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Morphometric indices of native sheep breeds of the Himalayan region of India using multivariate principal component analysis

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Summary

This study was performed to analyze the morphometric traits and indices in 3000 animals of five registered sheep breeds in the Himalayan region under a multivariate approach. Data were recorded under field conditions with equal coverage of the five breeds, viz., Karnah, Gurez, Poonchi, Bakerwal and Changthangi on body length (BL), height at withers (HW), chest girth (CG), ear length (EL), and tail length (TL). Furthermore, four derived traits (indices) were studied, which included an index of body frame (IBF), an index of thorax development (ITD), a Baron–Crevat index (BCI), and an index of body weight (IBW). Multivariate principal component analysis (PCA) was undertaken on nine morphometric traits. Kaiser's criterion was used to reduce the number of principal components for further analysis and interpretation. The adequacy of sampling was evaluated using Kaiser–Meyer–Olkin (KMO) test and Bartlett's test of sphericity. The mean BL ranged from 52.15 (Changthangi) to 71.13 (Gurez). The estimates of HW, CG, EL and TL were highest in Gurez (63.49), Bakerwal (84.82), Bakerwal (7.26), and Karnah (8.18) breeds, respectively. Among the derived traits, the highest IBF was observed in the Gurez breed with an estimate of 112.22. Upon multivariate PCA on the dataset, the first four principal components were able to explain 92.117% of the total variance. The KMO test, Bartlett's test of sphericity and estimated communalities showed the appropriateness of PCA on the evaluated traits. Four eigenvalues were greater than one and were extracted for further analysis. Morphometric traits were highly correlated, except for EL and TL that showed lower correlation estimates with other traits. The Changthangi population showed the lowest estimates of BL, HW, CG and rectangular body frame. The present study ascertained important morphometric traits/indices that can help in developing selection criteria and formulating sustainable breeding and conservation plans vis-à-vis the unique sheep breeds of the temperate Himalayas.

Introduction

India is bestowed with an immense genetic diversity of major species of farm animals that have been reared for food to date. At present, India is home to 44 well documented sheep breeds that are an integral part of the rural agrarian economy, especially in hilly and mountainous areas. The total ovine population of India is 74.26 million (Anonymous, 2019). The UT of Jammu & Kashmir/Ladakh has five sheep breeds that are documented and registered with the national nodal agency for animal genetic resources (National Bureau of Animal Genetic Resources, 2020). These breeds include Karnah, Gurez, Bakerwal and Poonchi from the UT of Jammu and Kashmir; and Changthangi from the UT of Ladakh. Karnah sheep are reared mainly in Kupwara and adjoining areas of Kashmir Valley with its breeding tract located between 73°50′E and 74°40′E longitude and 34°15′N to 34°45′N latitude (Khan *et al.*, 2021a). Gurez are raised in Jammu and Kashmir's Bandipora district, with its breeding tract located between 74°40′E and 74°90′E longitude and 34°15′N and 34°45′N latitude (Khan *et al.*, 2021b). Similarly, Poonchi and Bakerwal breeds are reared mainly in areas of Poonch, Rajouri and adjoining districts of Jammu division of UT of J&K. Their breeding range is located between 32°58′N and 33°35′N latitude and 70°4′E and 74°4′E longitude (Khan *et al.*, 2021c). Changthangi sheep are raised in the valleys of Ladakh, with its breeding tract located between 320°N and 360°N latitude and 750°E and 800°E longitude (Khan *et al.*, 2021d).

Most of the sheep breeds of the temperate Himalayas are threatened by different factors that include low economic value, mechanization and indiscriminate crossbreeding. Karnah and Bakerwal sheep breeds have reached endangered status (Khan *et al.*, 2021a,c). Body conformation is a very important trait of meat animals (Yakubu and Mohammed, 2012). Evaluation of morphometric traits and indices will help to improve the efficiency of selection in mutton and dual-purpose breeds and thereby enhance the profitability of farmers (Valsalan *et al.*, 2020).

Similarly, ethnological functional indices are important parameters that help in the determination of breed characteristics and gain valuable insights into the type, purpose and performance aspects of evaluated breeds (Esquivelzeta *et al.*, 2011).

