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The Effect of Age and Location Pattern on the Morphometry of Purebred Redhead Barbary Ewes Reared under Arid Climate

Research Article

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ABSTRACT

Tunisian Barbary sheep are well-known for their rusticity and adaptation to harsh environmental conditions, especially, those of the arid climate. Morphometric characteristics of this main breed, although, have not been extensively investigated. In this study, we provide a morphological characterization, via eight body measures, of 249 ewes, aged from one to nine years, and sampled from farms, belonging to two locations, which have been maintained a purebred nucleus of this breed. Analysis of variance revealed that morphometric traits are partially influenced by age group and location with different significance levels. Ewes reached the full morphological dimension broadly between 4 and 6 years of age, except for the tail part that tends to be longer precociously at 1-2 years of age. Thus, having a longer tail at an early age (<2 years), in the genetic architecture of this fat-tailed breed, could represent a form of adaptation to the arid climate, which is the main hypothesis-driven from the present morphometric analysis. This study provides insights into the morphological peculiarities of purebred Barbary ewes under the particular arid environment and reflects some possible adaptive properties, giving rusticity to this indigenous fat-tailed sheep resource.

KEY WORDS aridity, Barbary sheep breed, ewe, fat-tail, morphological measures, Tunisia.

INTRODUCTION

Barbary sheep are widely spread across North Africa, especially in East Algeria, North of Libya, and Tunisia. The name is derived from the Berbers who are the ancient dwellers of North Africa. The Barbary breed, also named "Nejdi" and "Arbi" locally, was exported to the United States of America, as a gift from Hamouda Becha Bey to George Washington (The Livestock Conservancy, 2020), around 1799, to give rise to the famous Tunis breed (Djemali *et al*. 1994). In Tunisia, exploited mainly for meat, Barbary is well represented among indigenous sheep breeds, with more than 60% of the total sheep population size (Bedhiaf-Romdhani *et al*. 2008). This weighty representation results essentially from its ability to adapt to dry climates and feed shortage periods, which mainly characterizes the arid zone that occupies a major part of the Tunisian climate. Among the components of adaptation, the accumulation of fat depositions in the tail, as an energy source to be used during harsh environmental periods (Atti and Bocquier, 1999; Atti *et al*. 2004). This peculiarity has allowed the widespread distribution of the Barbary breed through various bioclimatic stages, particularly, the arid stage. Bedhiaf-Romdhani *et al*. (2008) identified ten Barbary ecotypes in Tunisia, based on two qualitative descriptors: head colors and tail shapes; two ecotypes were dominantly distinguished: redhead and blackhead Barbary, disposing of various endpoint shapes of the bi-lobed fat-tail. However, few studies have been conducted to describe Barbary's morphometry. Atti and Ben Hamouda (2004) used firstly tail measurements of Barbary lambs to predict possible relationships with carcass composition traits and with live body weight afterward (Hamouda and Atti, 2011). In literature, to the best of our knowledge, only the study of Khaldi *et al.* (2011) has been carried out to characterize, with minor morphometric parameters, the body traits of three sheep breeds, including Barbary, in southwest Tunisia. Thus, morphological characteristics of the main Tunisian sheep breed have scarcely been investigated. The current study aims to quantitatively characterize the morphology of purebred redhead Barbary ewe, distinguished by a standard including a bi-lobed fat-tail form, white fleece without colored patches in the body, and the presence of a relatively large spot of red fleece behind ears and on the neck as a continuity to the red presented in the head. For that aim, we use eight morphological measures to provide a systematic morphological characterization of this breed, reared under an arid environment, and we investigate then how Barbary's morphology is influenced through the age and the location factors.

MATERIALS AND METHODS

The study area

This study was conducted in Sfax, a Governorate of Southeastern Tunisia, with decimal latitude and longitude coordinates, 34˚ 44'26.02"N, 10˚ 45'37.01"E, respectively, and ranged in the high arid bioclimatic stage, characterized by less than 200 mm of rainfall per year. Measurements were acquired from seven flocks belonging to state land office (OTD) farms: Chaal and El Salema. Selected farms have conserved a purebred nucleus of the Barbary breed under the control of the office of livestock and pasture (OEP). This choice guarantees the purity of selected animals and avoids the sampling of crossbred animals. The feeding system was based essentially on grazing different natural pastures, allocated separately to each sheepherder. A concentrate ration could be distributed only in the drier year or before breeding season. Animals of each flock have access to their collective water drinker.

