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RESEARCH ARTICLE

Comparative Geometrical Morphometries on the Mandibles of Anatolian Wild Sheep *(Ovis gmelini anatolica)* and Akkaraman Sheep *(Ovis aries)*

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Summary

Akkaraman sheep (*Ovis aries* Linnaeus, 1758) are densely breed in the region of Middle Anatolian in Turkey. Anatolian wild sheep (*Ovis gmelini anatolica* Valenciennes, 1856) is also subspecies of a wild sheep existing in the exact center of these lands and exists as little number only in the place of Bozdağ at the east of Konya. In this study, it is aimed that the mandibular bones of the Akkaraman sheep and Anatolian wild sheep are compared for morphologic and geometric morphometrics. In this study, the mandibular bones of 16 Anatolian wild sheep and 10 specimen Akkaraman sheep were used. In this study, the mandibular bones of the species were appeared quite similar. The geometric morphometrics analysis clearly determined the morphological differences between both species. On the lateral direction of the mandibular bones of each species, mutual ten each pieces homolog landmarks were used. In the analysis of the relative warp, RW1 explained 56.46% of total variation and RW2 explained 11.40% of total variation. Evident differences were determined among all of the homologous landmarks (except to anterio-ventral corner's point of P^2 tooth) used at the mandible of Anatolian wild sheep and Akkaraman sheep. As the most evident, firstly, posterio-ventral corner of M^3 tooth and homologous landmarks in the levels of anterior directed combination of lines of the angel for the vessels and dorsal-ventral masseteric ridges were observed.

Keywords: *Akkaraman sheep, Anatolian wild sheep, Anatomy, Geometric morphometrics, Mandible*

Anadolu Yaban Koyunu *(Ovis gmelini anatolica)* ve Akkaraman Koyununun *(Ovis aries)* Altçene Kemikleri Üzerinde Karşılaştırmalı Geometrik Morfometri

Özet

Akkaraman koyunu (*Ovis aries* Linnaeus, 1758), Türkiye'nin Orta Anadolu Bölgesinde yoğun olarak yetiştirilmektedir. Anadolu yaban koyunları da (*Ovis gmelini anatolica* Valenciennes, 1856), bu toprakların tam merkezinde ve günümüzde sadece Konya ilinin doğusundaki Bozdağ mevkiinde az sayıda bulunan bir yaban koyunu türüdür. Bu çalışmada Akkaraman koyunu ve Anadolu yaban koyunun mandibula kemiklerinin geometrik morfometrik ve morfolojik olarak karşılaştırılması amaçlanmıştır. Bu çalışmada, 16 adet Anadolu yaban koyunu ve 10 adet de evcil Akkaraman koyunu'nun mandibula kemikleri kullanıldı. Bu çalışmada her iki türe ait mandibula kemiği oldukça benzer gözüküyordu. Ancak geometrik morfometrik analizde, her iki tür arasındaki morfolojik farklılıklar açıkça belirlendi. Her iki türün lateral yönlü mandibula'ları üzerinde karşılıklı 10'ar adet homolog landmark kullanıldı. Relative warp analizinde; RW1 total varyansın %56.46'sını ve RW2 total varyansın %11.40'ını açıkladı. Anadolu yaban koyunları ve Akkaraman koyunlarının mandibula kemiklerinde kullanılan tüm homolog landmarklar (P^2 dişin anterio-ventral köşe noktası hariç) arasında belirgin farklılıklar tespit edildi. En belirgin olarak da öncelikle; M^3 (molar III. diş)'ün posterio-ventral köşesi, incisura vasorum facialium ve dorsal ile ventral masseterik çizgilerinin anterior yönlü birleşme düzeylerindeki homolog ladmarklarda gözlendi.

Anahtar sözcükler: *Akkaraman koyunu, Anadolu yaban koyunu, Anatomi, Geometrik morfometrik, Mandibula*

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INTRODUCTION

Anatolia is the place of intersection of civilizations since the time of before history in the near east geography, and is the junction point of the continents of Europe, Africa and Asia. Generally two regions are shown as the first domestication centers of animals in the world. First of them is the region of "Upper Euphrate" and East and Southeast Anatolia of Turkey. The second is "Çatal Höyük" and "Village of Aşıklı" in the Middle Anatolia. Important archeological findings devoted to domestication of animals have been found in the settlement places belong to 9500 years ago in the Çatal Höyük around Konya - Çumra [1-11].

