

Morphometric and testicular trait variation reveal genetic diversity and selection opportunities in Tunisian sheep breeds under arid conditions

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Abstract

Sheep breeding in Tunisia still plays a key role in rural life and food security. This is true even in dry areas affected by climate change. In this study, we analyzed genetic diversity and breed differences using 35 morphometric traits. These traits included body (21) and testicular (5) measurements. We studied 55 rams raised in southern Tunisia. They were from two breeds: Barbarin and Queue Fine de l'Ouest (QFO), and one crossbred sheep population. The results showed clear differences between breeds. For example, Barbarin rams had a larger chest girth ($105.43 \text{ cm} \pm 10.02$), compared to QFO ($96.67 \text{ cm} \pm 9.44$) and crossbred sheep ($98.24 \text{ cm} \pm 15.20$). crossbred rams had the highest testicular circumference ($28.86 \text{ cm} \pm 3.90$), followed by Barbarin ($28.79 \text{ cm} \pm 3.29$), while QFO had the smallest ($21.50 \text{ cm} \pm 9.35$). Moreover, hierarchical clustering showed that most crossbred rams had larger bodies. In contrast, QFO rams were smaller and more uniform. In addition, some traits such as ear length ($p = 0.016$), hip width ($p = 0.038$), left testicle length ($p = 0.025$), and tail width ($p < 0.001$) showed significant breed differences. Post-hoc tests confirmed that QFO and crossbred sheep differ in testicle length. The clustering dendrogram, heatmap, discriminant analysis, and principal component analysis grouped the animals into three main clusters. Moreover, we observed high variation in Barbarin sheep breed. This could be useful for future selection programs. Finally, since many traits are correlated (example chest width and body heights), targeting such key traits, in selection programs, may improve several at once. Therefore, morphometric and testicular measurements are useful tools for describing breeds, identifying resilient animals, and supporting breeding and conservation in harsh Tunisian environments.

Keywords Arid environment, clustering, Morphometric variation, Phenotypic characterization, sheep, Testicular traits, Tunisia

Introduction

Sheep breeding plays an important socioeconomic role and contributes to food security. However, sheep production is affected by climate variability, particularly changes in rainfall patterns (Mohamed-Brahmi et al., 2024). The Tunisian sheep population decreased from 6.5 million heads in 2016 to 3.7 million in 2017 and reached about 4.6 million heads in 2022 (INS, 2022). The Barbarin is the main fat-tailed sheep breed in Tunisia, while Queue Fine de l'Ouest (QFO), Noire de Thibar and Sicilo Sarde are also important native breeds (Kdidi et al., 2015; Khaldi et al., 2011). However, crossbreeding between Tunisian sheep breeds has contributed to genetic admixture, particularly between Barbarin and QFO (Kdidi et al., 2015; Ben Jemaa et al., 2019). Therefore, the characterization and conservation of local sheep genetic resources are important under changing production systems. In this context, morphometric traits such as body length, body height and chest circumference provide useful information on phenotypic variation and can help characterize sheep populations (Khaldi et al., 2011; Nunes et al., 2020; Rinaldi et al., 2024). Moreover, these traits can be related to body weight and growth performance, making them useful for selection and breeding programs (Arvandi and Nugartiningasih, 2024).

Testicular morphometric traits, particularly scrotal circumference and testicular volume, are useful indicators of reproductive development and potential in rams. Testicular volume is closely associated with sperm production. In fact, Montes-Garrido et al. (2023) reported strong positive correlations between total testicular volume and sperm production in Assaf rams. Similarly, Moulla et al. (2018) showed that testicular growth was associated with the progression of sexual maturation and changes in seminal characteristics in Tazegzawt ram lambs. Recent genetic evidence also indicates substantial heritable variation in scrotal circumference in sheep, supporting its potential use as a complementary criterion for the early evaluation and selection of young rams (Ma et al., 2024).

In Tunisia, several studies have investigated body morphometric traits in local sheep breeds; however, information on crossed sheep populations and testicular morphometric traits remains limited. Therefore, this study aimed to characterize the body and testicular morphometric traits of sheep raised in southern Tunisia, including local breeds and a crossed population.

Material and methods

Study Area and data collection

We conducted this study in the region of Southern Tunisia; it belongs to arid geographic part of Tunisia (Table 1). The climate is hot and dry, with annual rainfall below 200 mm. We selected 55 unrelated male sheep from three breeds (Figure 1): Barbarin ($n = 19$), crossed (Barbarin $\times$ Queue Fine de l'Ouest, $n = 27$), and Queue Fine de l'Ouest (QFO, $n = 9$), the age of all studied males is higher than 7 months. The number of animals included in this study is limited due to several factors. First, the sheep population in Tunisia has decreased significantly because of continuous years of drought, as described in the introduction. In addition, lambs are highly demanded for meat consumption and the religious festival Aid El-Edha, which reduces the availability of older animals. Because of these reasons, it was difficult to find unrelated rams older than 7 months. These breeds were chosen because they represent local genetic diversity adapted to arid conditions. The sheep belonged to smallholder farmers practicing intensive or semi extensive farming system. We sampled the animals during February–April 2025 to avoid seasonal effects on morphology. Farmers were informed about the study, and their consent was obtained before sampling.

Data Collection and Measurement Protocols

We measured 26 morphometric traits on each sheep, focusing on both body and testicular traits. The traits included head length (LT), head width (LTH), ear length (LO), neck length (LC), neck length in the downstream part (LC1), body length (Lcrps), pelvis length (LB), hip width (LH), ischial width (LISH), scapulo-ischial length (LSI), chest girth (TP), chest depth (PR), chest width (LP), height at withers (HG), height at back (HD), height at sacrum (HS), flank depth (PF), wool length at flank (LPI), cannon bone circumference (TCA), tail length (LQ), tail maximal width (LrQ), scrotal circumference (CS), testicle length (Ltest), testicle right length (LTr), and testicle left length (LTI). We also recorded qualitative traits such as coat color, presence of horns, beard, wattles, ear position, head profile, and dorsal line, but these were not used in the quantitative analyses (Figure 2).

