



Morphometric characterization of the indigenous goats of Odisha, India

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ABSTRACT

Goats contribute greater value to the rural economy. Phenotypic characterization is a first step to characterize the animals in a particular production environment. A multipurpose sampling of 248 goats (Black Bengal = 75, Ganjam = 70, Bolangir = 48, and Raighar = 55) was studied to characterize the unregistered (Raighar and Bolangir) goats of Odisha and registered (Black Bengal and Ganjam) goats of India. The univariate and multivariate statistical approaches and random forest analysis were used to differentiate the goat populations by their morphometric traits. The morphometric traits were significant for most of the traits between the goat populations. Raighar goats had consistently higher morphometric traits, such as wither height (62.54 cm), rump height (65.37 cm), heart girth (64.92 cm), paunch girth (69.77 cm), and leg length (43.68 cm), indicating the productive type of animals. Canonical discriminant analysis and random forest analysis revealed that body length, leg length, and height at the withers were good indicators to distinguish the goat population in the present study. The results of the present study suggest that random forest analysis can also be used to classify animal populations, provided it is validated by a large sample size. In conclusion, the present study highlighted the morphometric characterization of the indigenous goats of Odisha, India.

Keywords: Canonical discriminant analysis, Indigenous goats of Odisha, Morphometric characterization, Random forest analysis

Among livestock, goats are versatile with superior economic traits and adapt to different agro-climatic conditions (Venkatesh *et al.* 2022, 2023). Odisha accounts for 6.39 million goats and ranks ninth in the total goat population of India (20th Livestock Census 2019). Yet, Odisha has only one registered goat breed (Ganjam). Notably, Raighar and Bolangir goat populations of Odisha had different germplasm when compared with other goat populations in their native tract (Sah and Dixit 2021, Sharma *et al.* 2021). The knowledge of morphometric traits (genetic diversity) of indigenous animals not only serves as the foundation for community-based animal breeding practices but also helps prevent the production loss of animals due to inbreeding strategies by local farmers. Recent studies phenotypically characterized a few Odisha goats (Majumder *et al.* 2023, 2024) and extended works on assessing their thermal adaptability (Venkatesh *et al.* 2023) and molecular characterization of productive genes (Venkatesh *et al.* 2022). On the other hand, the classification of animals is usually carried out by discriminative multivariate classification approaches. More recently, machine learning methods, namely neural

networks and support vector machines, were used to predict the morphometric genetic resources of goats (Erduran *et al.* 2024). Machine learning is a frequent learning method that is used to classify the data either as binomial or multinomial by building a model with a greater accuracy rate (Jordan and Mitchell 2015). To the best of our knowledge, there were no prior studies involving random forest analysis (RFA) to classify the goat populations of India based on their phenotypic traits. This study was conducted to primarily characterize the unregistered indigenous goat populations (Raighar and Bolangir) of Odisha and the registered goat breeds (Ganjam and Black Bengal) of India by their morphometric traits using statistical and machine learning methods (RFA), which could be useful for framing better breeding policies and conservation of the germplasm of animals.

MATERIALS AND METHODS

Study area and sampling technique: The study was conducted in the state of Odisha, which occupies eastern India. Using an exploratory approach, a total of 248 healthy, adult (2-4 years) and non-pregnant female goats (Black Bengal = 75, Ganjam = 70, Bolangir = 48, and Raighar = 55) were sampled from thirteen districts in Odisha that represent eight agro-climatic zones. Further, the stepwise multi-purpose sampling technique was employed depending on goat population size, farmers with

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goat flocks, and household accessibility. The goats sampled in the present study were all reared in a semi-extensive system.

Measurements of morphometric traits: The phenotypic traits were recorded in each goat based on the breed morphological characteristics descriptor list of the National Bureau of Animal Genetic Resources, India. The morphometric measurements were recorded using a standard measuring tape and sliding rulers. The quantitative morphometric traits such as height at withers (the vertical distance between the highest point of the withers and the lowest point of the forelimb), height at rump (the vertical distance between the highest point of the pelvic girdle and the lowest point of hind limb), neck girth (the complete circumferential distance from the base of the neck), heart girth (the complete circumferential distance around the thorax region beneath to the point of the elbow), paunch girth (the complete circumference around the pelvis region in front of the sacrum), body length (the horizontal distance between the point of the shoulder blade and the pin bone), leg length (from the proximal olecranon process to the coronet's mid-lateral point), ear length (the vertical distance from both the extremities of the external ear at the midline) and ear width (the vertical measurement between either side of the ear at the midline) were all measured in centimeter units. Further, the qualitative traits such as head type, ear type, coat color, and the presence (or absence) of wattle, beard, and horn were recorded.