Principal component analysis (PCA) examines the relationships between multiple quantitative variables measured on a single object, reducing the number of variables under consideration to a small number of indices (called principal components) that are linear combinations of the original variables (Morrison, 1976). PCA results can be used to reduce the number of traits to be included in selection indices for improvement in the original traits (Karacaoren and Kadarmideen, 2008). PCA allows data to be viewed from different dimensions by combining the morphometric variables to produce indices or components that are uncorrelated (Manly, 1994). Keeping in view the above points, the present study was carried out to evaluate the linear morphometric traits and indices in five registered breeds of the temperate Himalayan region for selection and breeding purposes of elite animals.

Materials and methods

Data collection

The present study was conducted on 27,000 data points pertaining to nine traits in five indigenous registered breeds of sheep in Jammu and Kashmir and Ladakh. Data were collected on 3000 animals with equal coverage of five breeds, i.e. Karnah (Kupwara, Kashmir), Gurez (Bandipora, Kashmir), Poonchi (Poonch and Rajouri, Jammu), Bakerwal (Jammu) and Changthangi (Ladakh). These populations are reared in different geographic locations and experience different environmental and managemental conditions as follows:

- Bakerwal Sheep: The breed has no distinct home tract; entirely migratory, winter in the Pir Panjal ranges of the Jammu division, especially in Rajouri and a few in Udhampur, and in the summer they migrate to the Kashmir Valley, crossing the high mountain passes. Bakerwal sheep farmers spend the winter primarily in the Rajouri district and a few in Udhampur district of Jammu province (Table 3). The Bakerwal sheep are maintained by the farmers without any scientific management and breeding practices on depleted pasture. The sheep are mainly reared by the people for mutton and wool production. This sheep population is migratory in nature. Vaccination and dosing are regularly carried out by the Animal and Sheep Husbandry Departments.
- Changthangi Sheep: This sheep is mainly reared by a nomadic tribe called Changpa along with the pashmina-producing Changthangi goat. The economy of Changpas is largely dependent on animal rearing. It is reared for multiple purposes (mutton, wool, pelt, manure and dung energy). The breed is exclusively maintained through natural grazing during the summer. When the snow melts, nutritious clover sprouts in the pastures, but the sheep eat the dried surface grasses and some undersand herbs and shrubs after removing the top soil with their hooves. Vaccination and dosing are regularly carried out by the Animal and Sheep Husbandry Departments.
- Gurez Sheep: The sheep are reared by the Dardi Tribe of the Gurez valley of the Bandipora district. The Gurez valley is situated along the almost east-west flowing Kishan-Ganga river and embraces rough terrain of difficult accessibility. The valley encompasses over 57842 hectares of Himalayan mountain ranges. Vaccination and dosing are regularly carried out by the Animal and Sheep Husbandry Departments.
- Karnah Sheep: The breeding tract of the Karnah sheep breed was earlier in the entire Kupwara district and other adjoining regions of the valley. At present, the Karnah sheep breed is found only in Karnah Tehsil of Kupwara district. The narrow valleys and fine-edged mountains give this region a special ecosystem in the Kashmir Valley, which remains cut off from the major parts of Kashmir for 7–8 months because of snow cover in the long winters, which requires special housing for animals, while in summer, animals are on migration, where permanent houses are not feasible. The animals are flocked in the open, surrounded by logs or temporary stone- walls in grazing camps.
- Poonchi sheep: This sheep is locally known as Pahari and Desi sheep and is mainly reared by the nomadic communities of Jammu and Kashmir districts, namely Gujjar, Bakerwals and Pahari. Poonchi sheep are maintained by the farmers without any scientific management and breeding practices on depleted pasture. The sheep are mainly reared by the people for mutton and wool production. This sheep population is migratory in nature.

The study included five estimated and four derived traits (indices) on sheep maintained under field conditions. Body indices were calculated to infer the peculiar breed characteristics, body proportions, conformation, type and functional assessment of the studied breeds. Based on phenotypic appearance, the inheritance patterns of these animals varied from near-purebred to different levels of crossbred nature.