Morphometric data collection

Seven distant flocks were chosen to record MM in the two selected farms. A sample of forty animals per flock was taken randomly after fixing an upright place in which all chosen animals were measured in Centimeter by metric tape, and were weighted in Kilograms using an analog weighing scale. Each sampled animal was identified through its official number. Eight measurements, live body weight (BW), head length (HL), ear length (EL), shoulder height (SH), body length (BL), heart girth (HG), height at rump (HR), and tail length (TL), were recorded according to anatomical references described in FAO (2012) guidelines. MM is graphically illustrated in Figure 1 in which an animal, meeting the purebred standard of redhead Barbary sheep breed, is presented.

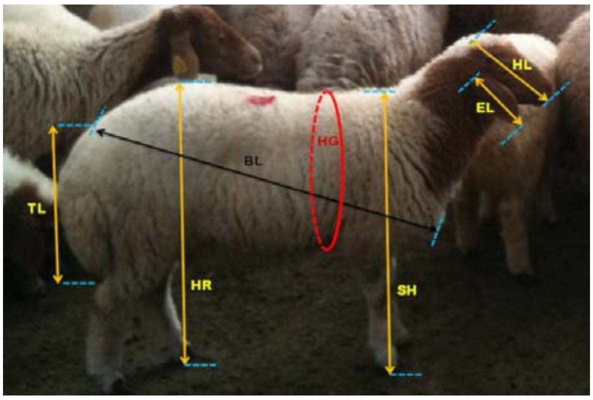

Figure 1 Anatomical reference points of recorded morphological measures. (HL: head length; EL: ear length; SH: shoulder height; HG: heart girth; BL: body length; HR: height at rump; TL: tail length)

The measuring process was conducted early in the morning by the same person, before grazing, for all farms, during the period ranged from February to April 2013. This period was conventionally marked by a well-conditioned morphological status of ewes whose lambing season (October and November) has been supposed to be finished. The age of ewe was determined as the difference between measurement and birth date. Oldest ewes (>9 years) and some problematic outliers were discarded from the statistical analysis in which morphometric data of 249 ewes through two locations and across eight age classes, as it is indicated in Table 1, have been maintained.

Statistical analyses

Packages implemented in R (R Core Team, 2018) software were used in the statistical treatment of data. Shapiro-Wilk test was used to check the normality of MM. A two-way ANOVA model, without interactions, was fitted to test the effect of two main factors: age categories (with 8 levels) and locations (with 2 levels), on varying MM. Comparisons of adjusted morphometric means were performed by Tukey test, at the probability level of 5% ($P<0.05$), implemented in the Agricola (De Mendiburu, 2017) package.

RESULTS AND DISCUSSION

Descriptive statistics and variance analysis of morphometric data

The arrangement of sampled ewes through age and location is presented in Table 1.

Table 1 Sample of Barbary ewes through age classes and locations

Age group (Years)	Number of ewes	
	L1: Chaal	L2: El Salema
[1-2]	04	16
[2-3]	19	28
[3-4]	21	13
[4-5]	08	08
[5-6]	11	13
[6-7]	21	22
[7-8]	23	16
[8-9]	16	10
T.P.L	123	126
Total	249	

L1: location 1; L2: location 2 and T.P.L: total per location.

Mean, standard deviation, coefficient of variance (CV) of MM, and the significance of age and location factors are ranged in Table 2. Means showed that Barbary ewes were taller on the rump (HR=66.71±0.16 cm) more than the shoulder (SH=64.55±0.16 cm). CVs ranged from 3.79 to 15.50%, with an overall mean of 7.2%. Higher CVs were shown for BW and TL, with coefficients 15.50% and 11.58%, respectively. Analysis of variance (Table 2) revealed an influence (P<0.001) for the age group on all MM, except for EL, HG, and HR. Moreover, the location had a high influence (P<0.001) on varying BW, EL, and TL, while SH, BL, and HR were not significantly affected by location change.

