Research Square

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Phenotypic Characterization of Nagavali Sheep: Morphometric Traits, Phenotypic Correlations, and Live-Weight Prediction in a Lesser-Known Genetic Group from the North Coastal Region of Andhra Pradesh, India

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Abstract

Indigenous sheep genetic groups harbour unique adaptations to local agro-ecological conditions and represent valuable components of national animal genetic resources. The present study characterizes Nagavali sheep (also known as Vizianagaram sheep), a lesser-known genetic group distributed in the North Coastal region of Andhra Pradesh, India, at the phenotypic, morphometric, and production-performance levels. Data were recorded on 451 animals (351 females and 100 males) across eight age groups (3 months to full-mouth dentition), sourced from the Livestock Research Station (LRS), Garividi, Vizianagaram district, and farmers' flocks across Vizianagaram, Srikakulam, and Visakhapatnam districts. Morphological observations revealed a predominantly white coat with tan, brown, or black patches, universally horned rams, polled ewes, and predominantly pendulous ears. A characteristic convex nasal profile develops by approximately 7 months of age. Adult rams attained body weights of 43.92 ± 1.53 kg (2-teeth) and 47.50 ± 1.66 kg (full-mouth); corresponding ewe weights were 20.21 ± 0.33 kg and 26.31 ± 0.31 kg. Sex significantly influenced ($P \leq 0.01$) height at withers, body length, and chest girth at most age groups. Chest girth showed the highest phenotypic correlation with body weight ($r = 0.83$, $P < 0.01$) and the highest single-trait coefficient of determination ($R^2 = 0.69$) in stepwise regression models, establishing it as the most reliable field-level indicator of live weight. Biometric values were phenotypically distinct from Nellore, Macherla, and Ganjam breeds. These findings provide the phenotypic baseline required for formal breed recognition and targeted conservation of Nagavali sheep under India's animal genetic resources framework.

Introduction

Livestock populations embody the cumulative result of centuries of natural selection, farmer-managed adaptation, and agro-ecological co-evolution. India ranks among the world's most livestock-diverse nations, possessing 44 formally recognized sheep breeds plus numerous uncharacterized genetic groups (DAHD 2019). With a national sheep population of 74.26 million, of which approximately 40% remain non-descript, a substantial proportion of the national flock is undocumented with respect to breed identity, phenotypic characteristics, and productive potential (DAHD 2012). These genetic groups are frequently highly productive within their local resource environments and more resilient than exotic or crossbred counterparts (FAO 2012).

Andhra Pradesh ranks second in India with 17.6 million sheep and harbours only one formally recognized breed, the Nellore, comprising three phenotypic variants: Nellore Jodipi, Nellore Brown, and Nellore Palla (DAHD 2019). In the North Coastal agro-ecological zone encompassing Srikakulam, Vizianagaram, and parts of Visakhapatnam districts, a locally well-adapted genetic group known as 'Nagavali sheep' (also referred to as Vizianagaram sheep, after the Vizianagaram district, or 'North Coastal sheep') is reared extensively. The name 'Nagavali' derives from the Nagavali river that drains this region. Preliminary observations by Gangaraju (2010) indicated that this group is phenotypically and productively distinct from Nellore sheep, though a comprehensive characterization study has been lacking.

Characterization of indigenous livestock is the foundational step in designing strategies for sustainable conservation, genetic improvement, and utilization of animal genetic diversity (Msanga et al. 2012). Without baseline documentation, unique phenotypic and adaptive traits may be irreversibly lost before their value is recognized (FAO 2012). The present study therefore aimed to: (i) establish breed descriptors for Nagavali sheep through morphological and morphometric assessment; (ii) evaluate growth performance and body measurements across age groups and sexes; (iii) determine phenotypic correlations between body weight and linear measurements; and (iv) develop regression models for field-level prediction of live weight.

Materials and Methods

Study area and animals

Data were collected from 451 sheep (351 females and 100 males) representing eight dentition-based age groups (3 months, 6 months, 9 months, 12 months, 2-teeth, 4-teeth, 6-teeth, and full-mouth) at the Livestock Research Station (LRS), Garividi, Vizianagaram district (organized sector; n = 140 adults), and from farmers' flocks in Vizianagaram, Srikakulam, and Visakhapatnam districts (unorganized sector; n = 165 adults and 146 growing animals), Andhra Pradesh, India. All procedures were non-invasive (observation and measurement only) and conducted in compliance with institutional guidelines.