Data were recorded under field conditions on body length (BL), height at withers (HW), chest girth (CG), ear length (EL) and tail length (TL). Furthermore, four derived traits (indices) studied in these sheep populations included an index of body frame (IBF) or index of length, index of thorax development (ITD), Baron–Crevat index (BCI) or index of confirmation and index of body weight (IBW). IBF is considered the ethnological index of animals that provides information about the breed characteristics. Other derived traits (ITD, BCI and IBW) are considered functional indices that provide additional information about the type, purpose and performance of animals (Esquivelzeta *et al.*, 2011).

The measurements were taken using flexible measuring tape along with the following points:

- Body length (BL): Length from the manubrium of the sternum to the pin bone while the animal is properly restrained in a standing position.
- Height at withers (HW): Height measured from ground level to the top-most point of withers when the animal is standing on a flat levelled surface.
- Chest girth (CG): CG was taken as the circumference of the chest at the level of the 6th rib.
- Ear length (EL): Distance between the base of the ear to its tip on the dorsal surface.
- Tail length (TL): Distance between the base of the tail to its endpoint.
- Index of body frame (IBF): Calculated as the ratio of BL to wither height that is then multiplied by a factor of 100.

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Table 1. Summary of morphometric traits and indices in five evaluated breeds

	Mean ± SE					
Trait	Overall	Poonchi	Bakerwal	Gurez	Karnah	Changthangi
BL	60.28 ± 0.12	59.88 ± 0.10	60.71 ± 0.11	71.13 ± 0.10	57.53 ± 0.16	52.15 ± 0.12
HW	56.94 ± 0.10	54.68 ± 0.14	60.65 ± 0.13	63.49 ± 0.11	55.15 ± 0.13	50.72 ± 0.09
CG	81.58 ± 0.06	80.03 ± 0.10	84.82 ± 0.10	82.57 ± 0.11	80.65 ± 0.14	79.86 ± 0.10
EL	5.90 ± 0.03	7.06 ± 0.04	7.26 ± 0.04	4.40 ± 0.04	5.20 ± 0.04	5.60 ± 0.05
TL	5.65 ± 0.04	4.47 ± 0.04	3.91 ± 0.03	7.16 ± 0.07	8.18 ± 0.04	4.50 ± 0.04
IFW	106.0 ± 0.15	109.86 ± 0.29	100.36 ± 0.27	112.22 ± 0.23	104.59 ± 0.36	103.01 ± 0.30
ITD	144.35 ± 0.23	146.83 ± 0.34	140.21 ± 0.33	130.29 ± 0.29	146.66 ± 0.39	157.80 ± 0.36
BCI	117.75 ± 0.20	117.51 ± 0.30	118.99 ± 0.35	107.70 ± 0.36	118.43 ± 0.46	126.14 ± 0.40
IBW	57.16 ± 0.11	59.93 ± 0.18	54.47 ± 0.16	51.25 ± 0.10	55.24 ± 0.18	64.92 ± 0.20

BCI: Baron–Crevat Index; BL: Body length; CG: Chest girth; EL: Ear length; HW: Height at withers; IBW: Index of body weight;IFW: Index of body frame; ITD: Index of thorax development; TL: Tail length.

- Index of thorax development (ITD): ITD was calculated as the ratio of CG to wither height that is then multiplied by a factor of 100.
- Baron–Crevat index (BCI): Calculated as the ratio of the square of CG to wither height.
- Index of body weight (IBW): Calculated as the ratio of body weight to wither height that is then multiplied by a factor of 100.

Statistical analysis

Data were analyzed using the General Linear Model (GLM) procedure to elucidate the effect of breed on measured and derived traits among the five breeds under study. The statistical model for fixed-effect analysis of morphometric traits is given below:

$$Y_{ij} = \mu + B_i + e_{ij}$$

where, Y_{ij} is the observation of morphometric traits in *j*th animals of *i*th breed (five different populations), μ is the overall mean for the respective traits, B_i is the fixed effect of *i*th breed on morphometric traits and e_{ij} is the error/residual term associated with the measurements and overall analysis.