Effect of age on MM

Table 3 summarizes the trend of adjusted morphometric means across age groups. This evolution is noticed by an irregularity across the age transitions. Except for EL, HG, and HR, all means were different (P<0.05) between age classes.

Ewes, with 4-5 years, were the tallest (SH=66±0.55 cm; HR=67.62±0.70 cm), having the long head (HL= 26.14±0.28 cm) and ear (EL=15.22±0.32 cm). The BL reached its maximum (BL=74.04±0.75 cm) later than other MM, at 5-6 years, the age at which heaviest ewes (BW=44.75±1.53 kg) were found out. Remarkably, younger ewes (Hoggets), with 1-2 years, had the tallest tail (TL=38.5±0.46 cm).

Effect of location on MM

Adjusted morphometric means between locations (Table 4) were different (P<0.05) for BW, HL, EL, SH, HG, and TL, while no significant differences were shown for BL and HR. Ewes, from El Salema location, exhibited superiority by +2.38 cm and +8.26 kg in TL and BW, respectively.

Morphological characterization studies of sheep resources offer an excellent opportunity to update the morphological standard of breeds.

In this study, morphometric means, summarized in Table 2, provide the morphological standard of purebred redhead Barbary ewes in the arid production environment of South-eastern Tunisia. While no published morphometric data – describing briefly the morphological standard of the purebred Barbary, was found, comparison or update is not possible. A superiority, by 2.16 cm of HR compared to SH, suggests that the body structure of ewes is slightly sloped on standing likewise in some others fat-tailed sheep breeds: Awassi ewes (2.6 cm, Tabbaa, 1998), Moghani lambs (1.35 cm, Ghavi Hossein-Zadeh and Ghahremani, 2017), Makuie female lambs (1.2 cm, Jafari and Hashemi, 2014), Balkhi (1.6 cm), Hashtnagri (2.1 cm) Michni (2.1 cm, Ibrahim *et al.* 2010). This structure may permit a better longitudinal development of the fat-tail and avoid that it gains the ground rapidly. The observation of this structure in various fat-tailed breeds suggests that it could be genetically controlled by a highly conserved genomic region despite the pattern of speciation. Compared to fat-tailed sheep, Barbary ewes are lighter than Assaf.E ewe (75.74 kg, Legaz *et al.* 2011) and shorter in stature than Awassi ewe (SH=79.17 cm, Abdallah and Abo Omar, 2017). The chest girth of Barbary is narrower than those of Assaf.E ewes (HG=105.68 cm, Legaz *et al.* 2011) and Awassi ewes (HG=99.87 cm, Abdallah and Abo Omar, 2017). The TL of Barbary ewe appears to be longer than Awassi ewe (TL=31.2 cm, Tabbaa, 1998). Khaldi *et al.* (2011) described the BW and three MM of southwestern sheep population: Barbary, Western Thin-Tail, and D'Men; the technical process used for measuring BL was different from that adopted in the present study. On the other hand, they did not report morphometric means for each breed and gender separately, which cannot allow a meaningful comparison with present study results. In contrast, considering the least square mean values adjusted for Barbary ewes (SH=64.48 cm, HG=85.20 cm, BW=40.53, Khaldi *et al.* 2011), the current study has a slightly superior morphometric means for SH, HG, and BW.

Table 2 Mean, standard error (SE), coefficient of variation (CV), and significance of age and location effects on morphological measures (MM) of purebred Barbary ewes

MM	Mean	SE	CV (%)	Effect	
				Age group	Location
BW	41.85	0.41	15.50	***	***
HL	25.43	0.07	4.56	***	**
EL	14.62	0.06	6.90	NS	***
SH	64.55	0.16	3.93	***	NS
HG	85.91	0.32	5.97	NS	*
BL	71.19	0.24	5.37	***	NS
HR	66.71	0.16	3.79	NS	NS
TL	36.01	0.26	11.58	***	***

BW: body weight; HL: head length; EL: ear length; SH: shoulder height; HG: heart girth; BL: body length; HR: height at rump and TL: tail length.
NS: non significant.
* ($P<0.05$); ** ($P<0.01$) and *** ($P<0.001$).

