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AN EVALUATION OF THE MACRO ANATOMY OF THE HAZEL DORMOUSE'S (*MUSCARDINUS AVELLANARIUS* LINNAEUS, 1758) (RODENTIA: MAMMALIA) SKELETAL SYSTEM IN TÜRKİYE

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ABSTRACT. *Muscardinus avellanarius,* one of the thirty species of the Gliridae family, is found in areas covered with deciduous forests, with a range stretching from Bursa (Uludağ) to Trabzon in Türkiye. Hazel Dormouse, classified as an endangered species and characterized by their deep hibernation patterns, possess significant value as bioindicators of environmental change. In this study, a macro-anatomical evaluation of the skeletal structure of forty-six specimens collected from the Eastern and Western Black Sea Regions between 1979 and 1983 were conducted. The evaluation revealed that the whole skeleton of *Muscardinus avellanarius* consisted of 225 bones. The morphometric variances and variations between the Eastern Black Sea and Western Black Sea specimens were detected by defining the skull and baculum bones that hold taxonomic value.

1. INTRODUCTION

The hazel dormouse (*Muscardinus avellanarius* L., 1758), a member of the Gliridae family, is a hibernating rodent that lives in Europe and Northern Anatolia [1, 2]. The hazel dormouse is a protected species by strict regulations through its inclusion in Annex IV of the Habitats Directive (Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora) and Annex II of the Bern Convention in Europe [3-5]. The main threats to the hazel dormouse population are habitat loss, habitat fragmentation and unsuitable forest management practices [6-8]. Special care and consideration are given to the protection of the hazel dormouse in certain Western European countries such as the United Kingdom, Germany, Denmark, the Netherlands, and Belgium [8]. Studies reported that the hazel dormouse population in the United Kingdom declined by 72%. The drop in the population has been attributed to climate change and forest habitat structure and quality [9,10]. *M. avellanarius* is an arboreal species living in woodland and scrub habitats and is often associated with wooded areas [11-13]. This glirid is known as an important bioindicator of environmental change due to its sensitivity to both climate and other environmental factors [14].

Keywords. Muscardinus avellanarius, macro anatomy, skeletal system, baculum, Türkiye
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The first record of *M. avellanarius* from Turkey was given by Nehring in 1903 from Istanbul-Alemdağ [15]. Miller (1908) [16] introduced a new record for *Muscardinus* from Trabzon-Coşandere named *M. trapezius,* but Ellerman (1948) [17] later described them as *M. avellanarius trapezius.* Kıvanç (1983) described *M. avellanarius abanticus* from Soğuksu (Bolu/Abant) [18]. Following their taxonomical descriptions based on morphologic differences [19,20], molecular studies also revealed the presence of these two subspecies [21,22].

Numerous studies have been conducted on the biology [23-26], ecology [24-30], population dynamics [24,31], behavior [32-35], dentitional variations [19,20] and karyotype [21,22] of *M. avellanarius*. Recent studies mostly focus on conservation biology and investigating the adverse effects of habitat fragmentation on the species [10,36,37].

Anatomical studies related to the hazel dormice are limited in number; however, there are studies available on the cranial and vertebral column of the *M. avellanarius* [38,39].

Despite the extensive research conducted on the taxonomy, biology, ecology, population dynamics, behaviour, dentitional variations, and karyotype of *M. avellanarius*, the skeletal structure and the bones that hold taxonomic value have yet to be fully revealed. To address the gaps in this subject, it is crucial to conduct further research to complete the existing deficiencies and disseminate the findings to the scientific community. Moreover, a comprehensive examination of *M. avellanarius'* skeleton including a complete definition and a total number of all bones has yet to be reported in any existing literature. This study aimed to identify the skeletal structure and bones with a taxonomic value of *M. avellanarius*, as well as to determine the differences between *M. avellanarius trapezius* (Eastern) and *M. avellanarius abanticus* (Western) specimens.