Pearson's coefficients of correlation between different traits were estimated to infer from the linear statistical relationship of different morphometric traits. Multivariate PCA with a correlation matrix was undertaken on nine morphometric traits using the SPSS (factor program) statistical package. Principal component analysis is a dimensional reduction technique that deals with correlated data and transforms it into orthogonal components that explain most of the variance in underlying traits. The number of principal components equals the number of traits under analysis. The first few principal components explain the higher variance, followed by subsequent principal components in order. Kaiser's criterion was used to reduce the number of principal components for further analysis and interpretation (Kaiser, 1960). Varimax orthogonal rotation procedure of principal components was done to enhance the interpretation process efficiently. Varimax rotation refers to the process of linear orthogonal transformation of factor solutions to simpler components and works on the maximization of column variance of the factor pattern matrix. The adequacy of sampling was evaluated using the Kaiser–Meyer–Olkin (KMO) test, which is considered a measure of sample adequacy during PCA and factor analysis. Bartlett's test of sphericity was used to test the validity of the dataset for factor analysis with a pre-set 1% level of significance. The communalities between different morphometric traits were also estimated. Eigenvalues and the proportion of variance explained by each principal component were determined.

Results and Discussion

The descriptive statistics (arithmetic mean with standard error and coefficient of variation) pertaining to various morphometric (estimated and calculated) traits are summarized in Table 1. The mean BL ranged from 52.15 (Changthangi) to 71.13 (Gurez). Gurez sheep possessed the longest body among the five breeds under study. The estimates of HW, CG, EL and TL were highest in Gurez (63.49), Bakerwal (84.82), Bakerwal (7.26), and Karnah (8.18) breeds, respectively. HW, CG, EL, and TL estimates were lowest in Changthangi (50.72), Changthangi (79.86), Gurez (4.40), and Bakerwal (3.91), respectively.

Changthangi breed showed the lowest average estimates of BL, HW and CG, which might be the reason for its adaptation to a cold and hypoxic environment. The BL of Karnah (57.53) was similar to that reported for adult Rampur–Bushair sheep by Sankhyan *et al.*, (2017) while that of Gurez sheep (71.13) was similar to that reported for Kajali sheep breed of India in an earlier study by Mishra *et al.* (2017). A higher BL of 77.5 has earlier been reported for Madgyal sheep by Yadav *et al.* (2016). Similarly, the average HW estimate of Gurez sheep was similar to that reported for Malpura sheep of India by Mehta *et al.* (1995). The average HW estimate of Bakerwal breed was similar to that reported for the adult Rampur–Bushair by Sankhyan *et al.* (2017).

The average CG estimates of Gurez (82.57) and Bakerwal (84.82) were comparable with those of Kajali and Madgyal sheep (Yadav *et al.*, 2016; Mishra *et al.*, 2017). The average CG estimate of other breeds was higher than that reported for the Rampur–Bushair and Malpura sheep breeds (Mehta *et al.*, 1995; Sankhyan *et al.*, 2017). The average EL of five evaluated breeds, ranging from 4.40 to 7.26 was comparable with that reported earlier for Malpura sheep (Mehta *et al.*, 1995). However, much larger estimates have been reported for other Indian sheep breeds, i.e. Rampur–Bushair, Kajali and Madgyal (Yadav *et al.*, 2016; Mishra *et al.*, 2017; Sankhyan *et al.*, 2017). The case was similar with the average TL estimate of five Himalayan breeds.

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Table 2. Pearson's correlation coefficient between morphometric traits and indices in evaluated breeds

	BL	HW	CG	EL	TL	IFW	ITD	BCI	IBW
BL	1.000	0.727	0.324	−0.207	0.262	0.542	−0.650	−0.458	−0.608
HW		1.000	0.457	−0.074	0.168	−0.180	−0.905	−0.637	−0.846
CG			1.000	0.128	−0.076	−0.079	−0.048	0.388	−0.356
EL				1.000	−0.482	−0.168	0.123	0.165	0.132
TL					1.000	0.153	−0.220	−0.230	−0.342
IFW						1.000	0.184	0.136	0.162
ITD							1.000	0.901	0.792
BCI								1.000	0.574
IBW									1.000

BCI: Baron–Crevat Index; BL: Body length; CG: Chest girth; EL: Ear length; HW: Height at withers; IBW: Index of body weight; IFW: Index of body frame; ITD: Index of thorax development; TL: Tail length.

