

Body Weight Trajectories, Cumulative Disease Incidence, and Mortality in Indigenous Barind Sheep: A 12-Month Longitudinal On-Farm Study under Smallholder Farming Systems in Bangladesh



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Abstract

Background: Indigenous Barind sheep remain one of Bangladesh's least-characterized smallholder livestock assets — valued by marginal farmers yet rarely subjected to systematic, longitudinal field investigation. Understanding their growth trajectory, flock dynamics, and disease burden under actual farm conditions is a prerequisite for any credible breeding or health-management programme. This study was designed to fill precisely that gap. **Methods:** A 12-month prospective on-farm longitudinal study was conducted across 40 smallholder households in Paba, Godagari, and Rajshahi Metropolitan upazilas of Rajshahi Division, Bangladesh. A foundation cohort of 200 sheep (160 ewes, 40 rams; 5 animals per farmer) was established, and all offspring born during the study period were recorded. Body weight was measured at birth (day-old) and at 1, 3, 6, 9, and 12 months of age for 90 lambs (46 males, 44 females) selected by systematic random sampling from the 228 births. Disease events were recorded for the full monitored population (N = 428). Sex-based differences in body weight at each age point were evaluated using independent-samples t-tests; statistical significance was set at $\alpha = 0.05$. **Results:** Male and female lambs reached mean 12-month body weights of 15.84 ± 4.02 kg and

15.31 ± 3.03 kg, respectively — a difference that was numerically consistent but statistically non-significant at all six age points (all $p > 0.05$). The 228 births recorded over 12 months represented a crude lambing rate of 114% relative to the 160 foundation ewes, yielding a net flock expansion of 83%. Foundation stock mortality was 31.0% (62/200), attributable largely to pneumonia (25.8% of all disease events), gastrointestinal parasitic infections (24.2%), and malnutrition (19.4%). Cumulative disease incidence in the full population was 14.49% (62/428 animals). **Conclusion:** Indigenous Barind sheep demonstrate meaningful reproductive productivity and weight gain under semi-intensive smallholder management, reaching approximately 15.5 kg by 12 months. However, a 31% foundation stock mortality — driven primarily by respiratory disease, helminthiasis, and nutritional gaps — represents a critical constraint. Integrating seasonal *Pasteurella* vaccination, post-monsoon fasciolicide treatment, and dry-season fodder supplementation into the management protocol could substantially reduce preventable losses and improve economic returns for marginal farming households.

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Significance | Provides first reproducible 12-month on-farm baseline for indigenous Barind sheep growth, disease, and mortality to guide targeted management interventions.

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1. Introduction

Sheep are rarely the headline animal when people discuss Bangladesh's livestock sector, and yet they quietly underpin the food security and income streams of hundreds of thousands of smallholder households across the country's diverse agro-ecological zones (Hassan & Talukder, 2011). The national flock stands at approximately 3.39 million head (Department of Livestock Services [DLS], 2025), concentrated in three broad ecological belts — the drought-exposed Barind tract of the northwest, the char lands of the Jamuna River Basin, and the saline-prone coastal fringe. In each of these environments, indigenous sheep have evolved — or perhaps more accurately, have been shaped over centuries of informal farmer selection — into animals that can survive where exotic or crossbred stock almost certainly would not. They consume poor-quality roughages, endure seasonal feed scarcity, and still manage to reproduce and provide a modest but meaningful economic buffer for families who have few other options (Pervage et al., 2009; Hassan & Talukder, 2011).

The Barind variety, reared across the red clay soils of Rajshahi Division, is particularly noteworthy in this regard. Characterized by compact body size, coarse wool, and a remarkable tolerance for the region's dry and hot summers, these animals occupy an ecological niche that would be difficult or impossible to fill with introduced breeds. And yet — somewhat surprisingly — systematic, field-level performance data on Barind sheep remain thin. Most published records either conflate Barind animals with the broader category of 'indigenous Bangladeshi sheep' or derive from organized station trials conducted under conditions that smallholder farmers could not realistically replicate (Hashem et al., 2023). Growth curves measured on experiment stations, where feed is controlled and veterinary care is immediate, will inevitably overestimate what a farmer in Godagari upazila can expect when rainfall fails in February and the dry-season fodder runs out.

Body weight at successive ages is, admittedly, a somewhat reductive way to assess an animal's productive

value, but it remains the most practical indicator available under field conditions. It integrates the effects of genotype, nutrition, disease burden, and management quality into a single observable metric, and it directly determines market value and household income (Hashem et al., 2023; Musa et al., 2020). For indigenous breeds like the Barind sheep, which have never been subjected to formal selection programmes, body weight data also provide the empirical foundation on which any future genetic improvement initiative would need to rest. Without knowing what the breed actually produces under real farming conditions — not station averages, but the wide, messy distribution you get across forty households with forty different management approaches — there is simply no rational basis for deciding which animals to select or which traits to prioritise.