In the process of domesticating of the wild animals, clear differences are seen in time at the general morphological and physiological features of these animals. Together with domesticated horns and long bones of animals become small and their body structures become large. It is observed that in the period of Neolithic, some morphologic changes occurred in domestication and wild sheep's wool and in their some bones [9,12-14].

One of the different domestic sheep races is the race of Akkaraman sheep in Turkey. It is densely breed in the Middle Anatolia [15-18]. Anatolian wild sheep *(Ovis gmelini anatolica)* is a kind of wild sheep which localizes only in Bozdağ and in eastern part of Konya, nowadays. Although this species was widespread 50 years ago, their numbers have been decreased rapidly because of harsh weather conditions, beasts of prey and being hunted, etc. It is reported that their numbers decreased to 30-40 in 1966 [19-26]. The Anatolian wild sheep, nowadays still lives in little number as the station of production in the area of Konya - Bozdağ and according to data of 2007, their numbers are only about 600 [23]. Horns of Anatolian wild sheep are in the position of supra-cervical and they are curled towards level of eye by drawing a large arch [13,24-28]. Anatolian wild sheep has 2n = 54 chromosomes. In terms of this number and karyotype, generally other mouflons resemble to wild sheep of North America and the whole domestic sheep in the world. It is argued that Anatolian wild sheep, with a great possibility, are origins or ancestors of the whole domestic sheep [5,11,14,28-33].

Studying about wild sheep in the world is generally done as about themes of genetics, nutrition, parasite, reproduction, behavioral and etc. In spite of this, there are very few morphologic studies on Anatolian wild sheep. These studies are done on the general outside morphologic features [20], (such as on head and tooth skeletons on same partial metric measures [17]), and also on the skeleton bones of Anatolian wild sheep and local Karaman sheep belongs only to ossa trunci [34]. However, apart from these, there is not any macro-anatomic or geometric morphometrics study as comparative on cranio-facial structure of Anatolian wild sheep and Akkaraman sheep in the area of Konya.

Thanks to these morphologic and molecular data which will be gained with 'Landmark and Morphometric' method from the bones of head and the mandibular bones of living mammals, phylogenetic relations can be discovered as comparative [35]. The last ten years in the general of the world, geometric morphometric method has been used in different science branches. This method has an analysis foundation based on shape and it is also rather a new method including strong statistical and analytical means. With this method, investigations can be done in two dimensional mandibula or in osteological structures, and in different themes and science disciplines (anatomic, biologic, morphometric, anthropologic, taxonomic, phylogenetic, ontogenetic, etc.) [36-39].

In this study, it is aimed that the mandibular bones belonging to Akkaraman sheep breeding densely in the region of Central Anatolia of Turkey and belonging to Anatolian wild sheep in the center of same region are compared for morphologic and geometric morphometrics. Thus, in this study it will be looked whether there is an existent morphologic change or not in the process of domestication in the region where two subspecies live in the exact center of domestication. Whether there are morphologic differences on the mandibular bones, these will be determined.

MATERIAL and METHODS

In this study, the mandibles of 16 adult (3 ♂, 13 ♀), Anatolian wild sheep (*Ovis gmelini anatolica* Valenciennes, 1856) were obtained from the animals died with natural causes in the area which is in the field of Bozdağ Protection of Wild Life. The mandibular bones are protected in Selçuk University, Education Faculty, Department of Biology. In addition, these examples which are restricted by Turkey Nature Protection Head Office of National Parks, Ministry of Environment and Forest (example codes: TR42: 01-02-03-04-05-06-07-08-09-10-11-12-13-14-15-16). In this study mandibles of 10 pieces adult Akkaraman sheep (10 ♀) (*Ovis aries* Linnaeus, 1758) were also used to compare with their wild forms. It was being brought to Konet slaughterhouse in Konya. The procedures of classic maceration were applied to the whole examples and the mandibular bones were brought out by cleaned. Lateral and medial surfaces of right and left mandibula were examined for macro-anatomic observations *(Fig. 1a, b)*. Similarities and differences between them were noted.