Among the derived traits, the highest IBF was observed in the Gurez breed with an estimate of 112.22. Morphometric indices are useful to describe the body proportions and conformation of breeds using linear traits. As per the standard classification based on IBF estimates, Poonchi (average IBF = 109.86), Gurez (average IBF = 112.22), Karnah (average IBF = 104.59) and Changthangi (average IBF = 103.01) breeds showed a rectangular body frame (or long line) with an estimate exceeding 103, while the Bakerwal breed (average IBF = 100.36) showed a square body frame (estimate less than 103 but higher than 97).

The overall average IBF estimate was 106.01 covering all breeds. All breeds except Gurez showed excellent development of the thorax with estimates of 146.83, 140.21, 146.66 and 157.80 for Poonchi, Bakerwal, Karnah and Changthangi breeds, respectively. The ITD estimate for Gurez breed was only 130.29. The highest ITD estimate for Changthangi goat was consistent with the needs of this breed to survive cold and hypoxic conditions in its breeding tract (Ladakh). The overall average for five breeds was 144.35. Based on BCI estimates, Changthangi was the strongest breed among the five sheep breeds with an average estimate of 126.14. The BCI estimate was lowest for the Gurez breed showing the lowest strength among studied breeds. The average IBW of different breeds ranged from 51.25 in Gurez to 64.92 in Changthangi sheep, with an overall average of 57.16.

The total phenotypic correlation between different morphometric traits and indices is presented in Table 2. The highest positive correlation was found between ITD and BCI with an estimate of 0.901. Among the linear morphometric traits, the highest correlation was found between BL and height at withers (HW) with an estimate of 0.727. However, for linear morphometric traits, negative correlation estimates were recorded for BL-EL, HW-EL, CG-TL and EL–TL combinations (Table 2). Among positive-correlated linear morphometric traits, a high correlation ($r > 0.40$) was found for BL-HW and HW-CG combinations while it was moderate ($0.20 > r < 0.40$) for BL-CG and BL-TL combinations. All other positive-correlated traits had low estimates ($0 > r < 0.20$). All the correlations were found to be statistically significant ($P < 0.01$). The significant and moderate to high estimates of the phenotypic correlation between different morphometric traits suggested the need for PCA to reduce the dimensionality and convert the variables into orthogonal components. The traits showing positive correlation implied that these variables may be under similar genetic control, while different genes with probable antagonistic effects formed the basis of traits showing negative correlations (Semakula *et al.*, 2010). Positive and negative correlation estimates may be implemented judiciously in indirect selection programmes for these breeds. Similar to our results, Yadav *et al.* (2016) reported low correlation estimates for different combinations of TL and EL with other morphometric traits in Madgyal sheep. Lower estimates of the correlation of EL and TL with other morphometric traits have also been reported in Zulu sheep (Mavule *et al.*, 2013). These traits are reported to be determined mainly by non-additive genetic effects, and any selection based on these traits may not lead to a significant genetic response in traits of economic importance.

Multivariate PCA-based analysis has been undertaken on morphometric traits in several species to understand the relationship between evaluated variables and principal components (PCs) and evaluate the contribution of each PC in explaining the total variance in original traits (Salako, 2006; Yadav *et al.*, 2016; Araújo de Melo *et al.*, 2020; Valsalan *et al.*, 2020). Upon multivariate PCA on the dataset, the first four principal components were able to explain 92.117% of the total phenotypic variance. The individual contributions of the first four PCs were 45.027%, 18.856%, 16.749% and 11.485% with eigenvalues of 4.052, 1.697, 1.507 and 1.034, respectively. The first three components explained 80.632% of the variance, whereas more than 90% of the variance was explained by the first four PCs in the evaluated traits. Only the first four components showed eigenvalues greater than one, indicating their usefulness in explaining the underlying variance in evaluated traits compared with original variances. These components were extracted for further analysis. Table 3 presents the eigenvalues, percentage variance explained and cumulative variances explained by different PCs of linear morphometric traits and indices. The first principal component (PC1) showed large loading of ITD (0.949), HW (0.940), IBW (0.890), BL (0.787) and BCI (0.776). Conversely, EL (0.680), IFW (0.645) and TL (0.604) showed a large contribution/loading to PC2. Similarly, CG (0.750), IFW (0.575) and BCI (0.557) contributed largely to the loading of PC3, while PC4 was largely loaded by IL (0.497), IFW (0.495) and EL (0.463). Bartlett's test for adequacy of sampling showed a highly significant (chi-squared estimate of 58409.059, $P < 0.001$). The KMO measure of sampling adequacy was observed to be 0.559. This was concurrent with that of Kaiser (1974) who recommended an estimate of 0.5 and above for sample adequacy. Khargharia *et al.* (2015) reported KMO estimates ranging between 0.22 and 0.98 for different morphometric traits of Assam Hill goats. A KMO estimate of