Statistical analysis of morphometric traits and classification of animals: The univariate, one-way ANOVA was employed to analyze the quantitative traits, with Tukey-Kramer analysis as a post hoc test. Qualitative traits were subjected to the Pearson Chi-square and correlation coefficient tests to find a significant difference between the goat populations and the degree of association between the recorded traits, respectively. The multivariate, canonical discriminant analysis (CDA) was used to test the classification of the goat population. In addition, a machine learning method called random forest analysis was employed to classify the animals using their morphometric traits. It is based on a prediction algorithm (boot resampling) with a collection of unpruned decision trees in which each tree has a vote (Breiman 2001). One-way ANOVA, the Chi-square test, and the CDA were carried out using the SPSS

22.0 statistical software program, while correlation (cor package) and RFA (randomForest package) were carried out using the R Studio 4.1.2 software.

RESULTS AND DISCUSSION

Variation and correlation in the morphometric traits: Phenotypic characterization is generally studied to characterize the genetic diversity of the animals in a particular production environment. The goat population studied in their native reproductive tract was presented in Fig. 1. These indigenous goat populations are mainly maintained by the traditional pastoralists with a partially known pedigree. The means and standard error values of all quantitative morphometric traits were presented in Table 1. The univariate analysis of morphometric traits showed that variation in all the quantitative morphometric traits was significant ($p < 0.05$) between the breeds except that neck girth between Black Bengal ~ Raighar, paunch girth between Ganjam ~ Raighar, and ear width between Raighar ~ Bolangir were found to be non-significant. Height at withers (62.54 cm), rump height (65.37 cm), heart girth (64.92 cm), paunch girth (69.77 cm), and leg length (43.68 cm) were all greater in Raighar goats than in Black Bengal, Ganjam, and Bolangir goats. Ganjam goats had the highest neck girth (35.49 cm) and body length



Fig. 1. Representative of the goats in the present study. From top to bottom, a) Ganjam goat b) Black Bengal goat c) Bolangir goat and d) Raighar goat.

Table 1. Morphometric traits of indigenous goats of Odisha, India (Mean $\pm$ standard error)

Morphometric trait	Black Bengal (n=75)	Ganjam (n=70)	Bolangir (n=48)	Raighar (n=55)
Height at withers (cm)	49.56 ^c $\pm$ 0.73	59.02 ^b $\pm$ 0.36	47.16 ^d $\pm$ 0.69	62.54 ^a $\pm$ 0.36
Height at rump (cm)	53.67 ^c $\pm$ 0.71	63.33 ^b $\pm$ 0.37	51.44 ^d $\pm$ 0.67	65.37 ^a $\pm$ 0.35
Neck girth (cm)	28.15 ^c $\pm$ 0.46	35.49 ^a $\pm$ 0.49	31.53 ^b $\pm$ 0.79	28.59 ^c $\pm$ 0.26
Heart girth (cm)	55.26 ^c $\pm$ 1.10	61.29 ^b $\pm$ 0.51	49.78 ^d $\pm$ 0.72	64.92 ^a $\pm$ 0.38
Paunch girth (cm)	62.76 ^b $\pm$ 1.27	67.58 ^a $\pm$ 0.53	53.76 ^c $\pm$ 0.77	69.77 ^a $\pm$ 0.42
Body length (cm)	41.09 ^d $\pm$ 0.44	57.37 ^a $\pm$ 0.37	53.32 ^b $\pm$ 0.49	49.66 ^c $\pm$ 0.35
Leg length (cm)	31.03 ^d $\pm$ 0.32	37.48 ^c $\pm$ 0.30	40.77 ^b $\pm$ 0.67	43.68 ^a $\pm$ 0.38
Ear length (cm)	12.35 ^b $\pm$ 0.24	12.91 ^d $\pm$ 0.16	14.47 ^a $\pm$ 0.38	12.15 ^c $\pm$ 0.17
Ear width (cm)	4.97 ^b $\pm$ 0.13	5.91 ^a $\pm$ 0.09	4.24 ^c $\pm$ 0.13	4.50 ^c $\pm$ 0.12

a,b,c,d Row means with different superscript letters are significant at $p < 0.05$