2. MATERIALS AND METHODS

In this study, skull and skeleton samples of 46 hazel dormouse collected from Northern Turkey (Black Sea Region) between 1979-1983 were evaluated. Samples boiled in a 15% ammonia solution at 70 ºC in a water bath for maceration, later cleaned and left to dry. Afterwards, the shapes of the bones were illustrated under magnification. Photographs were taken and bones were evaluated morphologically and morphometrically. Comparative analysis of the skeletal measurements was made between the specimens from the Western Black Sea region and Northern Black Sea Region to investigate the differences between subspecies of hazel dormice. Findings compared with the previous studies in the literature. A total of 12-character sizes (Figure 1) and Os glandis (baculum)

(Figure 2) measurements were taken with a digital caliper with an accuracy of up to 0-150 mm.

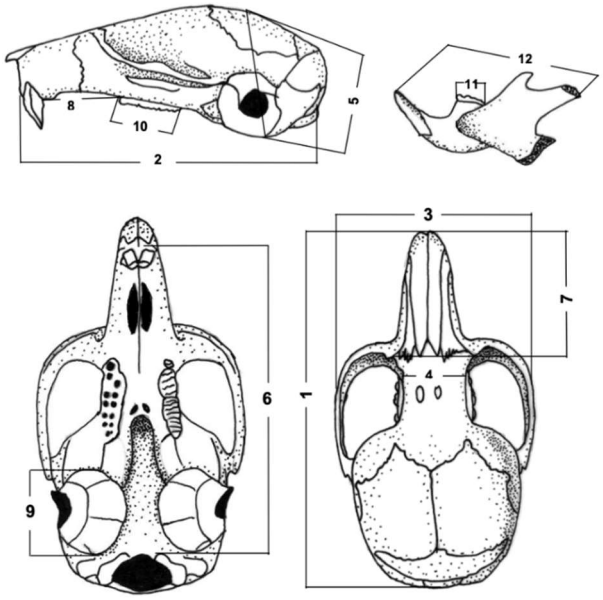

FIGURE 1. Internal character measurements are taken from the skull, teeth, and lower jaw. **1.** Occipito-nasal length, **2.** Condylo-basal length, **3.** Zygomatic width, **4.** Interorbital width, **5.** Brain capsule width, **6.** Basal length, **7.** Nasal length, **8.** Diastema length, **9.** Tympanic bulla length, **10.** Crown length of the upper molar, **11.** Crown length of the lower molar, **12.** Length of the mandible.

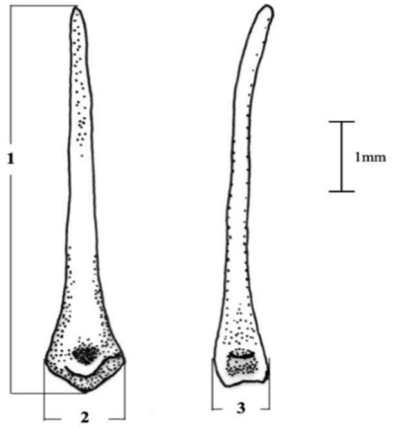

FIGURE 2. Definition of Os glandis (baculum) measurements. **1.** Total length and baculum length (BL), **2**. Proximal width from ventral and baculum base width (BaW) **3**. Proximal width from lateral and baculum base thickness (BaH)

3. RESULTS

The missing skeleton parts of the samples under examination in this study were completed from available samples. The study revealed that the entire skeleton consists of 225 bones, as shown in Figure 3. The skeletal system of *M. avellanarius* was examined in two parts, axial and appendicular.