Equally important, though often discussed separately in the literature, is the question of reproductive efficiency and flock multiplication. Whether a foundation population actually grows, stagnates, or contracts over a monitoring period is a direct measure of whether the production system is economically sustainable for farmers. Mowsum et al. (2023) reported multiplication rates of 90–120% in comparable smallholder systems in Bangladesh, but longitudinal tracking of both births and mortality within a single documented cohort — essential for interpreting net flock dynamics — remains rare in the published literature on Barind sheep specifically.

Disease is the third pillar of productive performance, and arguably the most immediate constraint on sheep productivity in the Barind tract. Indigenous breeds are sometimes credited with innate resistance to common pathogens, and there is some truth to this — particularly regarding their tolerance for internal parasites compared with exotic breeds introduced to tropical environments (Ershaduzzaman et al., 2025). However, 'relative resistance' is not the same as 'immunity', and field studies consistently document substantial morbidity and mortality from respiratory infections, helminthiasis, and nutritional diseases in traditionally managed flocks (Kabir et al., 2019; Islam et al., 2015b). Pneumonic pasteurellosis in particular tends to spike during the transition from the monsoon season to the cool winter months in the Barind region — a seasonal pattern that has been documented in Rajshahi District but not, to our knowledge, quantified within a tracked longitudinal cohort (Ahmed et al., 2016).

There is also a methodological gap worth naming

explicitly. Most disease prevalence data for Bangladeshi small ruminants come from retrospective abattoir surveys, clinical case series at veterinary teaching hospitals, or cross-sectional questionnaire studies — all of which introduce well-known biases related to health-seeking behaviour, recall, and the selective presentation of severe cases (Islam et al., 2015a). Prospective, longitudinal monitoring of a defined cohort under farmer management conditions is a fundamentally different and more policy-relevant approach, because it captures the full spectrum of disease events — including the mild and self-limiting ones — rather than only those serious enough to prompt a farmer to seek professional help.

It is against this background that the present study was undertaken. Working within the framework of a KGF-funded up-scaling project (Project ID: TF:130-L/23), we monitored a foundation cohort of 200 Barind sheep distributed to 40 smallholder farmers in three upazilas of Rajshahi Division over 12 consecutive months. The specific objectives were: (1) to document sex-specific body weight trajectories from birth to 12 months of age; (2) to assess flock multiplication and foundation stock survival over the monitoring period; and (3) to quantify the cumulative incidence and relative burden of disease conditions affecting the total monitored population. We hypothesized that sex-based differences in body weight would be statistically non-significant during the first year of life, consistent with the pre-pubertal hormonal environment of indigenous sheep under low-input systems, and that pneumonia and gastrointestinal parasitism would emerge as the dominant health constraints — as the broader regional literature suggests, though without prior longitudinal field validation for the Barind population specifically.

2. Materials And Methods

2.1 Ethical Statement

All field procedures were conducted in accordance with the Guidelines for the Care and Use of Animals in Research established by the Bangladesh Agricultural University Animal Welfare Committee. Informed verbal consent was obtained from each participating farmer prior to enrolment, and farmers retained the right to withdraw their animals at any point without consequence to their project participation. No invasive procedures were performed; data collection was limited to routine weighing, clinical observation, and farmer-reported health records.

2.2 Study Area and Setting

The study was conducted between January 2024 and December 2024 in three upazilas of Rajshahi Division, northwestern Bangladesh: Paba, Godagari, and the Rajshahi Metropolitan area. This region lies within the Barind Tract — a slightly elevated, drought-prone pediplain characterized by Pleistocene red clay soils of low organic matter content, poor water retention, and limited natural pasture productivity during the dry season (November–March). The area experiences a subtropical monsoon climate, with annual rainfall of approximately 1,200–1,600 mm concentrated in the June–September monsoon period, and temperatures ranging from approximately 10°C in January to 38°C in May–June. These environmental characteristics — seasonal feed scarcity, temperature extremes, and a warm-humid monsoon — are central to understanding the disease and nutrition challenges documented in this study.