We followed the standard protocols for sheep morphometrics (FAO, 2012), when taking measurements. For All measurements, we used a flexible measuring tape (in centimeters). All measurements were taken and recorded to the nearest 0.5 cm. To guarantee precision and reduce stress, the technician ensures to held the sheep in a standing position and on level ground when the researcher is taking the measurements. The researcher examined the dental and inquired the farmer for age determination. The data are entered and stored using Rumetrics program (Kdidi et al., 2025).

Data cleaning and preparation

The data cleaning resulted on the data (ID, breed, age, 26 morphometric traits, and qualitative traits) of 55 sheep.

Table 1. Geographic location and coordinates and sample sizes of studied sheep in southern Tunisia.

Locality	Governorate	Latitude	Longitude	N
Aziza	Medenine	33.3430	10.4989	1
Bedoui	Medenine	33.5190	10.5563	1
Bir Lahmer	Tataouine	~33.1786	10.4421	2
Bir Zouari	Gafsa	34.5506	8.8488	6
Beni Ghzaïel	Medenine	33.2675	10.4425	2
Beni Hamed	Tataouine	33.3770	10.5375	3
Chahbania	Medenine	33.2534	10.8374	1
Dar Dhaoui	Medenine	33.2931	10.7825	1
Darghoulia	Medenine	33.3888	10.6228	1
Dhafer	Medenine	33.2397	10.1115	1
Dkhila	Medenine	33.2643	10.3230	1
El Argoub	Tataouine	33.10704	10.35393	2
El Bhayer	Kebeli	33.7902	8.7773	4
El Gattar	Medenine	33.3510	10.4581	1
ELFja	Medenine	33.4986	10.6443	1
ElHezma	Medenine	33.2927	10.5309	7
Kassar Aoun	Tataouine	32.8711	10.88389	4
Mkassem 1	Gabes	33.8350	10.1136	1
Msareb	Tataouine	32.8488	10.5066	3
Oum Chyah	Kebeli	33.3120	9.7455	2
Ouerjijen	Medenine	33.21185	10.36253	1
Rass ElOued	Tataouine	32.75631	10.24747	4
Sidi Makhoulf	Medenine	33.5298	10.4871	1
Oued Ghafou	Kebeli	33.7148	9.0221	1
Oued Erbayaa	Medenine	33.1992	10.9334	1
Oued Seder	Medenine	33.41338	10.75233	1
Zarzis	Medenine	33.5022	11.0693	1

N: number of animals

Table 2: Descriptive statistics of morphometric traits across studied sheep breeds

Variable	Barbarin				QFO				Crossed			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Age	3.05	1.90	1.5	8	3.00	1.41	2	4	3.64	2.02	2	8
LTI	12.50	3.44	8	19	14.33	2.94	12	19	12.50	2.99	7	18
LT	22.21	2.15	17	25	20.67	1.75	19	24	22.81	2.23	19	27
LTH	7.42	0.93	6	9	8.00	0.00	8	8	8.03	1.44	6	12
LO	15.32	2.03	13	20	16.67	1.97	15	20	16.57	2.16	14	24
LC	28.14	3.78	23	36	27.50	2.43	24	31	26.90	2.83	21	33
LC1	31.79	3.85	25	37	30.17	3.87	27	37	30.02	3.49	23	37
Lcrps	74.00	5.66	65	82	71.67	3.83	67	76	78.00	9.60	61	95
LB	19.43	2.68	13	22	19.17	5.00	15	29	19.79	2.91	15	25
LH	26.50	7.67	21	51	18.83	2.14	15	21	24.57	6.15	18	40
LISH	21.00	7.47	14	45	16.00	2.10	13	19	19.00	5.44	13	37
LSI	78.00	7.74	59	91	73.00	6.45	68	85	79.21	9.03	65	105
TP	105.43	10.02	82	120	96.67	9.44	85	113	98.24	15.20	47	122
PR	44.07	4.76	33	51	42.67	2.16	40	45	44.24	5.51	34	52
LP	93.07	9.16	72	104	80.50	10.80	70	98	87.26	9.90	67	103
HG	81.50	6.30	71	95	82.50	5.68	77	90	84.17	8.89	66	99
HD	83.21	5.67	72	93	83.67	4.76	79	91	84.74	7.46	71	96
HS	85.86	5.92	74	95	85.50	4.93	82	94	85.88	8.72	68	95
PF	46.57	6.05	36	55	41.33	1.97	39	44	44.76	4.98	37	55
LPI	12.32	5.06	6	24	6.50	1.87	4	9	7.79	2.56	3.5	15
TCA	9.61	0.63	8	10.5	9.33	0.68	8	10	9.71	0.68	9	11
LQ	53.14	7.69	33	65	41.67	3.39	36	46	51.38	8.30	35	70
LrQ	23.07	6.49	13	34	9.17	1.72	7	12	15.62	5.69	8	29
CS	28.79	3.29	24	33	21.50	9.35	10	33	28.86	3.90	20	35
Ltest	10.29	1.33	8	12	17.33	11.88	9	35	10.62	2.40	8	20
LTr	10.69	2.50	7	16	11.33	2.66	8	14	12.78	2.69	8	18

SD : standard Deviation, Min : minimum, Max : maximum



Fig 1 : sheep populations: (A) Queue Fine de l'Ouest, (B) Barbarine, and (C) crossbred sheep.