Geometric morphometrics are method that brings out the similarities and differences which has a foundation of homologous landmarks on the biologic figures. This method has often been used in many science branches such as anatomy, biology, anthropology, etc. in recent years. Anatomic and morphologic differences, similarities and phylogenetic relations between races and species can be brought up easily via graphics and deformations which have a foundation of 'Thin Plate Spline' [36,37,40,41]. For geometric morphometric analysis, firstly millimetric graphic paper were made as background and photographs left lateral surfaces of the whale mandibula examples were taken images with digital camera (8.1 mp). Later, these digital images were transferred to the computer for analysis (at the format of TIFF and JPEG). The geometric morphometrics analysis, principle four phase producers were applied [40].

1. By ten pieces of "homologous landmarks" on the left lateral directed image of the examples of the whole mandibles, belong to both species, were determined with software of Tps Dig v.2.12 [42] *(Fig. 1c).*

2. On the whole examples, "General Procrustes Analysis" (GPA) were applied. Thus, differences between examples were removed with the procedures of super-imposition, translation, rotation and scale.

3. On the procedures, the analysis of relative warp was applied with the software of Tps Relw v.1.46 [43] *(Fig. 2a).*

4. The results were shown in the diagrams with the sofware of Tps. Percents of Relative Warp (RW) and polarizing between figures was determined. In the same way, "deformation grid" and differences in the vectorial to be directed were also compared *(Fig. 2b, c).*

"Nomina Anatomica Veterinaria" (NAV) [44] and "International Code of Zoological Nomenclature" (ICZN) [45] were used as guide book in the spelling of anatomic and zoology terms in this investigation.

RESULTS

In this study, some morphological differences on the mandibular bones of Anatolian wild sheep *(Ovis gmelini anatolica)* and Akkaraman sheep *(Ovis aries)* were determined. The caput of mandible was concave in both subspecies. It was observed that the mandibular symphysis in the mandibular bone occurred on structure of cartilaginous. It was not show an ossifying exactly in both domestic and wild sheep. Generally morphology of the mandibula nearly resembled each other in both subspecies. However, partial morphologic differences were also observed. The masseteric ridge structure was observed in the level anterior directional combination of dorsal and ventral masseteric lines occurring in the masseteric fossa of mandible examples belonging to both domestic and wild sheep. This structure was more evident in Anatolian wild sheep. In addition the line of ventral masseteric could be observed better than the dorsal's in both species *(Fig. 1a, b).*

Apart from, there were some differences in the general morphologic structure of teeth and their arrangement between two subspecies. There were defects in the general structure of teeth of 60% of Akkaraman sheep (6 specimens). P^2 (premolar II tooth) could not be observed in the 50% (5 specimens) of the whole domestic sheep

Fig 1. The lateral surface of left mandible. ***(a)*** Akkaraman sheep *(Ovis aries)*, ***(b)*** Anatolian wild sheep *(Ovis gmelini anatolica)*, ***(c)*** The identification of homologous landmarks of left mandible (10 points): **1.** The posterio-dorsal point of the dental alveolus I4 (incisive tooth). **2.** The anterio-ventral corner of P2 (premolar tooth). **3.** The posterio-ventral corner of the M3 (molar tooth) **4.** The tip of the coronoid process. **5.** The point of the mandibular notch. **6.** The posterior point of the mandibular condyle. **7.** The posterio-ventral mid-point of the mandibular angle. **8.** The point of the incisura vasorum facialium **9.** The anterior joining point of the dorsal-ventral masseteric ridges (anterior end of the dorsal-ventral edge of the masseteric fossa). **10.** The posterior border of the mental foramen