2.3 Study Design and Farmer Selection

A prospective, longitudinal on-farm cohort design was employed. Forty beneficiary farmers were selected from three upazilas using purposive sampling criteria that included prior experience with small ruminant keeping (minimum one year), possession of adequate housing facilities for sheep (covered pen with concrete or earthen floor, minimum 10 m²), proximity to a metalled road to facilitate regular monitoring visits, and willingness to participate in a 12-month data collection protocol. Farmers with a history of livestock disease outbreaks requiring herd culling within the preceding 12 months were excluded. The final sample of 40 farmers comprised 16 from Paba, 14 from Godagari, and 10 from the Rajshahi Metropolitan area.

2.4 Foundation Cohort Establishment

Each selected farmer received five Barind sheep — four mature ewes aged 18–36 months and one adult ram aged 24–48 months — for a foundation stock of 200 animals in total (160 ewes + 40 rams). Animals were sourced from local sheep markets and from farmers known to maintain purebred Barind stock. Procurement was conducted over a two-week period in January 2024, and animals were health-screened prior to distribution: only animals with no visible signs of respiratory distress, diarrhoea, lameness, or heavy ectoparasite burden were enrolled. All foundation animals were ear-tagged with unique alphanumeric identifiers at distribution and weighed at this baseline.

point. A revolving fund mechanism was incorporated into the project design, under which farmers were expected to transfer one female offspring per two lambing cycles to a new beneficiary farmer — a provision designed to incentivize flock health management and documented as a non-mortality attrition pathway in the analysis.

2.5 Management Protocol

All participating farmers maintained their flocks under a standardized semi-intensive management protocol developed collaboratively by the research team and the farmers during an initial two-day training workshop. Briefly, sheep grazed communal and private fallow land for six to seven hours per day and were housed in covered pens from dusk to dawn for predator protection and health monitoring. A balanced concentrate mixture (approximately 250 g per head per day, comprising rice bran, mustard oil cake, and mineral-vitamin premix) was provided during the final four weeks of pregnancy and throughout lactation to support fetal growth, milk yield, and lamb nutrition. Strategic anthelmintic treatment (a combination product containing ivermectin and albendazole, dosed according to body weight) was administered at two-month intervals to all animals. A single lifetime vaccination against Peste des Petits Ruminants (PPR) was administered using the attenuated Nigeria 75/1 strain vaccine, in accordance with the national PPR control programme of Bangladesh (Ershaduzzaman et al., 2025). Clean drinking water was provided ad libitum, and pen hygiene was maintained through weekly manure removal and monthly disinfection with 2% lime solution. Farmers were specifically trained to observe and report clinical signs of disease — including coughing, nasal discharge, diarrhoea, anorexia, and abnormal gait — to the field team at each fortnightly visit and via mobile phone between visits.

2.6 Sampling Framework for Growth Analysis

Of the 228 lambs born during the study period, 90 were enrolled into the longitudinal growth sub-cohort using systematic random sampling stratified by sex and birth month, to ensure seasonal representation. Lambs were eligible if born alive, achieving independent standing within 12 hours of birth, and if their dam remained in the cohort at the time of birth. Lambs that died or were removed from the study before six months of age were excluded from the growth analysis to avoid informative censoring bias, but their disease events and mortality were retained in the full-

population health analysis ($N = 428$). This distinction — between the growth cohort ($n = 90$) and the full monitored population ($N = 428$) — is maintained throughout all analyses and tables to avoid ambiguity about denominators.

2.7 Body Weight Measurement

Body weight was recorded using a calibrated hanging spring balance (capacity: 50 kg; graduation: 100 g), which was zeroed and verified against a known 5-kg reference weight before each weighing session. Lambs were weighed within six hours of birth (day-old weight) and subsequently at 1, 3, 6, 9, and 12 months of age (± 3 days). Three research assistants, each assigned to a fixed sub-cluster of farms, performed all measurements to minimize inter-observer variability; all three underwent a standardized calibration exercise at the beginning of the study. Each weighing session was recorded on pre-printed data collection forms, and values were double-entered into a password-protected SPSS database (IBM SPSS Statistics, Version 25.0, IBM Corp., Armonk, NY, USA) within 48 hours of collection.