Statistical Analysis

All statistical analyses were performed using R software version 4.4.3. First, we checked normality with the Shapiro-Wilk test and homogeneity of variances with Levene's test ($p < 0.05$). Morphometric traits were compared among breeds using one-way ANOVA for normal data with equal variances, Welch ANOVA for normal data with unequal variances, and Kruskal-Wallis test for non-normal data. Moreover, these tests were followed by post-hoc tests: Tukey HSD for ANOVA and Dunn's test for Kruskal-Wallis. In addition, Canonical Discriminant Analysis (CDA) was conducted using the candisc package, including all 26 morphometric traits as variables and breed as the grouping factor. Therefore, trait correlations were explored using Pearson's coefficients and visualized as a network, applying the corrr and igraph packages, with missing data handled by pairwise complete observations.

Results and discussion

Descriptive Statistics for morphometric and testicular traits

Descriptive statistics for morphometric and testicular traits across Barbarin, QFO, and crossbred sheep breeds are summarized in Table 2. In Barbarin rams, mean age was 3.05 ± 1.90 years (range: 1.5–8.0 years), with body length (Lcrps), chest girth (TP), and testicular circumference (CS) averaging 74.00 ± 5.66 cm, 105.43 ± 10.02 cm, and 28.79 ± 3.29 cm, respectively. Most body measurements in Barbarin exhibited moderate variability and relative homogeneity. QFO rams had a mean age of 3.00 ± 1.41 years (range: 2.0–4.0 years), Lcrps of 71.67 ± 3.83 cm, TP of 96.67 ± 9.44 cm, and a lower CS of 21.50 ± 9.35 cm. QFO sheep generally displayed uniform morphometric measurements, however, specific testicular parameters (e.g., Lttest) exhibited higher variation. Crossbred animals presented a mean age of 3.64 ± 2.02 years (range: 2.0–8.0 years), recording the highest head length (LT: 78.00 ± 9.60 cm), TP of 98.24 ± 15.20 cm, and CS of 28.86 ± 3.90 cm. Overall, crossbred sheep demonstrated the greatest overall phenotypic variability, QFO sheep were the most uniform, while Barbarin sheep displayed intermediate values across most metrics.

The differences in variability observed among populations may reflect differences in age structure, origin, and genetic background. Similar variation in morphometric traits has been reported among sheep populations, where age, breed and environmental conditions can influence body measurements (Markos et al., 2023). In Tunisian Barbarin sheep, morphometric traits were also reported to show different relationships according to age, confirming the importance of considering age when interpreting body measurements (Megdiche and Ben Hamouda, 2021).

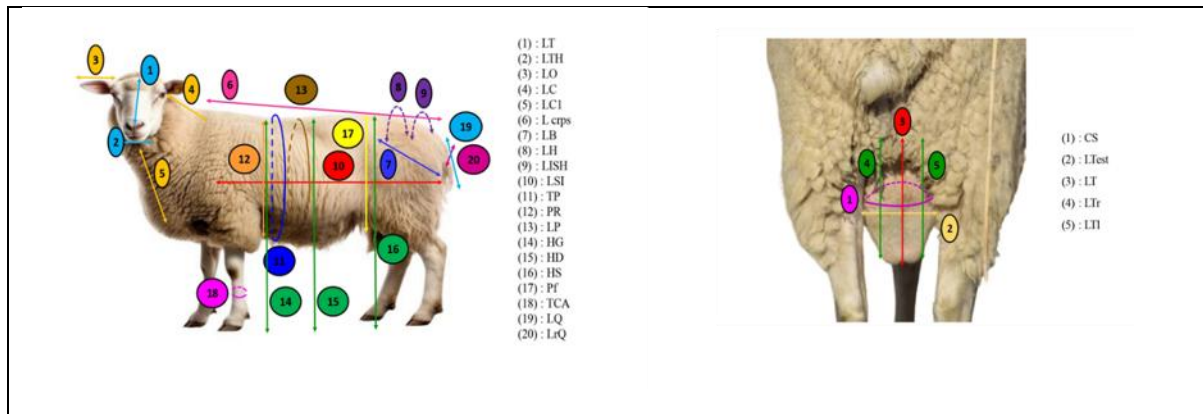


Fig 2. (A) Morphometric Measurements of Body Traits in Sheep, (B) Morphometric Measurements of Testicular Traits in Sheep

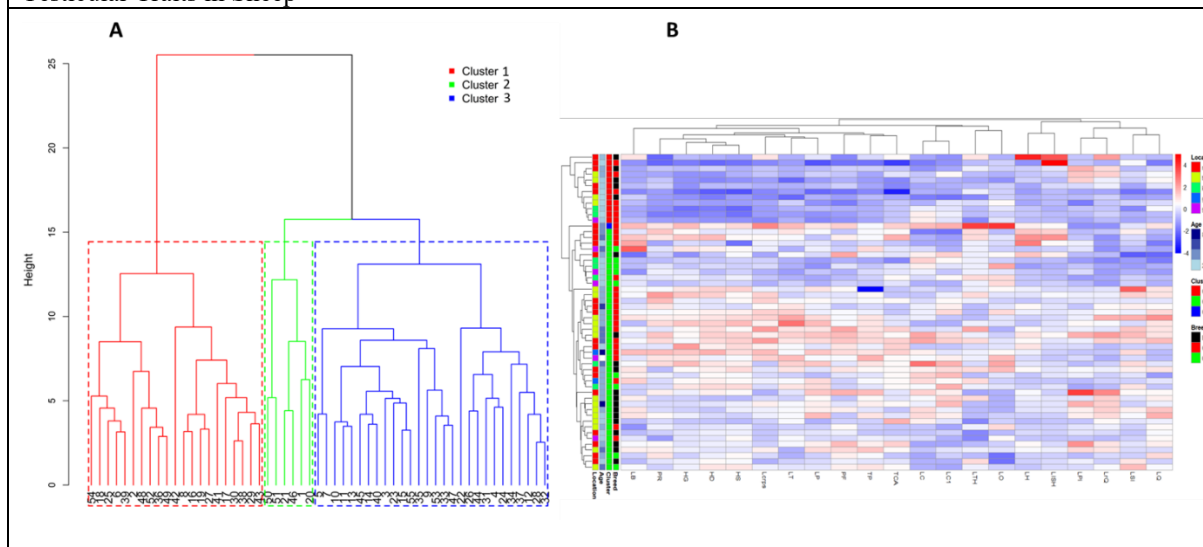


Fig 4. (A) Hierarchical clustering dendrogram of studied sheep based on morphometric traits (Ward's D2 method, k=3). Clusters are indicated by colored boxes (Cluster 1: red, Cluster 2: green, Cluster 3: blue), (B) Heatmap of Morphometric Traits with Breed, Cluster, Age, and Location Annotations across studied individuals which are clustered hierarchically