Şekil 1. Sol mandibula'ların lateral yüzü; ***(a)*** Akkaraman koyunu *(Ovis aries)*, ***(b)*** Anadolu yaban koyunu - *(Ovis gmelini anatolica)*, ***(c)*** Sol mandibula'nın homolog landmarklarının tanımlanması (10 nokta). **1.** I4'ün alveoli dentales'inin posterio-dorsal uç noktası. **2.** P2'nin anterio-ventral köşesi. **3.** M3'ün posterio-ventral köşesi. **4.** Processus coronoideus'un tepe noktası. **5.** Incisura mandibulae noktası. **6.** Caput mandibulae'nın posterior tepe noktası. **7.** Angulus mandibulae'nın posterio-ventral orta noktası. **8.** Incisura vasorum facialium düzeyi. **9.** Dorsal ve ventral masseterik çizgilerinin, anterior yönlü birleşme ve tepe noktası (Fossa masseterica'nın dorsal ve ventral çizgilerinin anterior uç noktaları). **10.** Foramen mentale'nın posterior kenarı

(oligodonty anomaly; but, it was observed the alveoli dentales in the mandibular bone) in a structure of rudimenter in the other 50%. In addition, it was observed that P^{2-3-4} teeth and alveolus sank into body of mandible in the 20% of domestic sheep in this study. In the other 10%, M^{2-3} (molar) teeth and the dental alveolus were disordered and they also sank into body of mandible. However, the whole structures of tooth and lines of tooth of the whole Anatolian wild sheep (100%) were sound as morphologic and the anatomic position of the dental alveolus was ordered. In addition, formulas of tooth belonging to mandible of both species were similar and they were in the form of 0033/4033 (I-C-P-M). There was a situation of the foramina mentalia in the posterior of the mental foramen and in the level of ventral of P^{2-3}. This extra situation of foramen was in the proportion of 90% (9 specimens) in both the mandibular bone of Akkaraman sheep. These foramens were observed in the proportion of 25% (4 specimens) in right and left mandible of Anatolian wild sheep.

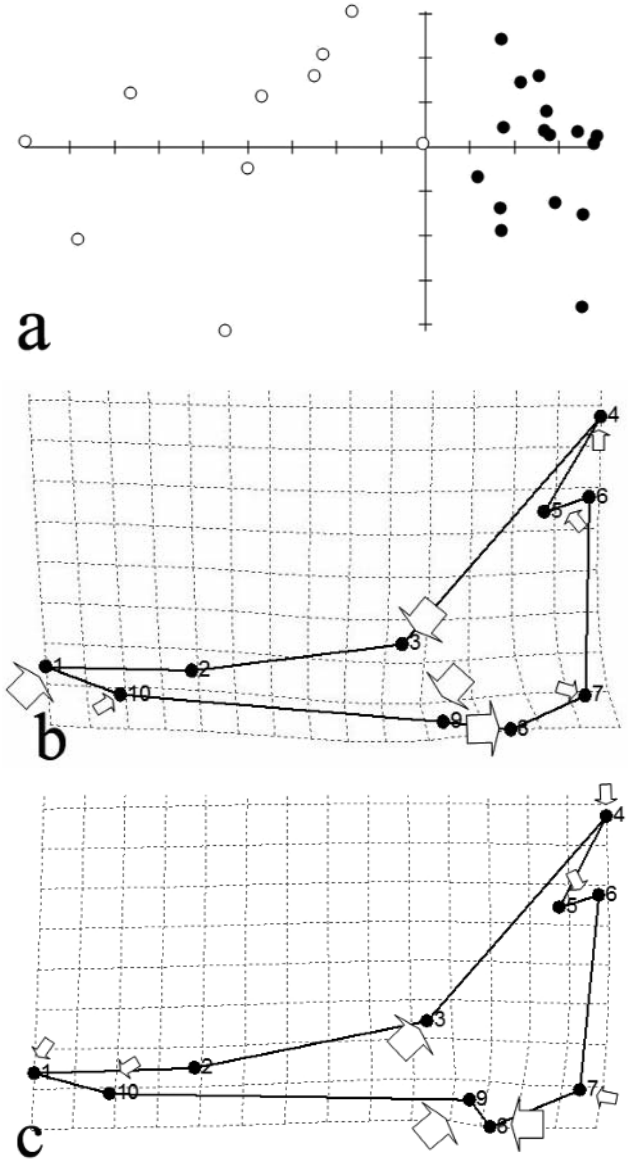

Fig 2. ***a:*** Relative warp analysis: **Rw1:** 56.46% - **Rw2:** 11.40%. O. aries, O. g. anatolica; ***b-c:*** TPS analysis, deformation grids and vector directions. ***b:*** Akkaraman sheep, ***c:*** Anatolian wild sheep