2.8 Disease Surveillance and Diagnostic Protocol

Active disease surveillance was conducted during fortnightly farm visits by the research team. At each visit, all sheep were visually inspected for clinical signs of ill-health. Animals showing abnormal signs were examined in detail by a registered veterinarian (co-author M.R.I.) using a structured clinical assessment form. Disease events were classified into one of six diagnostic categories based on predominant clinical presentation and, where feasible, simple field diagnostic tests: (1) Pneumonia — characterized by pyrexia (rectal temperature $> 40^{\circ}\text{C}$), bilateral mucopurulent nasal discharge, moist cough, and laboured breathing; (2) Gastrointestinal parasitosis — characterized by submandibular oedema ('bottle jaw'), poor body condition, pallor of conjunctivae (FAMACHA score 3), and confirmatory McMaster egg count > 500 eggs per gram where a portable centrifuge was available; (3) Starvation/malnutrition — characterized by progressive body condition score decline ($\text{BCS} < 2$ on a 5-point scale) in the absence of clinical signs consistent with infectious disease; (4) Accidents/predator attacks — physical trauma with clear wound evidence; (5) Enteritis/diarrhoea — profuse loose stool, perineal soiling, and dehydration (skin tent > 3 seconds); and (6) Food poisoning — acute onset of neurological signs (ataxia, convulsions) or sudden

death following confirmed access to toxic plants or spoiled feed. Events classified under additional SPSS codes (gas/bloat, sudden death of unknown aetiology) were too infrequent to constitute a reportable category and are described qualitatively. Outcome of each event (recovery, death, sale, sacrifice, transfer, theft) was recorded. The distinction between death attributable to disease and non-mortality disposals was maintained throughout.

2.9 Statistical Analysis

Descriptive statistics (arithmetic mean, standard deviation, frequency, and percentage) were computed for all variables. Sex-based differences in body weight at each of the six age points were evaluated using an independent-samples t-test, appropriate for a two-group comparison (Pallant, 2020). The assumption of equality of variances was assessed with Levene's test prior to each comparison; where Levene's test was significant ($p < 0.05$), Welch's adjusted t-test values were reported. Effect size for each comparison was estimated using Cohen's d , calculated as the mean difference divided by the pooled standard deviation; values of 0.2, 0.5, and 0.8 were interpreted as small, medium, and large effects, respectively (Cohen, 1988). Post-hoc power analysis for the 6-month comparison was performed using G*Power version 3.1.9.7, assuming $\alpha = 0.05$, observed effect size $d = 0.47$, and a two-tailed test. Statistical significance was set at $p < 0.05$ throughout. Cumulative disease incidence was expressed as the number of disease events divided by the total monitored population ($N = 428$). All analyses were performed in IBM SPSS Statistics, Version 25.0.

3. Results And Discussion

The findings reported below span three interrelated dimensions of Barind sheep performance under the smallholder conditions of the Barind tract: body weight trajectories from birth through 12 months of age, flock multiplication and foundation stock survival, and the cumulative burden of disease across the full monitored population. Each section presents quantitative findings followed by a contextual discussion that situates the results within the wider literature on indigenous sheep production in Bangladesh and comparable tropical environments.

3.1 Sex-Specific Growth Performance from Birth to 12 Months

Body weight data for the 90-lamb growth sub-cohort (46

males, 44 females) are presented in Table 1. At birth, mean day-old weight was 1.24 ± 0.12 kg for males and 1.20 ± 0.11 kg for females, giving a combined cohort mean of 1.22 ± 0.11 kg. These values sit comfortably within the range of 1.10–1.35 kg documented for indigenous Bangladeshi sheep breeds under semi-intensive management (Haque & Siddiqui, 2017; Pervage et al., 2009), and the narrow standard deviations at birth — smaller than those observed at any subsequent age point — are consistent with the homogenising effect of uterine environment on neonatal size in a population that has not been subjected to intensive selection for growth (Sarker & Alam, 2020).

Growth proceeded in a curvilinear trajectory, with the most rapid absolute weight gain occurring in the pre-weaning period (Table 1). By three months, males had reached 5.35 ± 0.99 kg and females 5.09 ± 0.75 kg — representing approximately four-fold increases over birth weight for both sexes. The between-sex difference widened marginally during the post-weaning phase, reaching a maximum divergence of 0.62 kg at six months (8.40 vs. 7.78 kg), before narrowing again at nine months (11.62 vs. 11.43 kg, a difference of only 0.19 kg) and settling at 0.53 kg at 12 months (15.84 vs. 15.31 kg). This non-monotonic pattern of sexual dimorphism — widening then contracting — is not unusual in indigenous breeds under variable resource environments; it likely reflects periods of feed scarcity during the dry season (November–March in the Barind tract) during which both sexes experience reduced nutritional planes, temporarily equalising their growth rates regardless of hormonal status (Musa et al., 2020).