Distribution of qualitative traits

Distribution patterns for categorical traits are shown in Figure 3. In this regard, we considered the white-creamy color as white. Fleece color was predominantly white across all studied animals: QFO (83%), crossbreds (>75%), and Barbarin (75%). Barbarin and crossbred sheep exhibited greater fleece color diversity than QFO. Head coloration varied by breed; white-black (wbl) and white-black-brown (wblbr) patterns were predominant in Barbarin (~30% each), whereas white heads prevailed in crossbreds (>40%) and QFO (where black heads comprised 11%). Brown eye color dominated in Barbarin and QFO (80%), whereas crossbreds showed higher yellow eye frequencies (>30% vs. 60% brown). Facial marks were predominantly absent across all breeds (QFO: 100%; Barbarin and crossbreds: ~87% each). Horn presence was elevated in Barbarin (79%) and crossbreds (75%), but they were mostly absent in QFO (68%). Beards were generally absent across all populations. Ear position differed distinctly: Barbarin showed 60% drooping ears, crossbreds displayed 50% semi-erect ears, and QFO had 55% drooping ears. Head profile analysis revealed balanced convex and straight profiles in Barbarin (>32%), convex/concave-line profiles in crossbreds (~40%), and a predominantly convex/concave profile in QFO (>60%). Dorsal line contours showed high variation: Barbarin exhibited high concave/convex frequencies (47 and 30%, respectively), crossbreds had 35% straight backs, and QFO presented equal proportions of concave and straight lines (45% each).

The observed differences in qualitative traits provide additional information for the phenotypic characterization of the three populations. Such qualitative characteristics, together with quantitative morphometric traits, are commonly used to describe QFO Barbarin and crossbred animals may also reflect the different genetic backgrounds present in these populations.

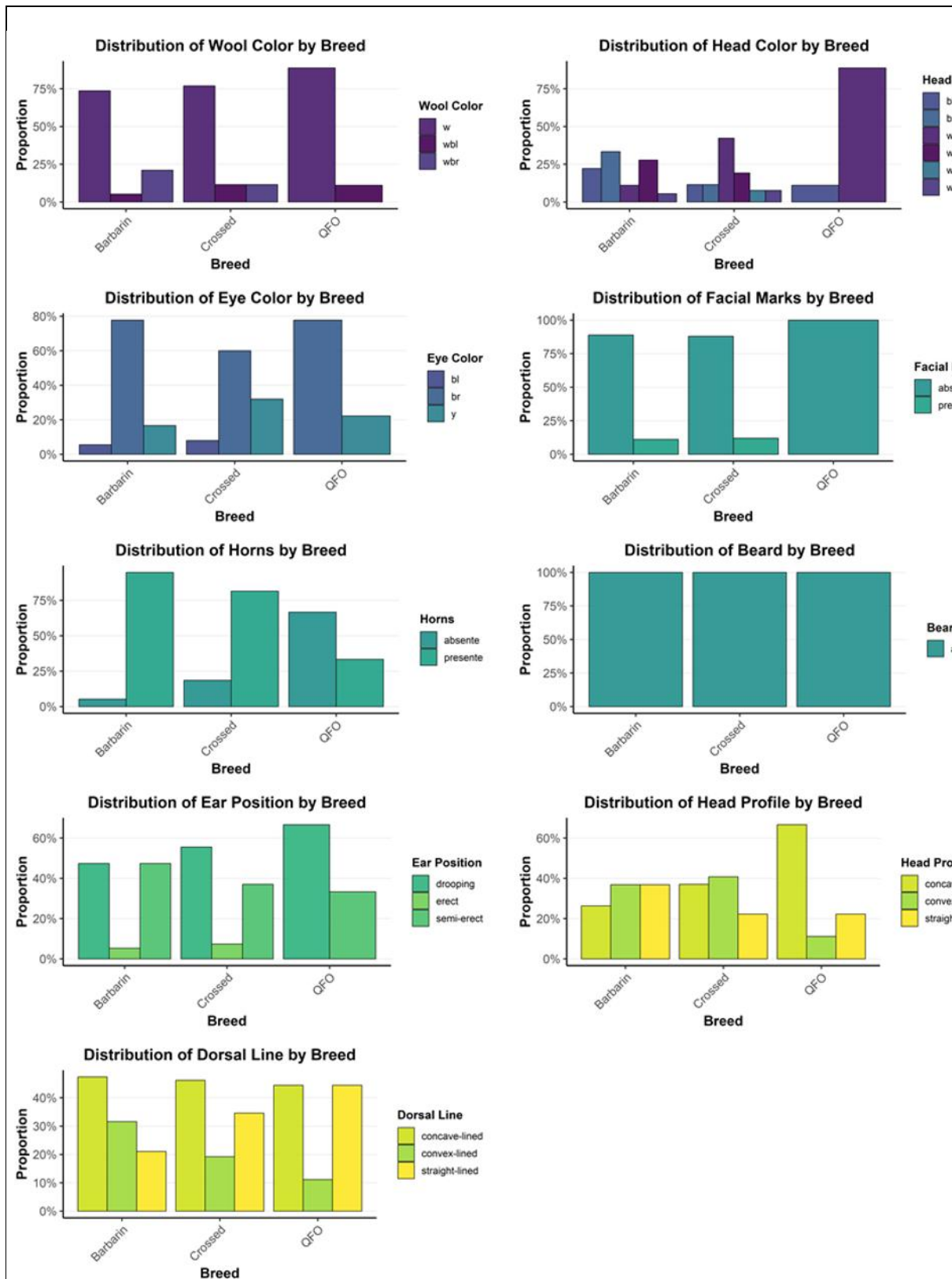


Fig 3. Distribution of categorical traits by sheep breed (Barbarin, crossed, and QFO) based on wool color, head color, eye color, facial marks, horns, beard presence, ear position, head profile, and dorsal line in a sample of 55 rams. br : brown , w : white, bl: black., y: yellow.