Morphological assessment

Qualitative traits such as coat colour, colour distribution pattern, horn status, ear type, and distinctive anatomical features were recorded by direct visual observation of individual animals following FAO (2012) phenotypic characterization guidelines. Ear type was classified as pendulous, tubular (semi-erect), or rudimentary. Animal age was determined by dentition pattern.

Morphometric measurements

Seven linear body measurements were recorded to the nearest centimetre (cm) using a standard measuring tape, with the animal standing squarely on an even surface in a natural posture (FAO 2012): height at withers (HT), body length (BL), chest girth (CG), face length (FL), ear length (EL), horn length (HL), and tail length (TL). Body weight (BW) was recorded using a calibrated spring balance.

Statistical analysis

Qualitative traits were analyzed using frequency procedures. Quantitative traits were analyzed using the General Linear Model (GLM) procedure of SPSS (Version 23.0) with the fixed model:

$Y_{ijk} = \mu + S_i + A_j + e_{ijk}$

where Y_{ijk} is the k-th observation of the i-th sex in the j-th age group; μ is the overall mean; S_i is the fixed effect of sex (male, female); A_j is the fixed effect of age group (j = 1–8); and e_{ijk} is the random residual error. Pairwise comparisons of least-square means (LSMs) were performed using Duncan's Multiple Range Test as modified by Kramer (1957). Descriptive statistics (mean ± SE) were computed following Snedecor and Cochran (1989). Pearson correlation coefficients (two-tailed) assessed the relationship between BW and linear measurements. Stepwise multiple linear regression with R^2 as the selection criterion identified the best predictive models for BW.

Results and Discussion

Morphological characteristics

Nagavali sheep are distributed across the North Coastal districts of Andhra Pradesh (Srikakulam, Vizianagaram, and Visakhapatnam). The majority of animals exhibited a white base coat with tan, brown, or black patches concentrated on the nose line, lateral face, neck, perineum, dorsal surface, and lower extremities. Black periocular patches and horn-ridge pigmentation are consistent phenotypic markers that reliably distinguish Nagavali sheep from co-distributed Nellore breed variants: Nellore Jodipi (white with black ventral patches), Nellore Palla (entirely white), and Nellore Brown (uniform brown coat). Rams are universally horned while ewes are polled. The majority of animals possessed pendulous ears (approximately 58%), with a notable proportion having tubular-type (semi-erect) ears and a minor proportion (~ 5%) with rudimentary ears. These proportions represent a shift from observations by Gangaraju (2010), who reported 54.2% pendulous, 37.4% long, and 8.4% rudimentary ears, potentially reflecting demographic drift or sampling differences. Hair growth was observed on the thighs, dewlap, and neck. A characteristic convex nasal profile develops by approximately 7 months of age and is not reported in any co-distributed breed, serving as a reliable visual identifier for the genetic group.

Morphometric measurements and body weight

Least-square means for body measurements and body weight across growing and adult age groups are presented in Tables 1 and 2. In growing animals (3–12 months), HT ranged from 39.50 ± 1.01 cm to 64.31 ± 0.72 cm and BW from 11.43 ± 1.74 kg to 21.78 ± 0.87 kg. In adults (2-teeth to full-mouth), HT ranged from 64.96 ± 0.48 cm to 67.22 ± 0.40 cm and overall BW from 22.10 ± 0.76 kg to 28.09 ± 0.62 kg. Adult rams attained body weights of 43.92 ± 1.53 kg (2-teeth) and 47.50 ± 1.66 kg (full-mouth), substantially higher than ewes (20.21 ± 0.33 kg and 26.31 ± 0.31 kg, respectively). Sex had a significant effect ($P \leq 0.01$) on HT, BL, and CG at most age groups, while FL, EL, and TL showed predominantly non-significant sex differences consistent with findings for Macherla sheep (Panduranga Reddy et al. 2021) and Nellore sheep (Rani 2012; Karthik et al. 2021). Males recorded significantly higher ($P \leq 0.01$) body weights than females at all ages, attributable to anabolic hormonal effects and greater skeletal and muscular development (Hafez 1962).