The combined 12-month mean of 15.55 ± 3.44 kg represents an approximately 12.7-fold increase over birth weight — a figure consistent with expected allometric growth in this breed type and comparable to the 14.5–16.0 kg reported by Haque and Siddiqui (2017) for indigenous sheep in northern Bangladesh under similarly semi-intensive management. It exceeds the 13.2 kg documented for extensively managed sheep in the coastal zone of Bangladesh (Mia et al., 2015), suggesting that the combination of daily grazing and strategic concentrate supplementation during late pregnancy adopted in this study supported growth performance at the upper achievable range for the Barind ecosystem. The progressive widening of standard deviations with age — from approximately 0.11 kg at birth to 3.03–4.02 kg at 12 months (Table 1) — is, we think, one of the more

practically important observations in this dataset. It reflects the cumulative divergence in growth outcomes attributable to variation in farmer management capacity, access to supplementary feed, and the timing and severity of disease events across the 40 participating households.

3.2 Statistical Comparison of Sex-Based Growth Differences

Independent-samples t-tests at each of the six age points consistently yielded non-significant results (all $p > 0.05$), with effect sizes (Cohen's d) ranging from negligible to small-to-medium (Table 2). The closest approach to statistical significance occurred at six months ($t(88) = 1.99$, $p = 0.050$, $d = 0.43$), which corresponds to the post-weaning period during which anabolic androgen levels in males begin to diverge from those of females and would be expected — in principle — to drive differential protein deposition rates. However, the current sample size ($n = 90$, split approximately equally between sexes) provided limited statistical power to detect an effect of this magnitude. A retrospective power analysis for the six-month comparison indicated that approximately 87 animals per sex group would be required to achieve 80% power at $\alpha = 0.05$ for an effect size of $d = 0.43$ — roughly four times the number available at this age point. Future longitudinal studies with expanded cohorts should revisit this question, ideally with a pre-specified sample size calculation.

The non-significant sex effect through 12 months is broadly consistent with reported findings for other South Asian indigenous breeds under comparable production environments. Rahman et al. (2016) and Haque and Siddiqui (2017) both reported statistically equivalent pre-weaning growth rates in male and female indigenous sheep in Bangladesh, and Dar et al. (2013), working with exotic and crossbred sheep in Kashmir, found that significant sexual dimorphism in growth typically emerges only in breeds subjected to intensive selection for muscle growth — a selection pressure that indigenous Barind sheep have not experienced. The practical implication for smallholder farmers is perhaps more useful than the statistical result itself: resource-constrained households that preferentially feed male lambs in the expectation of faster growth are unlikely to see a meaningful return on that investment during the first 12 months of life under current management conditions.

3.3 Flock Multiplication and Foundation Stock Survival

The multiplication status of the 200 foundation animals across the 12-month monitoring period is summarized in Table 3. By study close, 228 lambs had been born to the 160 foundation ewes, representing a crude lambing rate of approximately 143% per ewe ($228 \div 160$), or 114% relative to the full foundation cohort of 200. This range is consistent with the 90–120% flock-level multiplication rates documented by Mowsome et al. (2023) for comparable smallholder systems in Bangladesh, and implies that the majority of foundation ewes produced at least one lamb during the 12-month period, with a proportion producing twins. The 1.43 lambs per ewe figure broadly aligns with the kidding rates reported by Pervage et al. (2009) for Barind sheep, though direct comparisons are complicated by variation in management conditions and the length of the observation window.

Of the 200 foundation animals, 62 died during the study period, yielding a foundation stock mortality rate of 31.0% (Table 3). This figure is considerably higher than the 14.5–18.7% mortality range documented in organized farm settings in South Asia (Dar et al., 2013; Musa et al., 2020), and — in our view — represents the most concerning finding of this study. It is worth noting that the 31.0% mortality reflects the denominator of 200 foundation stock animals specifically, and should not be conflated with the 14.49% cumulative disease incidence figure reported for the full 428-animal monitored population (which includes the 228 births). These are two distinct epidemiological measures, and the manuscript maintains this distinction throughout. The elevated foundation stock mortality likely reflects a combination of factors: the stress of procurement and translocation to diverse new household environments, varying levels of farmer management competence across the 40 participating households, and the absence, in the project's current health protocol, of pre-distribution quarantine or post-distribution intensive monitoring during the critical first 30–60 days. Kabir et al. (2019) documented similar mortality spikes in the initial post-distribution period in sheep development projects in Bangladesh, attributing them largely to translocation stress and concurrent infectious challenge.

The net flock expansion from 200 to 366 animals — an increase of 83% over 12 months — demonstrates that,

Table 1. Sex-specific body weight (kg) of indigenous Barind sheep lambs at six age points over 12 months (mean $\pm$ SD). Note. Values are expressed as mean $\pm$ standard deviation. Growth cohort $n = 90$ lambs, selected by systematic random sampling from 228 total births (see Methods). SD = standard deviation.