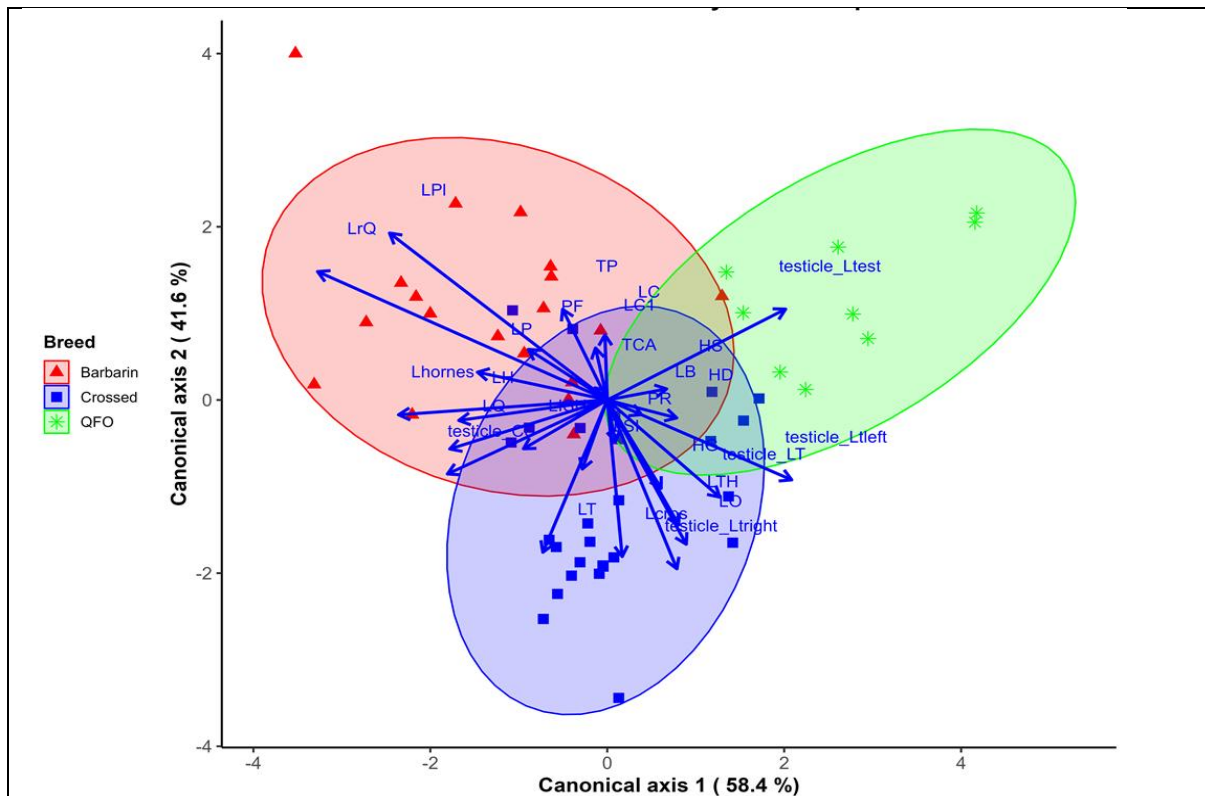


Fig 5. Canonical Discriminant Analysis (CDA) plot illustrating the morphological differentiation among three sheep breeds.

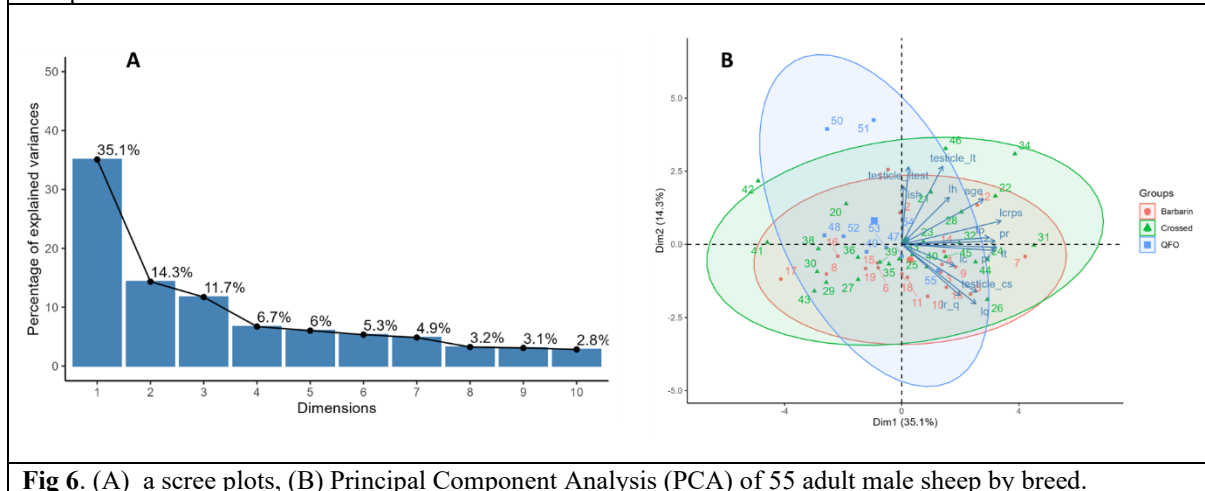


Fig 6. (A) a scree plots, (B) Principal Component Analysis (PCA) of 55 adult male sheep by breed.