Table 1
Least-square means (± SE) of body measurements (cm) and body weight (kg) of Nagavali sheep lambs (3–12 months)

Parameter	Sex	3 months	6 months	9 months	12 months
Height at withers (cm)	Overall	39.50 ± 1.01 (26)	59.47 ± 0.74 (40)	59.93 ± 0.76 (51)	64.31 ± 0.72 (29)
	Male	37.33 ± 0.66 (3)	61.78 ± 0.85 (19)	59.14 ± 1.31 (28)	66.00 ± 0.75 (20)
	Female	39.78 ± 1.13 (23)	57.38 ± 0.99 (21)	58.67 ± 0.60 (23)	60.55 ± 0.52 (9)
Body length (cm)	Overall	32.65 ± 0.94 (26)	55.61 ± 0.80 (40)	57.15 ± 0.57 (51)	61.36 ± 0.83 (29)
	Male	30.00 ± 0.00 (3)	58.10 ± 1.17 (19)	58.69 ± 0.78 (28)	63.22 ± 0.86 (20)
	Female	38.66 ± 0.66 (23)	53.35 ± 0.86 (21)	58.28 ± 0.68 (23)	57.22 ± 0.93 (9)
Chest girth (cm)	Overall	39.57 ± 0.62 (26)	60.85 ± 0.76 (40)	61.20 ± 0.66 (51)	68.44 ± 1.02 (29)
	Male	38.66 ± 0.66 (3)	63.86 ± 0.61 (19)	62.41 ± 0.95 (28)	71.25 ± 0.68 (20)
	Female	39.69 ± 0.69 (23)	58.11 ± 1.03 (21)	59.73 ± 0.82 (23)	62.22 ± 1.51 (9)
Face length (cm)	Overall	16.15 ± 0.18 (26)	21.07 ± 0.28 (40)	21.26 ± 0.31 (51)	23.74 ± 0.27 (29)
	Male	16.66 ± 0.33 (3)	21.47 ± 0.37 (19)	20.03 ± 0.49 (28)	24.20 ± 0.31 (20)
	Female	16.08 ± 0.20 (23)	20.71 ± 0.41 (21)	20.54 ± 0.33 (23)	22.72 ± 0.40 (9)
Ear length (cm)	Overall	11.75 ± 0.20 (26)	14.65 ± 0.29 (40)	14.69 ± 0.20 (51)	15.15 ± 0.33 (29)
	Male	11.33 ± 0.33 (3)	15.13 ± 0.36 (19)	14.73 ± 0.25 (28)	15.42 ± 0.28 (20)
	Female	11.80 ± 0.23 (23)	14.21 ± 0.45 (21)	14.43 ± 0.33 (23)	14.55 ± 0.86 (9)
Tail length (cm)	Overall	5.67 ± 0.10 (26)	10.56 ± 0.15 (40)	10.58 ± 0.19 (51)	11.15 ± 0.20 (29)

Values in parentheses are number of observations. Horn length (males only): 8.67 ± 0.88 (3 months), 12.15 ± 0.63 (6 months), 12.67 ± 0.88 (9 months), 20.90 ± 0.77 cm (12 months). †P ≤ 0.01 for sex effect on HT, BL, and CG at most age groups.

Parameter	Sex	3 months	6 months	9 months	12 months
	Male	6.00 ± 0.00 (3)	10.68 ± 0.21 (19)	9.75 ± 0.29 (28)	11.50 ± 0.22 (20)
	Female	5.60 ± 0.11 (23)	10.45 ± 0.22 (21)	10.93 ± 0.17 (23)	10.38 ± 0.33 (9)
Body weight (kg)	Overall	11.43 ± 1.74 (26)	15.66 ± 0.45 (40)	17.74 ± 0.46 (51)	21.78 ± 0.87 (29)
	Male	14.00 ± 0.57 (3)	17.18 ± 0.67 (19)	19.58 ± 0.54 (28)	24.42 ± 0.61 (20)
	Female	11.10 ± 0.32 (23)	14.28 ± 0.42 (21)	15.49 ± 0.48 (23)	15.93 ± 0.60 (9)

Values in parentheses are number of observations. Horn length (males only): 8.67 ± 0.88 (3 months), 12.15 ± 0.63 (6 months), 12.67 ± 0.88 (9 months), 20.90 ± 0.77 cm (12 months). †P ≤ 0.01 for sex effect on HT, BL, and CG at most age groups.