Sex (n)	Day-old	1 Month	3 Months	6 Months	9 Months	12 Months
Male (n=46)	1.24 $\pm$ 0.12	3.10 $\pm$ 0.59	5.35 $\pm$ 0.99	8.40 $\pm$ 1.56	11.62 $\pm$ 1.56	15.84 $\pm$ 4.02
Female (n=44)	1.20 $\pm$ 0.11	2.95 $\pm$ 0.47	5.09 $\pm$ 0.75	7.78 $\pm$ 1.33	11.43 $\pm$ 1.85	15.31 $\pm$ 3.03
Total (n=90)	1.22 $\pm$ 0.11	3.02 $\pm$ 0.54	5.21 $\pm$ 0.87	8.06 $\pm$ 1.46	11.53 $\pm$ 1.68	15.55 $\pm$ 3.44

Table 2. Independent-samples *t*-test results comparing body weight between male and female indigenous Barind sheep at six age points ($n = 90$). Note. *df* = degrees of freedom; *CI* = confidence interval; Cohen's *d* = effect size. All comparisons used independent-samples *t*-test with Levene's test for equality of variances ($p > 0.05$ at all age points; equal variances assumed). Mean difference = male minus female. $p < 0.05$ considered statistically significant.

Age point	t-value	df	p-value	Mean diff. (kg)	95% CI	Cohen's d
Day-old	1.68	88	0.097	0.04	[-0.01, 0.09]	0.35
1 month	1.44	88	0.153	0.15	[-0.06, 0.36]	0.30
3 months	1.55	88	0.125	0.26	[-0.07, 0.59]	0.32
6 months	1.99	88	0.050	0.62	[0.00, 1.24]	0.43
9 months	0.51	88	0.614	0.19	[-0.55, 0.93]	0.11
12 months	0.72	88	0.474	0.53	[-0.94, 2.00]	0.15

Table 3. Flock multiplication and foundation stock survival over 12 months ($N = 200$ foundation animals; $N = 428$ total monitored). Note. Foundation stock comprised 160 ewes + 40 rams (5 per farmer: 4 ewes + 1 ram, $n = 40$ farmers). Mortality % expressed relative to foundation stock ($n = 200$). Lambing rate per ewe = $228 \div 160 = 142.5\%$. Non-mortality disposals (sale, sacrifice, transfer, theft) are included in the surviving foundation count where animals remained on-farm and are noted qualitatively in the text.

Category	Frequency (n)	% of Foundation (n=200)
Foundation stock at study start	200	100.0%
Foundation stock deaths (all causes)	62	31.0%
Surviving foundation stock at study close	138	69.0%
Lambs born during study period	228	114.0% of cohort / 142.5% per ewe
Total live animals at study close	366	183.0% of initial foundation

Table 4. Cumulative disease incidence by diagnostic category in the monitored indigenous Barind sheep population over 12 months (N = 428). Note. Cumulative incidence (%) = (disease events / N) × 100, where N = 428 (total animals monitored, including foundation stock and all births). % of disease events = (events in category / 62 total events) × 100. Gas/bloat and sudden death of unknown aetiology were recorded in the SPSS dataset but are not presented as separate categories due to insufficient case numbers (n < 3 each); these are described qualitatively in the text.

Disease / condition	Cases (n)	Incidence (% of N=428)	% of disease events (n=62)	Rank
Pneumonia	16	3.74	25.8	1st
Gastrointestinal parasitosis	15	3.50	24.2	2nd
Starvation / malnutrition	12	2.80	19.4	3rd
Accidents / predator attacks	10	2.34	16.1	4th
Enteritis / diarrhoea	7	1.64	11.3	5th
Food poisoning	2	0.47	3.2	6th
Total	62	14.49	100.0	—

despite the substantial foundation stock mortality, indigenous Barind sheep maintain a positive reproductive trajectory under smallholder conditions. Non-mortality attrition pathways — including sales, religious sacrifices (Kurbani/Akika), revolving fund transfers to new beneficiary farmers, and theft — are not disaggregated in Table 3 because the primary SPSS disposal codes (STATUS variable) recorded these under shared categories not uniformly applied across all farms. Disaggregating productive (sale, transfer) from non-productive (death, theft) exits from the flock in future project cycles would substantially improve the interpretability of flock performance data.

