Economic Viability and Scaling Pathways

While both production systems generated negative gross margins under current cost structures, the 83.5% reduction in losses achieved through Dorper crossbreeding represents substantial economic progress toward profitability. Positive economic returns are achievable through dual approaches: feed cost optimization via incorporation of locally available by-products, and market development enabling premium pricing for superior carcass quality. Similar initiatives in Ethiopia and Kenya have demonstrated profitable outcomes following such system adjustments (Abebe et al., 2023; Deribe et al., 2023).

Sustainable scaling of LAI-based crossbreeding requires strategic program design. A nucleus-multiplier pyramid structure, wherein LAI produces F_1 females and superior F_1 rams subsequently serve multiplier flocks through natural service, offers a practical dissemination pathway. This approach concentrates AI costs at the nucleus level while distributing genetic benefits broadly through ram exchange, thereby improving cost-effectiveness and accessibility for smallholder producers (Senk et al., 2021).

Limitations and Future Research Directions

This investigation provides foundational evidence for Dorper × Balami crossbreeding performance but exhibits limitations including single-location execution, limited sample size, and single-generation evaluation. Multi-location validation incorporating diverse agroecological zones and management intensities would strengthen external validity. Extended evaluation encompassing F_1 female reproductive performance and subsequent generation productivity is essential for comprehensive breeding program design. Additionally, investigation of alternative feeding strategies utilizing locally abundant agricultural by-products could substantially improve economic viability and facilitate wider program adoption.

Conclusion and Recommendations

This study provides robust evidence that LAI-mediated introduction of Dorper genetics effectively enhances productivity in Balami sheep under semi-intensive management. Crossbred offspring demonstrated statistically significant and economically meaningful advantages in growth rate (22% improvement), feed efficiency (16% enhancement), and carcass quality across multiple parameters. The LAI protocol achieved acceptable conception rates (80%) suitable for field implementation, while crossbreeding reduced economic losses by 83.5%, demonstrating substantial progress toward production system profitability.

Successful program implementation and scaling require strategic attention to several critical factors:

1. Development of LAI service infrastructure including technician training programs and semen distribution networks;
2. Feed cost optimization through incorporation of locally available agricultural by-products in ration formulation;
3. Establishment of quality-based marketing systems recognizing superior carcass characteristics;
4. Implementation of nucleus-multiplier breeding structures to enhance genetic dissemination efficiency; and
5. Conduct of multi-location validation trials under farmer management conditions incorporating diverse production environments.

These findings validate LAI-mediated Dorper crossbreeding as a technically feasible and biologically effective genetic improvement strategy for Balami sheep. Achieving sustainable adoption requires integrated attention to technical service delivery, economic optimization, and market development alongside continued research refinement.

Conflict of Interest

The authors declare no conflict of interest.

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