Table 2
Least-square means (± SE) of body measurements (cm) and body weight (kg) of adult Nagavali sheep (2-teeth to full-mouth)

Parameter	Sex	2-teeth	4-teeth	6-teeth	Full-mouth
Height at withers (cm)	Overall	64.96 ± 0.48 (88)	66.86 ± 0.74 (46)	67.20 ± 0.69 (52)	67.22 ± 0.40 (119)
	Male	71.57 ± 2.63 (7)	77.00 ± 1.00 (2)	73.45 ± 0.83 (11)	77.40 ± 0.37 (10)
	Female	64.38 ± 0.42 (81)	66.40 ± 0.70 (44)	65.52 ± 0.63 (41)	66.29 ± 0.31 (109)
Body length (cm)	Overall	62.30 ± 0.42 (88)	65.13 ± 0.55 (46)	65.76 ± 0.81 (52)	65.89 ± 0.37 (119)
	Male	68.64 ± 2.23 (7)	74.00 ± 3.00 (2)	74.63 ± 0.93 (11)	73.40 ± 1.02 (10)
	Female	61.75 ± 0.36 (81)	64.72 ± 0.49 (44)	63.39 ± 0.59 (41)	65.20 ± 0.33 (109)
Chest girth (cm)	Overall	68.67 ± 0.64 (88)	72.33 ± 0.78 (46)	74.75 ± 1.07 (52)	76.76 ± 0.51 (119)
	Male	81.85 ± 4.62 (7)	85.50 ± 6.50 (2)	87.18 ± 1.54 (11)	88.80 ± 0.77 (10)
	Female	67.53 ± 0.39 (81)	71.73 ± 0.66 (44)	71.41 ± 0.61 (41)	72.05 ± 0.30 (109)
Body weight (kg)	Overall	22.10 ± 0.76 (88)	26.03 ± 0.75 (46)	28.89 ± 1.21 (52)	28.09 ± 0.62 (119)
	Male	43.92 ± 1.53 (7)	40.00 ± 0.00 (2)	44.95 ± 1.05 (11)	47.50 ± 1.66 (10)
	Female	20.21 ± 0.33 (81)	25.40 ± 0.63 (44)	24.58 ± 0.32 (41)	26.31 ± 0.31 (109)

Values in parentheses are number of observations. Horn length in males (cm): 39.20 ± 1.11 (2-teeth), 48.50 ± 10.50 (4-teeth), 51.18 ± 1.82 (6-teeth), 56.60 ± 1.73 (full-mouth). †P ≤ 0.01 for sex effect on HT, BL, CG, and BW at all dentition stages.

Compared with co-distributed breeds, Nagavali sheep showed lower body weights and biometric values than Macherla sheep (Panduranga Reddy et al. 2021) and Nellore sheep (Rani 2012; Harini 2016), consistent with their adaptation to the lower-resource North Coastal agro-ecological environment. Biometric values also differed from Ganjam sheep of Odisha (Arora et al. 2010), Deccani (Kumar et al. 2017), Ramnad White (Mahendran 2009), and Madras Red sheep (Arthy et al. 2018), confirming phenotypic differentiation at the regional level. Importantly, comparison between organized farm (LRS Garividi) and farmers' flock animals revealed no statistically significant differences in any biometric trait

(Table 3), confirming phenotypic consistency across management systems and supporting Nagavali sheep as a distinct genetic group rather than a management-driven phenotype.

Table 3
Comparison of biometric traits (± SE) of Nagavali sheep between organized farm (LRS Garividi) and unorganized (farmers' flock) rearing systems in adult animals

Sector (n)	BW (kg)	BL (cm)	HT (cm)	CG (cm)	FL (cm)	EL (cm)	TL (cm)
Organized LRS (140)	25.51 ± 0.65	63.91 ± 0.38	66.11 ± 0.43	71.51 ± 0.57	24.46 ± 0.17	15.11 ± 0.19	11.31 ± 0.07
Unorganized farmers' flocks (165)	26.76 ± 0.57	65.40 ± 0.35	66.85 ± 0.33	72.65 ± 0.48	25.18 ± 0.45	12.72 ± 0.46	11.16 ± 0.06

Differences between sectors were not statistically significant (P > 0.05) for any trait. BW body weight, BL body length, HT height at withers, CG chest girth, FL face length, EL ear length, TL tail length.

Phenotypic correlations

Phenotypic correlations among body measurements and body weight (pooled across age groups and sexes) are presented in Table 4. All correlations were positive and highly significant (P < 0.01). Chest girth showed the strongest correlation with body weight (r = 0.83), followed by body length (r = 0.74) and height at withers (r = 0.73). Ear length exhibited the weakest association with body weight (r = 0.31). The dominant role of chest girth reflects the contribution of thoracic volume encompassing bones, major muscles, and viscera to total body mass (Thiruvenkadan 2005), and is consistent with reports in Macherla sheep (Panduranga Reddy et al. 2021) and Ethiopian indigenous sheep (Belete et al. 2017).