3.4 Cumulative Disease Incidence and Health Constraints

Across the full monitored population of 428 animals (200 foundation stock + 228 births), 62 disease events were recorded over 12 months, yielding a cumulative disease incidence of 14.49% (Table 4). It should be noted that this figure represents cumulative incidence — the proportion of the population experiencing at least one disease event during the observation period — rather than point prevalence in the strict epidemiological sense, and should be interpreted accordingly (Rothman et al., 2008). Animals experiencing more than one disease event were counted once per event category; the 62 recorded events represented 62 distinct clinical episodes across 58 individual animals (four animals experienced two disease events each).

Pneumonia emerged as the single most prevalent condition, accounting for 16 cases (3.74% of the total population; 25.8% of all disease events; Table 4). This finding is consistent with the well-established dominance of respiratory disease in sheep production systems across subtropical Bangladesh, and specifically with the role of *Pasteurella multocida* and *Mannheimia haemolytica* as leading causes of pneumonic pasteurellosis in sheep in Rajshahi District (Ahmed et al., 2016). The Barind tract's climatic transition from the warm, humid monsoon to the cool, dry winter — with minimum temperatures dropping below 10°C in December and January — creates conditions of heightened respiratory vulnerability in animals housed in poorly ventilated pens, and this seasonal pattern should inform the timing of preventive interventions in future cycles. Specifically, a booster *Pasteurella* vaccine administered in October, before the onset of the cool season, would be a low-cost, high-impact

addition to the current health protocol.

Gastrointestinal parasitic infections ranked second (15 cases; 3.50% of population; 24.2% of events). The Barind tract's monsoon-flooded lowlands provide near-ideal habitat for *Lymnaea* snails — the intermediate host of *Fasciola hepatica* — and the warm, moist post-monsoon soil conditions sustain high burdens of free-living nematode larvae (Chowdhury et al., 2018). The bimonthly ivermectin-albendazole deworming protocol implemented in this study may have been insufficient to control *Fasciola* specifically, as albendazole in single-dose field use has limited efficacy against adult liver fluke; triclabendazole administered once annually after the monsoon recession (typically October–November) is the agent of choice for definitive fluke control in endemic zones (Ershaduzzaman et al., 2025). The SPSS dataset also coded anaemia separately (DISEASES = 3), and although insufficient cases were recorded for a separate reportable category, clinicians should be aware that anaemia in this population may represent an overlapping manifestation of hepatic fasciolosis rather than a distinct nutritional entity.

Malnutrition and starvation ranked third (12 cases; 2.80% of population), reflecting the predictable consequence of the Barind dry season, during which natural pasture desiccates, groundwater falls, and farmers with limited fodder storage capacity struggle to maintain adequate nutritional planes. Sarker and Alam (2020) have documented this feed gap in detail, noting that even brief periods of negative energy balance in late-pregnant ewes can substantially impair lamb birth weight and survival. The concentrate supplement provided during the final four weeks of pregnancy in this study partially addresses this window, but mid-lactation and post-weaning nutritional gaps for lambs remain inadequately covered. On-farm establishment of drought-tolerant fodder plots — Napier grass (*Pennisetum purpureum*) as a bulk roughage and *Stylosanthes hamata* as a protein-rich legume supplement — could substantially reduce malnutrition-related attrition during the lean season and is a feasible intervention within the resource constraints of Barind smallholders.

Accidents and predator attacks were the fourth-ranked category (10 cases; 2.34% of population; 16.1% of events), a figure that is particularly worth reflecting on because these are, in principle, entirely preventable losses — unlike infectious disease, which requires veterinary inputs and supply chains. Rahman et al. (2016) identified stray dog predation during daytime grazing as a major

sheep loss pathway in the Barind area, and the present findings suggest this remains an unaddressed vulnerability even under the study's supervised management protocol. Simple, inexpensive interventions — securing perimeter fencing around grazing areas, training farmers on nighttime penning practices, and repairing gaps in existing sheep housing — could eliminate a meaningful fraction of the 31% foundation stock mortality.

Enteritis/diarrhoea (7 cases; 1.64%) and food poisoning (2 cases; 0.47%) were the least frequently recorded conditions. The relatively low diarrhoea prevalence may reflect the partial effectiveness of the colostrum management and pen hygiene protocols implemented in this study, though it could also reflect under-reporting of mild, self-limiting enteric disease — a limitation inherent in any farmer-reported surveillance system with fortnightly visit intervals. Food poisoning, though rare, resulted in two fatalities and highlights the need for farmer education on the identification and fencing-off of known toxic plant species in the Barind landscape.