(57.37 cm). Ear length and ear width ranged from 12.15 cm to 14.47 cm and 4.24 cm to 5.91 cm, respectively, across breeds. The disparities in genetic features and the diverse ways of rearing goat production could be the reasons for the different conformation of these goat populations. These morphometric traits are comparable to the morphometry of the Southern Odisha goats, such as Narayanpatna and Malkangiri goats (Majumder *et al.* 2023, 2024). However, the traits such as height at withers, body length, heart girth, and paunch girth recorded for Ganjam goats in the present study were lower than the other Ganjam study that was conducted more recently (Majumder *et al.* 2023).

Goat populations in the study showed considerable within- and between-population variation in morphometric traits, indicating the environmental and non-genetic influence on their body confirmation aside from the genetic effects. This insists on the need for conservation efforts to preserve the distinguished germplasm of the indigenous goats of Odisha, India. Future studies should aim to establish the genetic diversity by means of molecular markers such as mitochondrial DNA, as demonstrated by a study on Indian goats (Diwedi *et al.* 2020). On the other hand, Raighar goats had consistently higher morphometric traits, namely, withers and rump height, indicative of good productive-type animals; however, it should be warranted by future growth parameter studies. Further studies should mine the genetic variants responsible for different production and morphometric traits in these goats as uncovered for Ganjam and Keonjhar goats of Odisha, India (Venkatesh *et al.* 2022).

Qualitative morphometric traits such as head type, ear type, coat color, and the presence or absence of wattle and horn were found significant (between goat populations) for a few traits but not all as presented in Table 2. In particular, beard type was found non-significant between the goat populations. The medium to long ear length and black and brown coat colors in the studied goat population may be one of the reasons for the animal's coping ability with

more stressful agro-climatic zones of Odisha (Venkatesh *et al.* 2023). The correlation coefficients (Fig. 2) of the quantitative morphometric traits were mostly positively correlated ($p < 0.05$, $p < 0.01$, and $p < 0.001$) between them, except for the traits' height at rump-ear length, paunch girth-ear length, and ear width-leg length, which were negatively correlated ($p < 0.05$). The strong correlation (0.98) between height at the withers and height at the rump may be an indicator of the production type of goats. Conversely, the strong correlation between heart and paunch girth suggests a uniform body shape (growth) in the studied goats. The positive and strong correlation between the traits in the present study was comparable to the morphometric correlation obtained in Ganjam goat and Kotdhar goat studies (Dinesh *et al.* 2024, Karna *et al.*

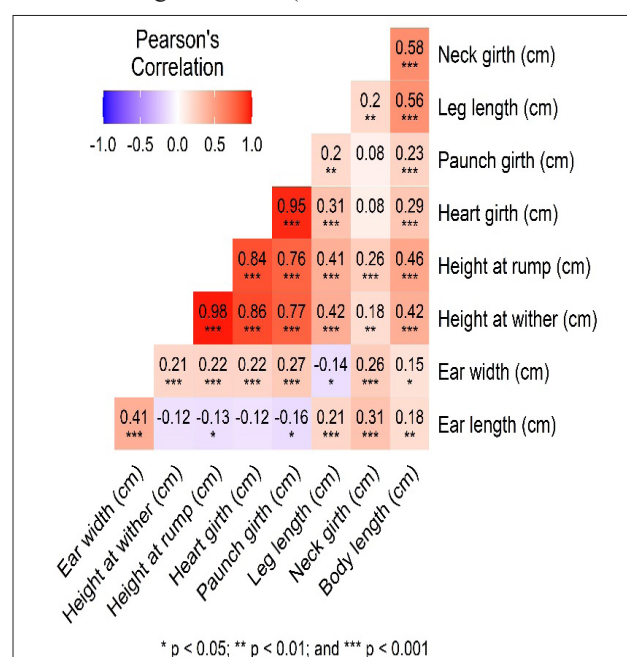


Fig. 2. Correlation plot of Pearson coefficient of correlation of quantitative morphometric traits.