Table 3 Age-adjusted means ± standard error of morphological measures of purebred Tunisian Barbary ewes

AG	BW	HL	EL	SH	BL	HG	HR	TL
[1-2]	40.30 ± 1.26^{b}	24.09 ± 0.29^{c}	14.29 ± 0.21^{a}	62.80 ± 0.61^{c}	69.35 ± 1.03^{b}	86.70 ± 1.53^{a}	65.98 ± 0.67^{a}	38.50 ± 0.46^{a}
[2-3]	40.78 ± 1.05^{b}	25.09 ± 0.12^{b}	14.56 ± 0.15^{a}	64.21 ± 0.36^{abc}	69.76 ± 0.48^{b}	85.40 ± 0.68^{a}	66.55 ± 0.31^{a}	37.65 ± 0.67^{ab}
[3-4]	40.55 ± 0.76^{b}	25.31 ± 0.17^{ab}	14.58 ± 0.14^{a}	64.71 ± 0.36^{abc}	71.47 ± 0.46^{ab}	86.17 ± 0.91^{a}	66.87 ± 0.38^{a}	35.82 ± 0.63^{ab}
[4-5]	44.44 ± 1.62^{ab}	26.14 ± 0.28^{a}	15.22 ± 0.32^{a}	66.00 ± 0.55^{a}	72.56 ± 1.03^{ab}	89.25 ± 0.42^{a}	67.62 ± 0.70^{a}	37.81 ± 0.77^{ab}
[5-6]	44.75 ± 1.53^{a}	25.75 ± 0.29^{ab}	14.36 ± 0.17^{a}	65.09 ± 0.50^{ab}	74.04 ± 0.75^{a}	86.08 ± 1.05^{a}	66.91 ± 0.57^{a}	34.66 ± 0.50^{b}
[6-7]	43.51 ± 1.03^{ab}	25.82 ± 0.18^{a}	14.82 ± 0.13^{a}	65.40 ± 0.46^{a}	71.97 ± 0.56^{ab}	85.90 ± 0.77^{a}	66.93 ± 0.45^{a}	35.23 ± 0.64^{b}
[7-8]	41.56 ± 1.01^{ab}	25.54 ± 0.12^{ab}	14.55 ± 0.15^{a}	63.61 ± 0.26^{bc}	70.83 ± 0.56^{b}	85.38 ± 0.82^{a}	66.02 ± 0.33^{a}	34.56 ± 0.68^{b}
[8-9]	40.11 ± 1.06^{b}	25.70 ± 0.19^{ab}	14.70 ± 0.22^{a}	64.96 ± 0.44^{abc}	70.65 ± 0.81^{b}	84.46 ± 0.98^{a}	67.25 ± 0.48^{a}	35.00 ± 0.94^{b}

AG: age group; BW: body weight; HL: head length; EL: ear length; SH: shoulder height; HG: heart girth; BL: body length; HR: height at rump and TL: tail length.
The means within the same column with at least one common letter, do not have significant difference ($P>0.05$).

Table 4 Location-adjusted means ± standard error of morphological measures of purebred Tunisian Barbary ewes

Location	BW	HL	EL	SH	BL	HG	HR	TL
Chaal	37.67 ± 0.38^{b}	25.29 ± 0.10^{b}	15.03 ± 0.08^{a}	64.91 ± 0.22^{a}	70.93 ± 0.34^{a}	85.08 ± 0.47^{b}	66.64 ± 0.22^{a}	34.81 ± 0.40^{b}
El Salema	45.93 ± 0.50^{a}	25.56 ± 0.10^{a}	14.22 ± 0.08^{b}	64.20 ± 0.22^{b}	71.45 ± 0.34^{a}	86.71 ± 0.44^{a}	66.77 ± 0.22^{a}	37.19 ± 0.31^{a}

BW: body weight; HL: head length; EL: ear length; SH: shoulder height; HG: heart girth; BL: body length; HR: height at rump and TL: tail length.
The means within the same column with at least one common letter, do not have significant difference ($P>0.05$).