Normality and differences among populations

Normality evaluation across 28 continuous variables indicated that 15 traits (53.6%; HD, HG, LB, LC, LC1, LP, LQ, LSI, LT, Lcrps, PF, PR, Ltl, and LTr) were normally distributed ($p \geq 0.05$; Supplementary Table 1, Supplementary Figure 1). Conversely, 13 variables (46.4%; Age, HS, LH, LISH, LO, LPI, LTH, Lhones, LrQ, TCA, TP, CS, and Ltest) departed significantly from normality ($p < 0.05$). ANOVA and Kruskal-Wallis tests revealed significant inter-breed differences for six traits (Supplementary Table 2): LO, LH, LPI, Lhones and Ltl. Other parameters, such as LT ($p = 0.102$), LC ($p = 0.714$), and HG ($p = 0.415$), showed no significant differentiation among breeds.

Post hoc grouping confirmed that all three breeds shared the same statistical group ('a') for most morphometric traits (LT, LTH, LO, LC, LC1, Lcrps, LB, LH, LISH, LSI, TP, PR, LP, HG, HD, HS, PF, LPI, TCA, LQ, LrQ, Lhones, CS, and Ltest). However, significant separation occurred in testicular metrics. For LTr, crossbred–Barbarin and QFO–Barbarin pairs shared group 'ab', while QFO–crossbred separated into group 'b'. For Ltl, QFO assigned to group 'a', crossbreds to group 'b', and Barbarin took group 'ab'. These patterns highlight significant testicular trait differentiation between QFO and crossbred rams, with Barbarin maintaining an intermediate phenotype.

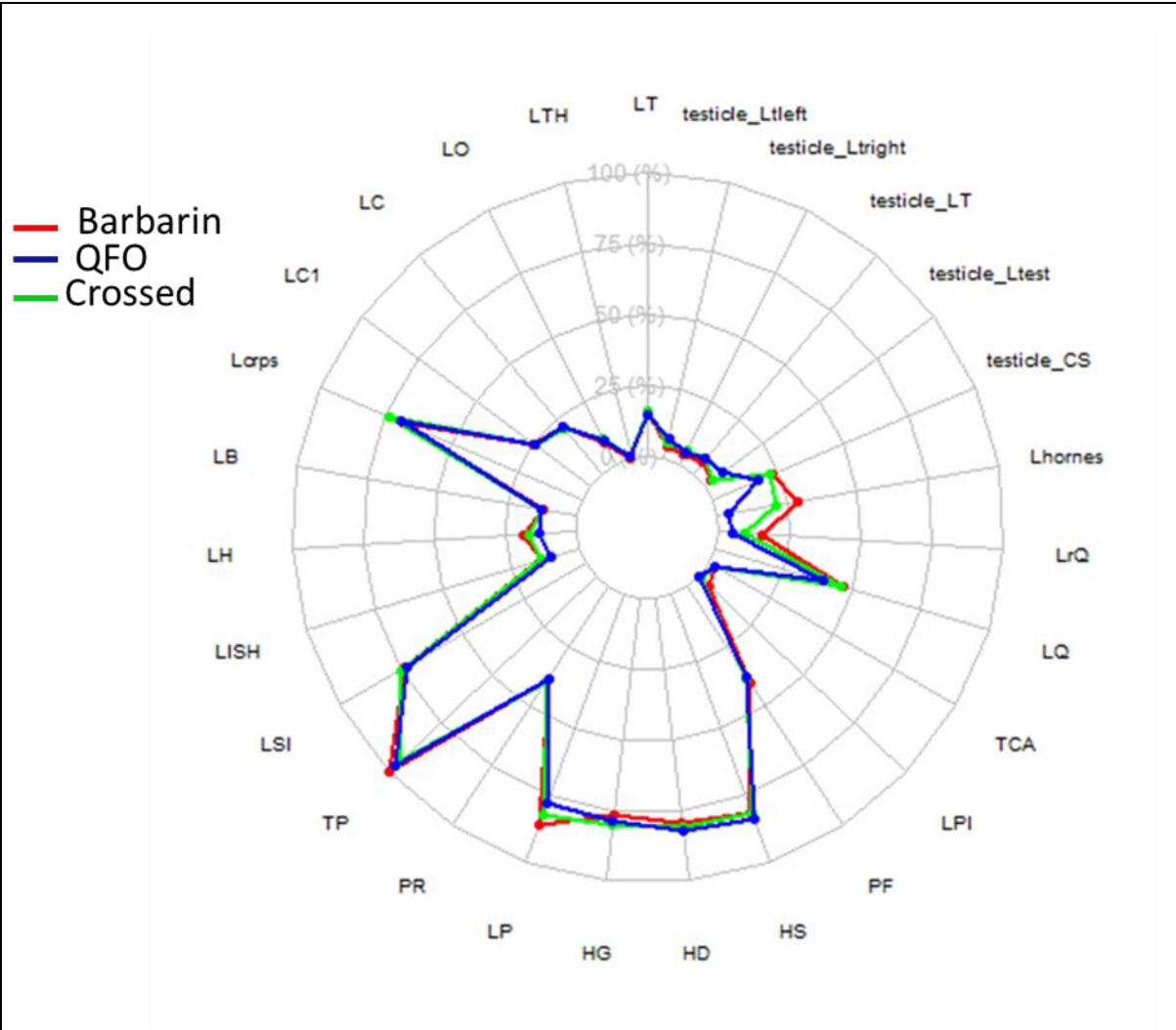


Fig 7. Radar plot illustrating the mean standardized values of morphological and testicular traits for three sheep breeds