Table 3. Total variance explained by different principal components, extracted and rotated components

PC	Initial eigenvalues			Extracted sum of squares loadings			Rotated sum of squares loadings		
	Total	% of variance explained	Cumulative % variance explained	Total	% of variance explained	Cumulative % variance explained	Total	% of variance explained	Cumulative % variance explained
1.	4.052	45.023	45.023	4.052	45.023	45.023	3.830	42.553	42.553
2.	1.697	18.853	63.876	1.697	18.853	63.876	1.544	17.154	59.707
3.	1.507	16.749	80.625	1.507	16.749	80.625	1.493	16.586	76.293
4.	1.034	11.489	92.114	1.034	11.489	92.114	1.424	15.822	92.114
5.	0.525	5.837	97.951						
6.	0.177	1.968	99.919						
7.	0.005	0.060	99.979						
8.	0.001	0.016	99.995						
9.	0.000	0.005	100.000						

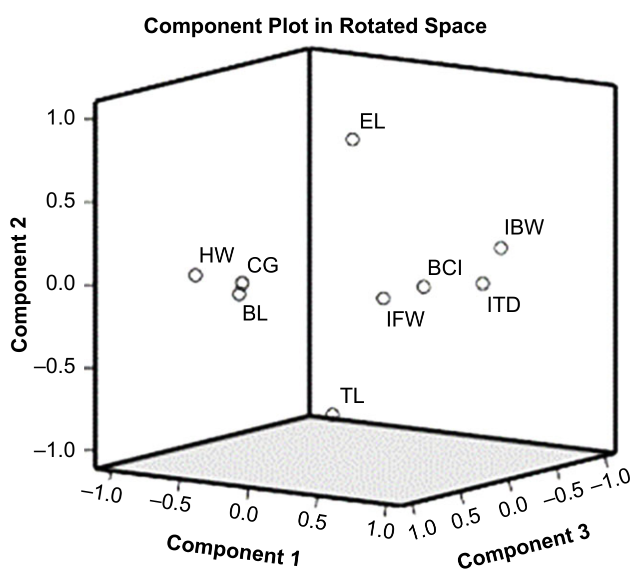

Figure 1. Component plot showing the distribution and clustering of different traits and indices in different planes.

greater than 0.5 revealed that considerable variation in underlying traits was caused by PCs. Bartlett's test revealed that the correlation matrix based on morphometric traits was significantly different from the identity matrix. It also showed the adequacy and suitability of data for factor analysis using PCA.

Upon 2D varimax rotation of PCs, the first three factors explained 76.295% of the total variance. When the first three rotated factors were plotted across components, four different clusters were formed, which stratified morphometric indices into one cluster (Fig. 1). Among linear morphometric traits, BL, CG and HW were clustered together. TL and EL traits were plotted separately and distant from each other and other clusters (Fig. 1). Most of the linear morphometric traits and indices showed high communality estimates, which indicated that underlying variance in these traits was shared between various variables. It also further stressed the usefulness of PCA on this dataset. Therefore, in breeding programmes for these sheep breeds, PCs with loadings from different traits can be used instead of using multiple traits individually (Yadav *et al*., 2016).

In conclusion, the PCA technique explored the interdependence of the original morphometric traits and indices simultaneously rather than individually. Morphometric traits were highly correlated, except for EL and TL. The KMO test, Bartlett's test of sphericity and estimated communalities showed the appropriateness of PCA on the evaluated traits. More than 90% of the total variance in evaluated traits was explained by the top four PCs. Morphometric traits (linear and indices) in the sheep breeds of the temperate Himalayas can be improved by loadings in top PCs. The study will be helpful in the selection of genetically elite animals, in developing sustainable breeding programmes to expedite genetic gains vis-a-viz sheep breeds of the temperate Himalayas.

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