Table 4
Phenotypic correlation coefficients among body measurements and body weight of Nagavali sheep (pooled across age groups and sexes; n = 451)

Trait	BL	HT	CG	FL	EL	TL	BW
BL	1.000	0.911**	0.885**	0.603**	0.477**	0.728**	0.744**
HT	0.911**	1.000	0.881**	0.543**	0.502**	0.738**	0.726**
CG	0.885**	0.881**	1.000	0.574**	0.481**	0.709**	0.830**
FL	0.603**	0.543**	0.574**	1.000	0.316**	0.476**	0.526**
EL	0.477**	0.502**	0.481**	0.316**	1.000	0.451**	0.315**
TL	0.728**	0.738**	0.709**	0.476**	0.451**	1.000	0.491**
BW	0.744**	0.726**	0.830**	0.526**	0.315**	0.491**	1.000

***P < 0.01. BW body weight, BL body length, HT height at withers, CG chest girth, FL face length, EL ear length, TL tail length.*

Regression analysis for live-weight prediction

Stepwise multiple regression results are presented in Table 5. Chest girth alone provided the highest single-variable R^2 (0.69), confirming its supremacy as a practical field-level predictor of live weight. The full model incorporating BL + HT + CG + FL + EL + TL improved R^2 marginally to 0.72, a negligible gain given the operational difficulty of restraining animals for multiple measurements under field conditions. The model incorporating CG alone (R^2 = 0.69) or CG with BL and HT (R^2 = 0.692) is therefore recommended for routine field-level weight estimation. These findings concur with reports from Macherla sheep (Panduranga Reddy et al. 2021) and Nellore sheep (Vani et al. 2018), and confirm chest girth as a universal predictor of live weight across divergent sheep breeds.

Table 5
Stepwise multiple regression models for predicting live body weight from linear body measurements in Nagavali sheep

Model (predictors)	Intercept	b_1 (BL)	b_2 (HT)	b_3 (CG)	b_4 (FL)	b_5 (EL)	b_6 (TL)	R^2
CG alone	−19.301	—	—	0.631	—	—	—	0.691
BL alone	−15.286	0.637	—	—	—	—	—	0.550
HT alone	−20.271	—	0.692	—	—	—	—	0.523
BL + HT	−18.889	0.419	0.267	—	—	—	—	0.563
BL + HT + CG	−18.336	0.069	0.096	0.643	—	—	—	0.692
BL + HT + CG + FL	−18.911	0.040	0.086	0.631	0.112	—	—	0.695
BL + HT + CG + FL + EL	−13.942	0.043	−0.051	0.649	0.119	−0.584	—	0.706
BL + HT + CG + FL + EL + TL	−13.377	0.081	0.016	0.670	0.136	−0.485	−0.975	0.722

BL body length, HT height at withers, CG chest girth, FL face length, EL ear length, TL tail length. Dashes indicate trait not included in model. R^2 coefficient of determination.

Conclusions

Nagavali sheep represent a phenotypically distinct indigenous genetic group of North Coastal Andhra Pradesh, characterized by a unique coat pigmentation pattern (white with periocular and horn-ridge black patches), a diagnostic convex nasal profile developing by seven months of age, universally horned rams and polled ewes, and biometric values significantly different from Nellore, Macherla, and Ganjam breeds. The genetic group demonstrates superior adaptation to the North Coastal agro-ecological environment, explaining farmer preference despite lower average body weights than Nellore and Macherla sheep. Chest girth is established as the most practical field-level indicator of live weight (R^2 = 0.69; r = 0.83 with BW). These phenotypic, morphometric, and comparative findings provide the evidence base required to formally propose Nagavali sheep for registration as a distinct breed under ICAR-NBAGR's breed

registration framework a critical step toward targeted conservation and sustainable utilization of this genetic resource.

Declarations

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Competing interests

The authors declare no competing interests.

Ethics approval and animal rights

All data collection was non-invasive (observation and measurement only). No experimental procedures or interventions were performed on animals. Institutional approval for farm-level data collection was obtained. The study did not involve clinical trials or patient data. All procedures conformed to the ethical standards of the institution.

Author contributions

B. Prasanna and R. Vinoo: data collection and analysis; Muralidhar Metta: study design, supervision, and manuscript revision; Ch. Venkatasesaiah: farm management and data access; Krovvidi Sudhakar: statistical analysis; Panduranga Reddy Punuru: genetic context and manuscript preparation. All authors read and approved the final manuscript.

Data availability

Data will be made available upon reasonable request

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