Şekil 2. ***a:*** Relative warp analiz: **Rw1:** %56.46 - **Rw2:** %11.40. O. aries, O. g. anatolica; ***b-c:*** TPS analiz, deformasyon gridler ve vektörel yönelmeler. ***b:*** Akkaraman koyunu, ***c:*** Anadolu yaban koyunu

Homologous landmarks (10 point each) were used on the left lateral directional mandibles of both subspecies *(Fig. 1c).* The evident differences were observed between two subspecies in the result of geometric morphometric analysis applied to the whole figures. This situation was observed in the analysis of relative warp and in the defects of deformation grid structures and also in the directions of the vectorial figures *(Fig. 2a, b, c).*

In the base of polarizing in coordinate axis, it was clearly determined that the whole examples of both species were collected separately in right and left axis. It was observed that example of domestic sheep was at the left of axis and they were clustered. It was observed that Anatolian wild sheep were at the right of axis and they were clustered. In the analysis of relative warp, Rw1 explained 56.46% of total variation and Rw2 was explained 11.40% total variation (first two relative warp axes together accounted for 67.86% of the total shape variation in the data). In the whole samples the example of mandibula of only one domestic sheep (number 3) reflected the common anatomic features and characteristic of both species *(Fig. 2a).*

In the examples of domestic sheep, landmarks with the numbers of 3-9 were anterio-ventral directional. However, in the wild forms these points were posterio-dorsal directional. The level of landmark with the number of 8 was posterior directional in domestics and anterior directional in wilds *(Fig. 2b, c).*

The differences being observed in secondary degree were at the level of landmarks with the numbers of 1, 7 and 10. The points of sign with the numbers of 1 and 10 were posterio-dorsal directional in the domestic forms and both of them were the position of anterio-ventral in wild forms. The landmark with the number of 7 was in more posterior situation in Akkaraman sheep than in Anatolian wild sheep *(Fig. 2b, c).*

The differences in tertiary degree were at the level of homologous landmarks with the numbers of 4, 5 and 6. The landmarks with the numbers of 5-6 were anterio-dorsal directional in Akkaraman sheep, yet landmarks with the numbers of 4, 5 and 6 in the examples of mandible belonging to wild sheep were posterio-ventral

directional. On the other hand, in the examples of domestic sheep, landmark with the number of 4 was dorsal directional and ventral directional in wilds. The point of landmark with the number of 2 showed a similar localization in both subspecies *(Fig. 2b, c).* Generally, there was observed no evidence of sexual dimorphism between mandibles of the Anatolian wild sheep.

DISCUSSION

Generally together with domestication of animals, some morphologic changes in time can be observed. These changes are shortening of nose gathering, lessening of teeth and changing of their number, decreasing of size of brain, and differences in the structures of horn and fur [10,11]. In our study, we also observed some differences on the mandibles of both subspecies.

It has clearly been emphasized the similarities and other differences between domestic and wild sheep in some different studies. Taşbaş [34] has showed some morphologic differences between Anatolian wild sheep and Karaman sheep. It has been expressed that the cervical vertebrae of Anatolian wild sheep are somewhat bigger and that also the spinous process of the cervical vertebrae are longer in wild forms. Kaya and Çelik [23] reported that the tooth and alveolus similarities in the both subspecies. They have fixed that there are some morphologic differences in addition to anatomic similarities in the mandibula bones belonging to both subspecies. In this study, we also observed similarities and differences on the mandibles.