Table 2. Percentage values of qualitative morphometrical traits of indigenous goats of Odisha, India (N = 248)

Character		Black Bengal (n=75)	Ganjam (n=70)	Bolangir (n=48)	Raighar (n=55)
Head profile	Straight	71(53) ^c	83(62) ^b	92(44) ^a	93(51) ^a
	Convex	29(22) ^a	17(8) ^b	8(4) ^c	7(4) ^c
Ear form	Drooping	39(29) ^a	38.5(27) ^a	39.5(19) ^a	31(17) ^b
	Horizontal	33(25) ^b	7(5) ^d	29(14) ^c	47(26) ^a
	Erect	15(11) ^b	1.5(1) ^c	23(11) ^a	18(10) ^b
Wattle	Pendulous	13(10) ^b	53(37) ^a	8.5(14) ^c	4(2) ^d
	Present	13(10) ^b	20(14) ^a	2(1) ^c	10(6) ^b
	Absent	87(65) ^b	80(56) ^c	98(47) ^a	80(49) ^c
Beard	Present	13(10)	7(5)	6(3)	7(4)
	Absent	87(65)	93(65)	94(45)	93(51)
Horn	Present	67(50) ^b	94(66) ^a	92(44) ^a	94.5(52) ^a
	Absent	33(25) ^a	6(4) ^b	8(4) ^b	5.5(3) ^b
Colour	Black	57(44) ^a	47(33) ^b	19(9) ^d	25(14) ^c
	Brown	33(25) ^d	43(30) ^b	58(28) ^c	62(34) ^a
	White	8(6) ^c	10(7) ^b	23(11) ^a	13(7) ^b

a,b,c,d Row means with different superscript letters are significant at $p < 0.05$

2024). These strong correlations between traits should be considered while assessing the body conditions and predicting the body weight of the animal, as demonstrated elsewhere (Karna *et al.* 2024).

Canonical discriminant analysis of the quantitative morphometric traits: The results of stepwise CDA (Supplementary Table 1) with the default F value (entry = 3.84 and removal = 2.71) revealed three discriminants (CAN1, CAN2, and CAN3) as the best fits in the current study with the proportions of 50.9%, 28.2%, and 20.90%, respectively. The stepwise analysis reduced the morphometric traits based on the default 'F' value (removal). Thus, the analysis reduced the initial input traits (nine) into seven traits in the final step. Based on the 'F' value of the traits (Table 3), body length contributed more to the analysis, and neck girth contributed the least to the discriminant functions. From the results of CDA, body length, leg length, and height at wither could be good indicators in differentiating the goat population in the present study. At the primary characterization level, these traits can be used to classify and discriminate the goat populations in the native tract. CDA classified (Supplementary Table 2) the animals based on their morphometric traits with an accuracy rate of 97.6%. The four goat populations in the present study were well separated (Fig. 3). However, Bolangir slightly overlapped with the Ganjam goats. This suggests that some

genetic exchange could have happened between these two goat populations. This is likely because Ganjam is the only established goat breed in Odisha, India, and farmers would have crossbred Ganjam with other indigenous goats, which was suggested by the results of a previous study in Odisha native goats (Venkatesh *et al.* 2023). However, although significantly different ($p < 0.05$), the contribution of morphological traits (body and leg length) to the model cannot be ruled out as a reason for the existing overlap between these breeds. Notably, Ganjam and Bolangir had the body length (cm) and leg length (cm) of 57.37 ± 0.37 and 53.32 ± 0.49 and 37.48 ± 0.30 and 40.77 ± 0.67 , respectively. Conversely, the morphometric distinguishment of the Raighar and Bolangir goat populations corroborated the findings of studies that distinguished their germplasm by the microsatellite markers (Sah and Dixit 2021, Sharma *et al.* 2021). The CDA results of the present study did not agree with the results of the most recent study conducted on the Kotdhar goats of Himachal Pradesh, India (Dinesh *et al.* 2024). They concluded head length, heart girth, chest depth, rump length, bicoastal width, shoulder width, cannon bone circumference, and body weight as the most discriminating traits in their study.