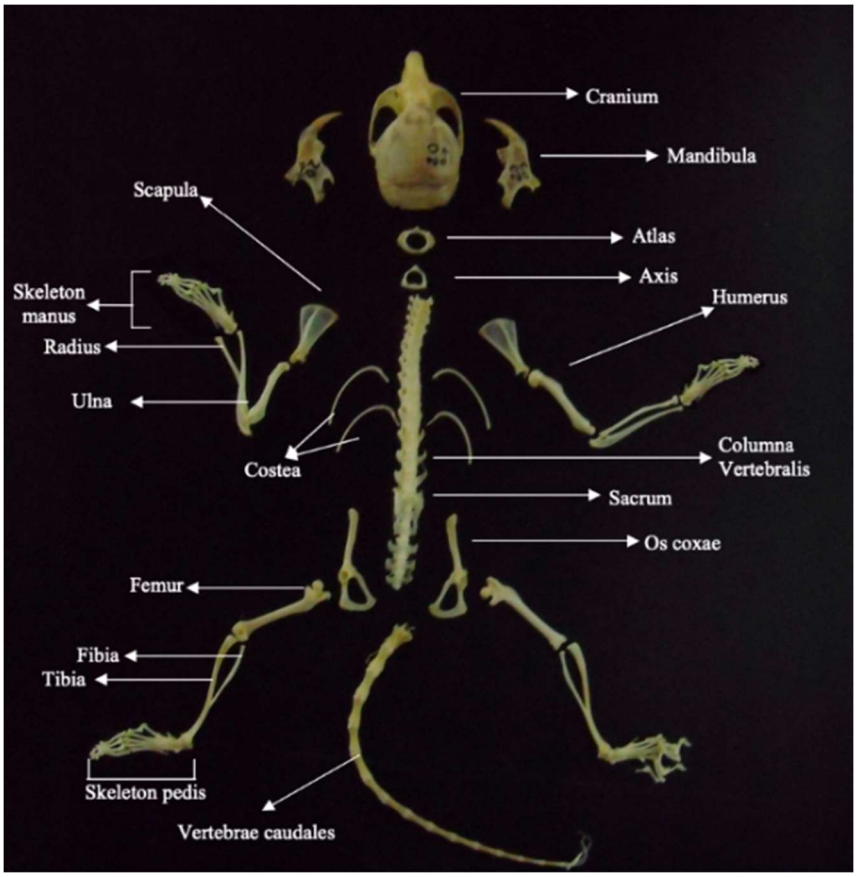

FIGURE 3. Skeleton of *Muscardinus avellanarius.*

Skeleton Axiale: The axial skeleton is comprised of three parts skull bones, the spinal column, and the rib cage. The bone characteristics of the axial skeleton of *M. avellanarius* are presented in Table 1, including the quantity of the bones and their names.

TABLE 1. The bone characteristics of the skeleton axiale of the *Muscardinus avellanarius*.

Division of the skeleton	Regions of Skeleton Axiale		Name of the bone	Quantity	Local bone count/total bone count
Skeleton Axiale	Ossa Cranii	Neurocranium	Os Occipitale	1	11
			Os Interparietale	1	
			Os Sphenoidale	2	
			Os Pterygoideum	1	
			Os Temporale	1	
			Os Parietale	2	
			Os Frontale	1	
			Os Ethmoidale	1	
			Os Vomer	1	
		Viscerocranium (Ossa Faciei)	Os Nasale	2	13
			Os Lacrimale	2	
			Os Maxillare	2	
			Os Incisivum	2	
			Os Palatinum	1	
			Os Zygomaticum	2	
			Mandibula	2	
	Columna Vertebralis		Vertebrae cervicales	7	54
			Vertebrae thoracicae	13	
			Vertebrae lumbales	6	
			Os Sacrum	3	
			Vertebrae Caudales	25	
	Skeleton Thoracis		Costae	26	27
			Sternum	1	
			Total	105	105

The cranial region, called Ossa cranii, consists of 24 bones. The anatomical structures, photographs, and drawings of *Muscardinus avellanarius* cranium are given in Figure 4. Evaluations showed that this species' cranium is thin and fragile. The nasal section is tapered, and its average length is 8.2 mm in western specimens and 7.9 mm in eastern specimens. The zygomatic arches widely outward with an average width of 13.7 mm in western specimens and 12.5 mm in eastern specimens. The pterygoid processes extend to the tympanic bulla and are in contact with them, which are snail-like shaped. The average bulla length is 6 mm in western samples and 5.4 mm in eastern samples. The average bulla length is 6 mm in western specimens and 5.4 mm in eastern specimens. Cranium measurements of the Western and Eastern Black Sea samples are illustrated in Table 2 and Table 3, respectively.