Hoefs and Bunch [46] have demonstratied diseases of mandibular tooth and anomalies in wild sheep. They reported rather excessive in wild sheep in North America (23-29%), and 5.7% in *Ovis orientalis musimon* (318 examples). It has been expressed 0% in *Ovis orientalis gmelini* with 6 examples). However, it has been expressed that this proportion is 5% in domestic animals (1028 examples). Hoefs [47] has informed that the situation of oligodonty anomaly is common in sheep of New World 3.2% *(Ovis musimon),* but it is very rare in wild sheep of old world *(Ovis gmelini gmelini).* This situation is 4.3% in domestic sheep. Our findings were similar with these results. In this study, it was fixed in the general structure of teeth in 60% of Akkaraman sheep. Especially in terms of P^2 (premolar II. tooth), a situation of anomaly in proportion of 50% was observed in the whole domestic sheep. In the other 50%, it was determined that these teeth were in a structure of rudimenter. All of the tooth structures and tooth arrangements were sound in the 10% of Anatolian wild sheep. The formula of tooth belonging to mandible was similar in both subspecies. It was in the form of 0033/4033 (I-C-P-M). The morphologic differences in the structures of tooth of domestic sheep may be due to of domestication and different nutrition, and environmental conditions. It has been informed that domestic sheep are fed with feeds such as straw, dense, etc. in addition to grasses such as pasture and meadow [48]. It has been argued that Anatolian wild sheep eats about 100 species kinds of plants in 22 families [23].

In this study, it was seen a foramina mentalia in both subspecies just as in carnivor and pigs [44]. This foramen was observed in the proportion of 90% in Akkaraman sheep and in the proportion of 25% in Anatolian wild sheep. It was localized at the level of ventral of P^{2-3} tooth and in the posterior of the mental foramen in the lateral surfaces of the mandibular bone in both subspecies. Similarly, Halstead et al.[49] have expressed that the situation of foramen mentale has often been observed in the ventral of P^{2-4} tooth in domestic sheep.

In this study, the morphologic differences were defined at on the mandibular bones of both species with the geometric morphometrics analysis (except the anterio-ventral corner of P^2 tooth). In this study, in the analysis of relative warp, Rw1 explained 56.46% of total variation and Rw2 explained 11.40% of total variation (The first two principal components account for 67.86% of the total variation). It was clearly showed that the both species was been collected separately in right and left axes.

In this study, the difference in the level of landmark with the number of 9 was quite remarkable (the union level directed anterior of the lines of dorsal and ventral masseteric ridges forming the masseteric fossa). In this level, different causes can be that sticking mark of the chewing muscles (the level of insertio of anterior fibers of the profound masseter muscle) was directed anterio-ventral at the Akkaraman sheep. It was directed posterio-ventral at the Anatolian wild sheep. In this level the structure of protuberance was cleared in the forms of wild in terms of both morphological and geometric morphometric. Especially in different situations such at the conditions of environment and habits of nutrition change masseter muscles adapt to this situation in the process of domestication of these species. It was remarkable that the partial differences on the chewing surfaces belong to teeth. In this study, the distance between the ranges of premolar and molar tooth of domestic sheep was shorter. There was not a development in P^2 tooth of domestic sheep. Also, Dedeoğlu [17] states that the lengths of diastema of the Anatolian wild sheep are longer than domestic sheep.

As a result, it is quite difficult to distinguish the

morphological differences between the mandibles of both subspecies. In this investigation, geometrical morphometric differences were put forward clearly as comparatively. We think that there are many important results of the phenotypic features and these results of data belonging to both subspecies since both of the types are in the same region and in the main center of domestication as geographic. Also, as Zeder [9] state, available anatomic and morphologic changes must be observed in the center of the domestication in area where they live. In this study, the forms of domestic and wild sheep race were chosen in the center area of Central Anatolia. In some study, it is argued that domesticating come true in different geographic areas and as independent separately [50]. According to wild forms, domestic animals have more different morphological features because of migration, changes of climate, and differences of nutrition, artificial selection with human's hand at the light of the archeological and morphological data.

Consequently, on the races of Anatolian wild sheep with other local sheep in Turkey, other genotypic and phenotypic variations can be appeared and compared. In this study, similar results can be obtained by using the geometric morphometric method on the other osteological structures of same types. These new data and results can be tested with the other molecular, genetic, systematic, taxonomic, zoological, zoo-archeological, biological, and anatomic etc. studies.

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