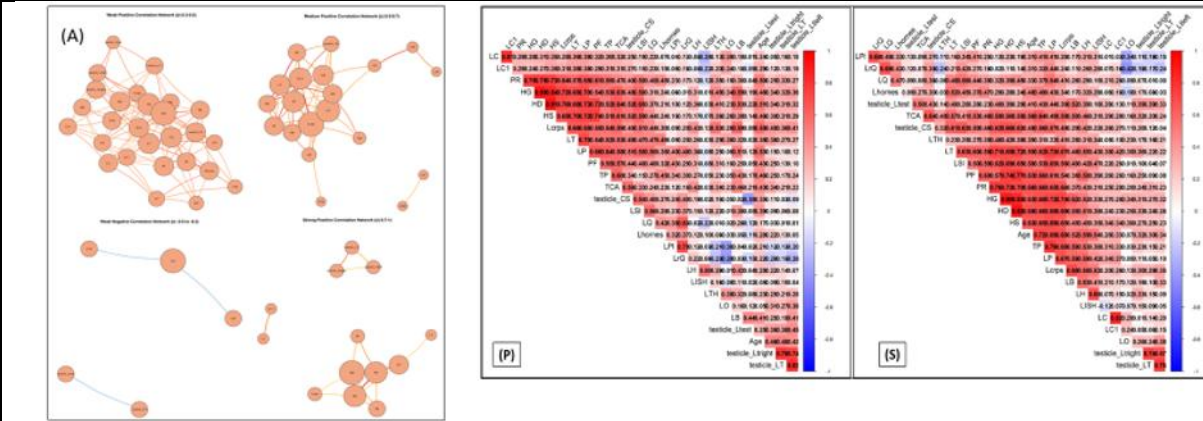


Fig 8. A: Trait correlation networks of morphometric traits, Nodes represent traits, and edges represent Pearson's correlations. And two correlation heatmaps:(P) Pearson's correlation coefficients among morphological and testicular variables for the studied sheep population; (S) Spearman's rank correlation coefficients for the same set of traits.

The limited number of traits showing significant differences suggests that the three populations share many common body dimensions. Similar results have been reported in sheep morphometric studies, where several body measurements showed high similarity among populations while some specific traits were more useful for differentiation (Nunes et al., 2020). The significant differences observed for LrQ, Lhorns and Ltl may therefore provide useful traits for phenotypic characterization of these populations. For the testicular traits, the differences between QFO and crossbred rams are also of interest because testicular size is related to reproductive development and sperm production in rams (Moulla et al., 2018; Montes-Garrido et al., 2023). However, these differences should be interpreted with caution because testicular measurements can also be affected by age and other environmental factors.

Hierarchical clustering

Hierarchical clustering resolved three main phenotypic groups based on morphometric dimensions (Figure 4A, 4B). Cluster 1 contained smaller-framed individuals; Cluster 2 grouped medium-to-large animals (elevated chest depth [PR] and body length [Lcrps]); and Cluster 3 comprised larger-framed sheep. Inter-breed overlapping was observed within clusters. Barbarin sheep spanned Clusters 1 and 2, reflecting wide adaptive variation. Crossbreds formed Cluster 2 exclusively, suggesting hybrid vigor for frame size, whereas QFO sheep clustered predominantly in Cluster 2. Age and geographical origin also influenced clustering: older sheep were concentrated in Cluster 2, younger animals in Cluster 1, Kebili sheep exhibited small-to-medium sizes, and Medenine animals displayed larger body frames.

The overlap observed between populations indicates that the three groups cannot be completely separated using body dimensions alone. The concentration of older animals in Cluster 2 also agrees with the known effect of age on sheep morphometric measurements (Markos et al., 2023). Therefore, clustering appears to reflect not only population differences but also variation in age and geographical origin. The position of crossbred animals mainly in Cluster 2 may reflect the combination of morphological characteristics inherited from their parental populations. However, this pattern should not be interpreted directly as evidence of heterosis without appropriate genetic or performance data.

Canonical discriminant analysis and principal component analysis

Canonical Discriminant Analysis (CDA; Figure 5) effectively separated Barbarin, QFO, and crossbred populations with minimal overlap. Canonical Axis 1 accounted for 58.4% of total variation, while Axis 2 explained 41.6%. Barbarin discriminated leftward along vector loadings for LrQ and Lhorns, QFO shifted rightward driven by testicular dimensions (Ltest and Ltl), and crossbreds clustered downward associated with body length (LT and LCRPS). Principal Component Analysis (PCA; Figure 6A, 6B) showed that dimension 1 explained 35.1% of overall variance, decreasing to 2.8% by dimension 10. The separation observed between the populations was mainly associated with differences in body and testicular measurements. This agrees with previous studies showing that multivariate analyses can be useful for the phenotypic characterization and differentiation of sheep populations (Nunes et al., 2020; Sarma et al., 2024). The partial overlap between Barbarin and QFO in the PCA may also be consistent with the historical and genetic relationships among Tunisian sheep populations reported in previous studies (Kdidi et al., 2015).

Radar plot

Radar visualization (Figure 7) confirmed high LrQ and Lhorns in Barbarin, superior Ltest and Ltl in QFO, and maximum overall body dimensions (LT, Lcrps) with lower variance in crossbreds. The higher testicular measurements observed in QFO for Ltest and Ltl are particularly relevant because testicular biometry has been associated with reproductive characteristics in rams. Hasani Al-Ameri (2022) reported age-related changes in testicular weight, length, width and diameter in Awassi rams, together with changes in spermatozoa concentration. In addition, Montes-Garrido et al. (2023) reported positive relationships between total testicular volume and sperm production in rams.

Correlation analysis

Advanced statistical analyses like correlation matrices allow to identify key traits for genetic improvement (Markos et al., 2023). Our correlation matrices, resulted in the two heatmaps represented in Figure 8 (P) and (S) and Trait Correlation Network displayed in the Figure 8 (A), show strong positive relationships between several body size traits such as body length, chest circumference, and height. Moreover, other central traits like LT, Lcrps, and LQ have many strong connections. These findings indicated their importance in genetic selection of breeds. In fact, morphometric traits are strongly correlated with production and reproductive performance (Sarma et al., 2024). Moreover, testicular measurements are highly correlated with each other. According to Hasani Al-Ameri (2022) such measurements are of an interest for predicting male fertility and optimizing ram selection. In addition, some negative correlations, such as between ear length and tail maximal width, suggest possible trade-offs that are important for breeding decisions.