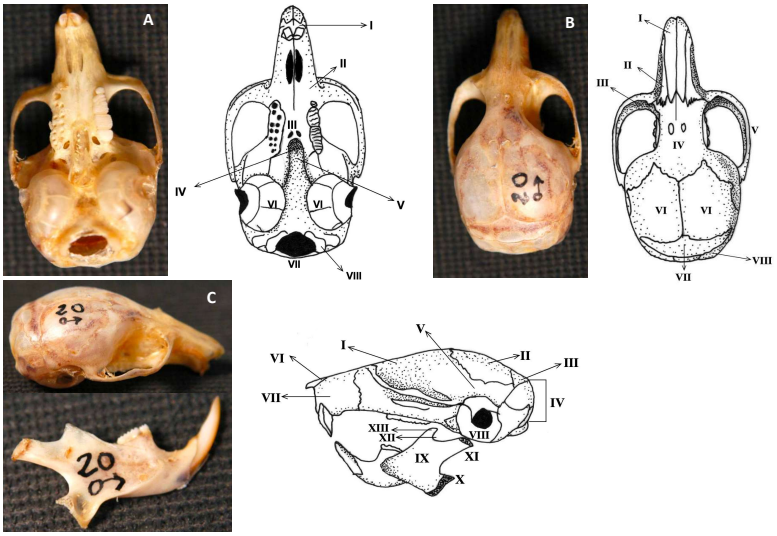

FIGURE 4. Ventral (**A**), dorsal **(B)** and lateral **(C)** view of the skull and lateral view of the mandible **(C)** of *M. avellanarius*; **A:** I) Os incisivum, II) Os maxillare, III) Os palatinum, IV) Presphenoidale, V) Basisphenoidale, VI) Bulla tympanica, VII) Foramen magnum, VIII) Condylus occipitalis. **B**: I) Os nasale, II) Os incisivum, III) Os maxIllare, IV) Os frontale, V) Os zygomaticum, VI) Os parietale, VII) Os interparietale, VIII) Os occipitale. **C:** I) os frontale, II) os parietale, III) Os interparietale, IV) Os occipitale, V) Os temporale, VI) Os nasale, VII) Os incisivum, VIII) bulla tympanica, IX) mandibula, X) processus angularis, XI) processus condyloideus, XII) incisura mandibulae, XIII) processus coronoideus.

TABLE 2. Internal measurements of the skull of *M. avellanarius* from Western Black Sea Specimens

Characters	Number	Min. – Max. (mm)	Mean (mm)	Standard deviation (mm)
Occipito-nasal length	20	23.2-25.7	24.0	3.8
Condylo-basal length	21	20.8-24.0	22.4	0.7
Zygomatic width	20	12.8-14.7	13.7	0.5
Interorbital width	23	3.3-3.7	3.5	0.1
Braincase width / cranial width	22	7.2-7.7	7.3	0.1
Basal length	21	19.0-22.4	20.9	0.7
Nasal length	22	7.6-9.2	8.2	0.4
Tympanic bulla length	17	5.6-6.4	6.0	0.2
Diaestema length	23	5.7-6.7	6.0	0.3
Mandibulae length	23	14.0-15.8	14.7	0.5
Upper molar length from crown	23	4.5-5.0	4.7	0.1
Lower molar length from crown	23	4.3-4.7	4.5	0.1

TABLE 3. Internal measurements of the skull of *M. avellanarius* from Eastern Black Sea Specimens

Characters	Number	Min. – Max. (mm)	Mean (mm)	Standard deviation (mm)
Occipito-nasal length	11	21.6-24.1	23.0	0.9
Condylo-basal length	11	19.7-22.4	21.3	0.8
Zygomatic width	10	11.3-13.6	12.5	0.8
Interorbital width	11	3.3-3.7	3.4	0.1
Braincase width / cranial width	11	6.7-7.4	7.0	0.2
Basal length	11	18.2-20.7	19.7	0.9
Nasal length	11	7.3-8.8	7.9	0.4
Tympanic bulla length	11	4.9-6.0	5.4	0.3
Diaestema length	11	5.3-6.4	5.9	0.4
Mandibulae length	23	13.4-14.7	14.0	0.4
Upper molar length from crown	23	4.0-4.6	4.3	0.2
Lower molar length from crown	23	4.0-4.4	4.1	0.1

Dental anatomy: In studies regarding taxonomy, dental formula and dental structures have special importance. In this regard, particular attention was paid to the dental structure of *M. avellanarius* when evaluating the skull bones. The total number of teeth in *M. avellanarius* is 20, with a dental formula of I(incisor) / C(canine) / P(premolar) / M(molar) of 1013 / 1013 on the upper and lower jaws. Additionally, the Eastern and Western specimens showed variations in the root structure of their upper and lower molars. Besides, the observed variations in the upper and lower molar lengths between Eastern and Western specimens were significant enough to allow for accurate taxonomic differentiation between the two subspecies.