Random forest analysis for classification of the animals: Machine learning methods are becoming widely attractive in the field of animal genetics and breeding. Random forests were built with multiple trees, which has the advantage of reducing the overfitting of data (Breiman 2001). It is less sensitive to outliers and takes account of missing data while fitting into the model. The classification based on CDA was tested with RFA. The model was built by splitting the data into the train (70%) and test (30%) parts with 500 trees with three variables tried at each split. The built model was found to be significant ($p < 0.05$) for both train and test data. The confusion matrix yielded an OOB error rate of 3.31% and 1.49% for train and test data, respectively. The model classified the animals with an accuracy of 97.98% (Supplementary Table 3) and 98.51% (Supplementary Table 4) for training and test data, respectively. The parameters called "no information rate" were estimated as 0.28 and 0.36 for the train and test confusion matrix, respectively. All these results suggest that the model has good accuracy with a low error rate. The kappa value was observed as 1.00 and 0.98 for the train and test data, respectively. This shows almost perfect agreement (0.81–1.0), which validates the accuracy of the model (Landis and Koch 1977). The importance components (Table 4) showed that body length, leg length, and wither height were the important traits that contributed to the variation that classified the animals. They were first selected based on the mean decrease accuracy, followed by the mean decrease gini values. This result corroborated the classification results of the CDA, in which body and leg length and wither height emerged as discriminating traits in the present study. This strongly reinforces the idea that these traits are very important to distinguish the indigenous goats of Odisha, India. A recent study predicted morphometric traits of Turkish goats, such

Table 3. Summary of final discriminative variables in the stepwise canonical discriminant analysis

Morphometric trait	Wilk's lambda	F value
Body length (cm)	0.036	179.725
Leg length (cm)	0.023	83.255
Height at wither (cm)	0.018	50.929
Paunch girth (cm)	0.015	27.758
Ear width (cm)	0.016	38.440
Ear length (cm)	0.015	28.634
Neck girth (cm)	0.013	12.618

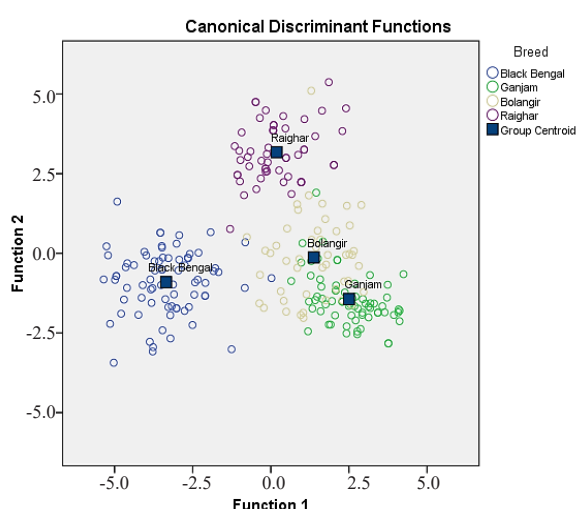


Fig. 3. Scatter plot of canonical discriminant analysis describing the classification of animals.

Table 4. Importance components and contribution of each morphometric variable to the random forest analysis

Trait	Black Bengal	Bolangir	Ganjam	Raighar	Mean decrease accuracy	Mean decrease gini
Height at withers (cm)	8.213	18.980	13.677	19.832	22.123	16.319
Height at rump (cm)	7.474	20.135	12.746	18.107	21.892	16.321
Neck girth (cm)	4.242	4.503	14.992	12.533	17.296	8.871
Heart girth (cm)	1.674	14.114	5.003	10.605	16.351	7.538
Paunch girth (cm)	4.657	14.560	8.990	9.563	17.093	8.220
Body length (cm)	31.628	21.138	36.390	20.578	41.582	35.655
Leg length (cm)	26.507	17.521	18.809	33.819	37.997	30.136
Ear length (cm)	2.218	5.059	7.262	5.060	9.314	2.915
Ear width (cm)	0.126	8.729	13.342	11.072	5.517	18.146

as rump width, chest girth, chest depth, and shinbone girth, using a random forest analysis (Erduran *et al.* 2024). Further studies should extend the random forest approach of the present study with larger sample sizes to classify as well as predict the morphometric traits (Erduran *et al.* 2024).

In conclusion, the present study phenotypically characterized the non-descriptive and indigenous goat population of Odisha, India, in which Raighar indigenous goats showed higher values of morphometric traits. The confirmational distinguishment of the goat population may be due to different agro-ecological zones and breeding practices followed by the farmers. The within-trait variation in goats calls for conservation efforts in their native tracts. From the results of the present study, RFA showed the potential to classify the animals; however, it should be warranted by future studies with large sample sizes. The various production traits of these goat populations should be studied to determine their potential within the system that will contribute to the identification of a commercial market as well as to the *in-situ* conservation of these animals. Thus, identifying these goat populations and registering them as breeds could be useful for better breeding policies and conservation of the germplasm that could contribute to the welfare of the farmers.

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