Notwithstanding the sexual dimorphism, the range of CVs (3.79-15.5%) was similar to those observed in Assaf.E sheep (3.73-15%) with a closely global CV to Assaf.E ewes (7.03 %, Legaz *et al*. 2011). In Zulu sheep, the highest CVs were found for tail circumference (31.2 %) and length (26.8%), EL (26.3%), and BW (23.4%, Mavule *et al*. 2013).

Arguably, in this study, BW and TL exhibited wide heterogeneity. CV of TL was lower than that of Zulu, which could be attributed to the inclusion of both sex measures in the analysis of Zulu data. Further, it was near to a previous finding in Barbary lambs (CV=10%, Atti and Ben Hamouda, 2004). Despite its use as a criterion in selecting hoggets, by visual assessment, TL trait indicates a relatively expansive heterogeneity among Barbary ewes. This result bespeaks a weakness of the selection process affecting the tail part, and / or may, possibly, the tail is influenced by environmental stimuli more than other body parts. The fat-tail of Barbary sheep was shown to confer adaptation to feed shortage period, due to the ability of ewe to deposit and mobilize fat reserves (Atti and Bocquier, 1999; Atti *et al*. 2004).

Indirectly, this animal part is thus connected with the external environment, in particular, the fluctuation of resource availability. Indeed, Ermias and Rege (2003) found that TL had a high genetic correlation (r=0.86) with dissected tail and rump fat, average daily gain (r=0.84), and efficiency of feed utilization (r=0.92) in Menz and Horro fat-tailed sheep. Taken together, TL seems to be a key player in the adaptive and growth processes of fat-tailed sheep breeds in general. In essence, the variation in response among animals for these physiological processes may explain the wide heterogeneity found for TL. The highest heterogeneity observed in BW could be driven by the wide heterogeneity of TL. Tabbaa (1998) found that TL was affected ($P<0.05$) by the linear component of BW in Awassi sheep, and, generally, fat-tail measures were more sensitive to BW change compared to other body measures.

Globally, age affects sheep's morphometry (Tabbaa, 1998; Kunene *et al*. 2007; Khaldi *et al*. 2011; Legaz *et al*. 2011; Agaviezor *et al*. 2012; Birteeb *et al*. 2012; Mavule *et al*. 2013; Hayelom *et al*. 2014). Except for EL, HG, and HR, this study confirms the effect of age on varying BW and

MM of Barbary ewes. These results are in line with those found for BW in Barbary sheep (Khaldi *et al.* 2011), EL and HR in Assaf.E ewes (Legaz *et al.* 2011), and TL in Elle and Awassi sheep (Tabbaa, 1998; Hayelom *et al.* 2014). Otherwise, our findings gainsay from those observed for HG in Barbary and Elle sheep (Khaldi *et al.* 2011; Hayelom *et al.* 2014), and TL in Zulu sheep (Mavule *et al.* 2013). Such discrepancy could be accredited to dissimilarity in physiological characteristics through age and among breeds. Broadly, the amount of Barbary ewe's conformation was shown at 4-5 years, excepting BW and BL (5-6 years).

This result opposes the conclusion suggesting that the full confirmation is observed at the maximum bodyweight (Tabbaa, 1998) and argues relatively with those reported for Bergamasca, Balami, Yankasa, and Uda sheep in which most MM reach their maximum at 5-6 years (Riva *et al.* 2004; Agaviezor *et al.* 2012). The BL of Barbary ewes reached maturity later than other parts. The same result was seen in Elle sheep (Hayelom *et al.* 2014). In contrast, WAD sheep reached a full-body dimension precociously at 2-3 years, excepting BL and HR (3-4 years, Agaviezor *et al.* 2012). The decrease of morphological adjusted-means after 6 years could be associated with the aging process, wherein a decline in the body's performance could be considered (Soulsbury and Halsey, 2018). Among its components, the increase of oxidative stress and DNA damage into organisms (Petralia *et al.* 2014; Soulsbury and Halsey, 2018).