3.5 Integrated Interpretation and Practical Implications

Taken together, the three datasets in this study present a coherent and — in some respects — sobering picture of the productive potential and health vulnerabilities of indigenous Barind sheep under smallholder farming conditions. The growth trajectory (1.22 kg at birth to 15.55 kg at 12 months, with non-significant sex differences throughout) confirms that the breed is capable of meaningful productive output under semi-intensive management, and that the management protocol implemented in this study — particularly the strategic concentrate supplementation and bimonthly deworming — supported growth performance at the upper range achievable in the Barind ecosystem. At prevailing live-weight market prices in the Rajshahi region (approximately BDT 400–450 per kilogram), a 12-month male animal weighing 15–16 kg represents roughly BDT 6,000–7,200 in market value, equivalent to several weeks of income for a marginal farming household.

However, the 31.0% foundation stock mortality — equivalent to losing roughly one in three distributed animals within 12 months — substantially erodes the economic viability of the model as currently implemented. Even allowing for the contribution of births (net flock expansion of 83%), a mortality rate of this magnitude represents an unacceptable economic risk for households

that received the foundation animals as part of a poverty-reduction initiative. Three targeted interventions, if added to the existing protocol, would address the primary mortality drivers identified in this study. First, a 14-day post-distribution quarantine and observation period for all procured foundation animals, during which close health monitoring and a booster deworming and respiratory vaccination course could be administered, would reduce the high early mortality associated with procurement stress. Second, annual *Pasteurella* vaccination in October — before the cool season — would substantially reduce the leading infectious cause of death (pneumonia, 25.8% of events). Third, post-monsoon triclabendazole treatment (October–November) would address the fasciolicide gap in the current bimonthly deworming protocol. Collectively, these three additions represent a modest increase in per-animal health expenditure that is likely to be substantially outweighed by the reduction in preventable mortality.

This study has several limitations that should inform the interpretation of findings and the design of follow-up research. The growth cohort ($n = 90$) was adequate for the descriptive objectives of this baseline study but underpowered to detect small-to-medium sex effects, particularly at six months. The farm-level management heterogeneity across 40 households — which we believe is reflected in the widening variance of body weight with age — was not statistically controlled; a mixed-effects model accounting for farm as a random effect would provide more precise estimates of the true breed-level growth trajectory. Disease diagnosis relied on clinical assessment rather than laboratory confirmation for most categories, introducing the possibility of misclassification, particularly for conditions presenting with overlapping signs (e.g., parasitic anaemia vs. nutritional anaemia). Future studies should incorporate laboratory diagnostics — at minimum, faecal egg counts for helminths and nasal swabs for respiratory pathogens — to enable pathogen-specific incidence estimates and guide targeted treatment protocols.

4. Conclusion

This 12-month prospective on-farm study provides the first comprehensive, reproducible baseline characterisation of body weight trajectories, flock multiplication dynamics, and cumulative disease incidence in indigenous Barind sheep under smallholder farming conditions in Bangladesh. Male and female lambs reached comparable body weights across all six age points (all $p > 0.05$), achieving a

combined mean of 15.55 ± 3.44 kg by 12 months — a modest but economically meaningful productive output for resource-limited households. Flock multiplication was positive, with 228 births yielding an 83% net expansion over the initial foundation cohort. However, a foundation stock mortality of 31.0% — driven primarily by pneumonia (25.8% of events), gastrointestinal parasitism (24.2%), and dry-season malnutrition (19.4%) — represents a critical constraint that substantially undermines the economic sustainability of the current model. Three evidence-based additions to the management protocol — post-distribution quarantine monitoring, pre-cool-season *Pasteurella* vaccination, and post-monsoon fasciolicide treatment — are identified as priorities for the next programme phase. Longitudinal studies with larger, pedigree-tracked cohorts and laboratory-confirmed disease diagnoses are needed to build on these baseline findings.

Author Contributions

B.R.P.: conceptualization, methodology, data curation, formal analysis, writing — original draft, writing — review and editing, project administration. M.A.I.: investigation, data collection, writing — review and editing. R.K.: investigation, data collection, writing — review and editing. H.A.: investigation, data collection. M.R.I.: clinical disease assessment, investigation, writing — review and editing. M.H.I.: investigation, data collection, supervision. M.J.U.S.: conceptualization, supervision, funding acquisition, writing — review and editing. All authors have read and approved the final manuscript.

Competing Financial Interests

The authors declare no competing financial interests. The funding body (Krishi Gobeshona Foundation, KGF) had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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Data Availability Statement

The de-identified datasets generated and analysed during the current study are available from the corresponding author (B.R.P.) on reasonable request. The authors intend to deposit the anonymized growth and disease surveillance datasets in a publicly accessible repository (e.g., Mendeley Data or Figshare) upon acceptance of this manuscript.

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