P^1 (Upper Premolar) is the smallest tooth and has a single root. However, three specimens with two rooted P^1 were found among the Western Black Sea samples, while all the Eastern Black Sea samples are single-rooted. For M^1, out of the 44 specimens, 40 have four roots and two specimens from each of the Eastern and Western Black Sea regions have a small additional fifth root. The M^2 (second upper molar) has 4 roots in all specimens from both the Eastern and Western Black Sea regions. The M^3 (Third upper molar) has 4 roots in all the Western Black Sea samples (n=26), whereas in the Eastern Black Sea samples, 10 have four roots, 3 have three roots, and 2 have two free and two transversely fused roots (Figure 5A).

P_1 (Lower premolar) is single-rooted in all specimens. M_1 (First lower premolar) has 3 roots in 21 of the Western Black Sea samples (n=27) and 11 of the Eastern Black Sea samples (n=16), four roots in one specimen from Western and 4 specimens from Eastern Black Sea samples, two free and two transversely fused roots (total of 4 roots) in 1 Western and 5 Eastern Black Sea samples. M_2 (second lower molar) has 4 roots in all 44 specimens from both the Western (n=27) and Eastern (n=17) Black Sea samples. M_3 (third lower molar) has 4 roots in all the Western Black Sea samples (n=27) and 13 Eastern Black Sea samples (n=17), however, 4 specimens from the Eastern Black Sea regions have 3 roots.

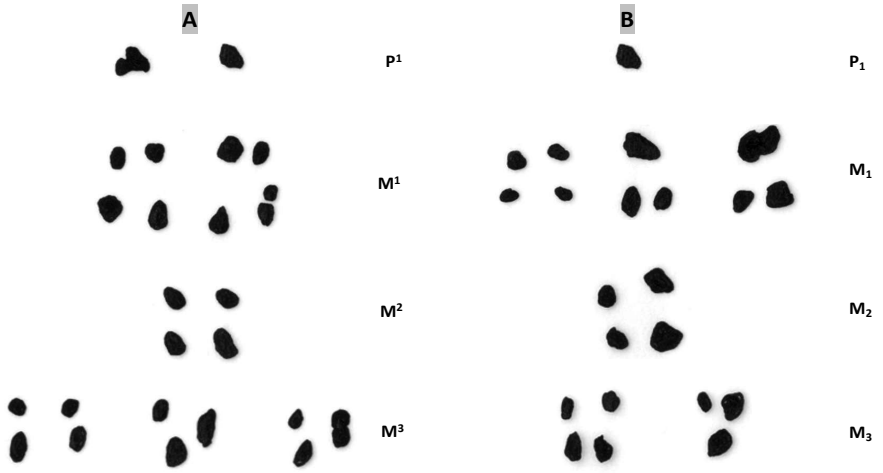

FIGURE 5. Variations on the roots of upper (A) and lower (B) molars

In *M. avellanarius*, the columna vertebralis is divided into five regions as in most vertebrates. These regions are vertebrae cervicales (Figure 6A), vertebrae thoracicae (Figure 6B), vertebrae lumbales (Figure 6C), vertebrae sacrales (Figure 6D, E) and vertebrae caudales (Figure 6G). Columna vertebrae consist of 54 vertebrae. The observations showed that the cervical vertebrae are formed by the union of 7 vertebrae, the thoracic vertebrae are formed by the union of 13 vertebrae, and the lumbar vertebrae are formed by the union of 6 vertebrae. Additionally, the os sacrum is formed by the union of 3 vertebrae, as illustrated in Figures 6D and E. Atlas and axis, the first two vertebrae of vertebrae cervicales display structural changes unique to *M. avellanarius.* The atlas is in the form of a ring. Arcus dorsalis is slightly curved medially. The tuberculum dorsal is underdeveloped, while the tuberculum ventral is more prominent (Figure 7A). The axis of *M. avellanarius* is characterized by the presence of short dens (Figure 7B).