Such damage could touch all levels of organization in the body, from simple molecules to organs, and could be illustrated as the consequences of metabolic defects (high levels of reactive oxygen), excessive activities of genes, mutation accumulation in the genome, and antagonistic pleiotropy; the accumulation of these deleterious effects impacts the decline of animal's fitness at different levels of biological organization (Fabian and Flatt, 2011; Gladyshev, 2016).

Interestingly, adjusted morphometric means across age (Table 3), highlighted an early development of TL compared to other measures, at 1-2 years. In general, recorded animals of this age group were close (a few months) to reach two years. These hoggets showed the tallest tail. This result could be carefully interpreted as, a priority in tail development, compared to other parts. Hence, we hypothesize that the fat-tail in Barbary ewe, which confers adaptation against feeding resource scarcity (Atti and Bocquier, 1999; Atti *et al.* 2004), is privileged to reach longitudinal development precociously (<2 years) in the genetic architecture of this breed. A noticeable agreement appears between Barbary and Yankasa sheep (Agaviezor *et al.* 2012) in showing an earlier (1-2 years) long tail, despite having two different tail types: bi-lobed fat-tail for Barbary and a long thin tail for Yankasa. We believe that this peculiarity is related to the adaptability to arid conditions, where the two breeds are known to be mainly reared. Morphometric studies targeted with some physiological evidence could validate or not this hypothesis.

The location pattern, tested here as the second source of morphometric variance, showed a high influence on ewe's morphometry (Table 4), similar to earlier sheep findings (Kunene *et al.* 2007; Legaz *et al.* 2011; Agaviezor *et al.* 2012; Silva *et al.* 2013; Hayelom *et al.* 2014; Harkat *et al.* 2015; Boujenane and Petit, 2016; Abdallah and Abo Omar, 2017). Environmental Factors, such as altitude, were seen to evolve significant variation on MM of sheep (Riva *et al.* 2004; Harkat *et al.* 2015); sheep elevated in plains had the longest and tallest body, with wide HG, compared to those of higher altitudes (Harkat *et al.* 2015). Herein, altitude was not verified due to the known of a moderately plane topographic feature between locations. We suggest that this variability could be assigned to different ewe's genotype and breeding stock (between flocks), as well as, the better management of flocks, known from interviews and visits, favorites to show heavier ewes in El Salema location. Atti and Ben Hamouda (2004) estimated a strong correlation for tail circumference measure with tail fat (r=0.87) and total body fat (r=0.83); with less amplitude, the correlations of TL, respectively, were, r= 0.59 and r= 0.64. Moreover, Tabbaa (1998) emphasizes the significant effect of fat-tail measures, particularly TL, on response to the BW change in Awassi sheep. With this in mind, superiority showed in TL (+2.38 cm), for El Salema ewes, may favorite more accumulation of fat deposition and, consequently, more contribution to the bodyweight gain. This could explain, partly, the BW difference (+8.26 kg) seen between locations.

CONCLUSION

To summarize, under the arid conditions, purebred redhead Tunisian Barbary ewes share a medium-sized body with a slightly sloped body structure on standing, and a bi-lobed fat-tail that remarkably reaches its full longitudinal development, precociously, at less than two years of age. We believe that this peculiarity could be involved in the adaptive process of this rustic breed to harsh arid conditions. The full morphological dimension is achieved mostly at 4-5 years, expecting BW and BL that reach maturity, later, at 5-6 years. The location pattern seems to significantly affect Barbary ewe's morphometry. This influence was notably seen in TL and BW measures, addressing new questions regarding the physiological processes involved between the three components: TL, tail fat accumulation, and BW in this rustic fat-tailed breed. To the best of our knowledge, the present study is a unique study that dissects the morphometry of the purebred Barbary ewes through wide MM and across large age classes (1-9 years). The results give insights about how the parameters of morphometry of Barbary ewe are under an arid environment and underlie some possible morphological adaptive properties to the harsh arid conditions.

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