Conclusion

Morphometric and testicular characterization provides an accessible and cost-effective strategy for differentiating Tunisian sheep populations and identifying key traits for breeding programs.

Declaration of competing interest The authors declare that there are no conflicts of interest regarding the publication of this article.

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References

- 1) Al-Kawmani AA, Alfuraiji MM, Abou-Tarboush FM, Alodan MA, Farah MA, 2014. Developmental changes in testicular interstitium in the Najdi Ram Lambs. *Saudi Journal of Biological Sciences* 21(2): 133–137. doi.org/10.1016/j.sjbs.2013.09.001
- 2) Arvandi FD, Nugartiningih VA, 2024. Correlation between morphometric traits and body weight in fat-tailed sheep. *BIO Web of Conferences* 88: 00026. doi.org/10.1051/bioconf/20248800026
- 3) Ben Jemaa S, Kdidi S, Gdura AM, Dayhum AS, Eldaghayes IM, Boussaha M, et al., 2019. Inferring the population structure of the Maghreb sheep breeds using a medium-density SNP chip. *Animal Genetics* 50(5): 526–533. doi.org/10.1111/age.12831
- 4) Djimon AM, Offoumon OTLF, Worogo HSS, Worogo JSBS, Alabi CAD, Idrissou Y, Soulé F, Alimi N, Yacoubou AM, & Assani AS (2024). Profitability of sheep farming in Benin. *Journal of Livestock Science*, 15, 267-275. https://doi.org/10.33259/JLivestSci.2024.267-275
- 5) Hasani Al-Ameri M, 2022. Evaluation of testicular biometry and spermatozoa recovered after slaughter from cauda epididymal of Awassi ram. *Archives of Razi Institute* 77(6): 2329–2334. 10.22092/ari.2022.358950.2338
- 6) INS, 2022. Institut National de la Statistique (Tunisia): Statistics page 87. Accessed 2025.
- 7) Kdidi S, Calvo JH, González-Calvo L, Sassi MB, Khorchani T, Yahyaoui MH, 2015. Genetic relationship and admixture in four Tunisian sheep breeds revealed by microsatellite markers. *Small Ruminant Research* 131: 64–69. doi.org/10.1016/j.smallrumres.2015.08.012
- 8) Kdidi S, Halmous O, Hajji H, Dbara M, Hammadi M, Khorchani T, Najari S, Yahyaoui MH, 2025. Rumetrics: a digital solution for precision livestock data management and genetic selection in developing countries. *Farm Animal Health and Nutrition* 4(2): 21–27. https://doi.org/10.58803/fahn.v4i2.75
- 9) Khaldi Z, Haddad B, Souid S, Rouissi H, Gara AB, Rekik B, 2011. Caractérisation phénotypique de la population ovine du sud-ouest de la Tunisie. *Animal Genetic Resources/Recursos Genéticos Animales* 49: 1–8. doi.org/10.1017/S2078633611000361.
- 10) Ma Z, Wang W, Zhang D, Wang X, Li S, Zhao L, Zhang Y, Li X, Lin C, Cheng JWJ, Xu D, Yang X, Huang Y, Cui P, Liu J, Zeng X, Zhai R, Huang Z, Weng X, Zhang X, 2024. Polymorphism in IGFALS gene and its association with scrotal circumference in Hu lambs. *Animal Biotechnology*. 35(1): 2295928. doi.org/10.1080/10495398.2023.2295928
- 11) Markos D, Masho W, Baye M, Bayou E, 2023. Morphometric traits and stepwise regression of indigenous sheep in southwestern region, Ethiopia. *Journal of Agriculture and Food Research* 14: 100666. 10.1016/j.jafr.2023.100666
- 12) Megdiche S, Ben Hamouda M, 2021. The Tunisian barbary sheep: correlations among morphometric traits in purebred ewes maintained under arid conditions. *Agricultural Science Digest* 41: 225–230. 10.18805/ag.D-250
- 13) Mohamed-Brahmi A, Ameer M, Mekki I, Tenza-Peral A, Nasraoui M, Yagoubi Y, Smeti S, Ben Saïd S, Atti N, Lobón S, Mahouachi M, 2024. Analysis of management practices and breeders' perceptions of climate change's impact to enhance the resilience of sheep production systems: a case study in the Tunisian semi-arid zone. *Animals* 14(6): 885. doi.org/10.3390/ani14060885
- 14) Montes-Garrido R, Anel-Lopez L, Riesco MF, Neila-Montero M, Palacin-Martinez C, Soriano-Úbeda C, Boixo JC, de Paz P, Anel L, Alvarez M, 2023. Does size matter? Testicular volume and its predictive ability of sperm production in rams. *Animals* 13(20): 3204. doi.org/10.3390/ani13203204
- 15) Nunes SF, Ferreira J, Silveira RMF, Sales DC, de Sousa JER, Paiva SR, Façanha DAE, 2020. Morphometric characterization and zoometric indices of white Morada Nova breed: the first step for conservation. *Small Ruminant Research* 192: 106178. doi.org/10.1016/j.smallrumres.2020.106178
- 16) Rinaldi R, Novianti I, Nurgartiningih VMA, 2024. The evaluation of body weight and morphometric traits in local and crossbred sheep at birth age. *BIO Web of Conferences* 123: 01042. doi.org/10.1051/bioconf/202412301042
- 17) Sarma O, Rather MA, Shahnaz S, Barwal RS, 2024. Principal component analysis of morphometric traits in Kashmir Merino sheep. *Journal of Advances in Biology & Biotechnology* 27(9). 10.9734/jabb/2024/v27i91306