Ala sacralis is reduced in the os sacrum (Figure 6F). The vertebrae caudales of *M. avellanarius* consist of 25 vertebrae, with the first three having a normal structure (Figure 6G). However, the corpus of the subsequent vertebrae is reduced, and the processus spinosus, arcus, and articular processes are absent (Figure 6H).

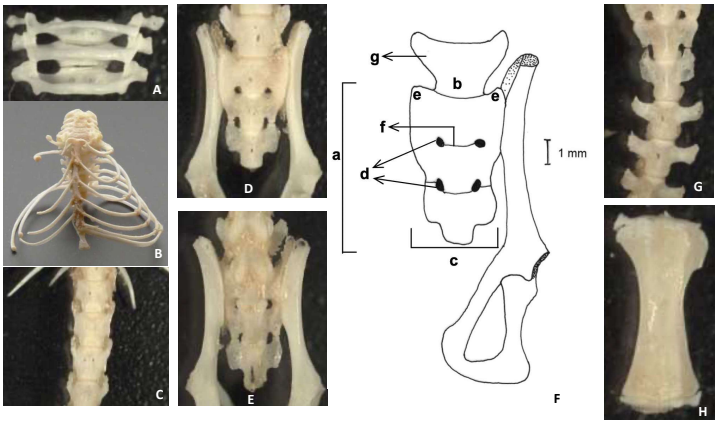

FIGURE 6. Vertebrae cervicales, **(B)** vertebrae thoracicae, **(C)** vertebrae lumbales, **(D)** ventral view of os sacrum, **(E)** dorsal view of os sacrum, **(F)** drawing of os sacrum and os coxae surface from ventral view; a) os sacrum, b) basis ossis sacri, c) apex ossis sacri, d) foramina sacralia ventralis, e) ala sacralis, g) sixth lumbar vertebrae, f) linea transverse. **(G)** first tail vertebrae, **(H)** general view of the tail vertebra of *Muscardinus avellanarius.*

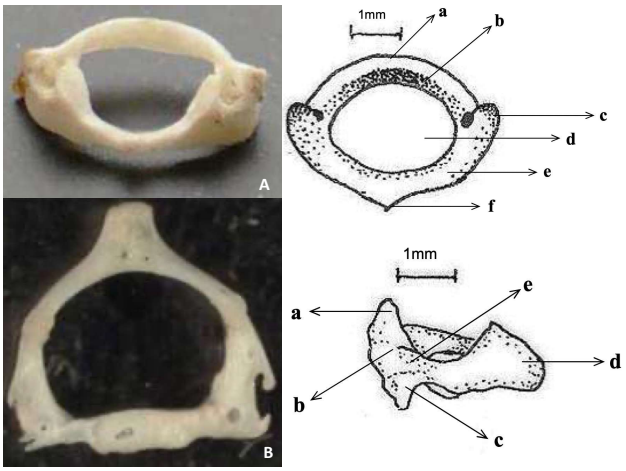

FIGURE 7. **(A)** atlas; a) tuberculum dorsale, b) arcus dorsalis, c) fovea articularis cranialis, d) foramen vertebrae, e) arcus ventralis, f) tuberculum ventrale, **(B)** axis; a) dens, b) facies articularis lateralis, c) processus costotransversarius, d) processus spinosus, e) foramen costotransversarium in *M. avellanarius*.

The sternum (breastbone) and costea (ribs) in the skeleton thoracis consist of a total of 27 bones (Figure 8-1). The sternum (B) is a solitary bone that consists of six sternebrae (b), whereas the corpus sterni (d) is formed by five sternebrae (as illustrated in Figure 8-3).

M. avellanarius possesses 13 pairs of costae, with five of them being attached to separate sternebrae in the sternum. The 6th to 10th costae attaches to the last sternebrae. It was determined that the 11th, 12th, and 13th costae do not attach to the sternum, and they form the costae fluctuantes (floating ribs).

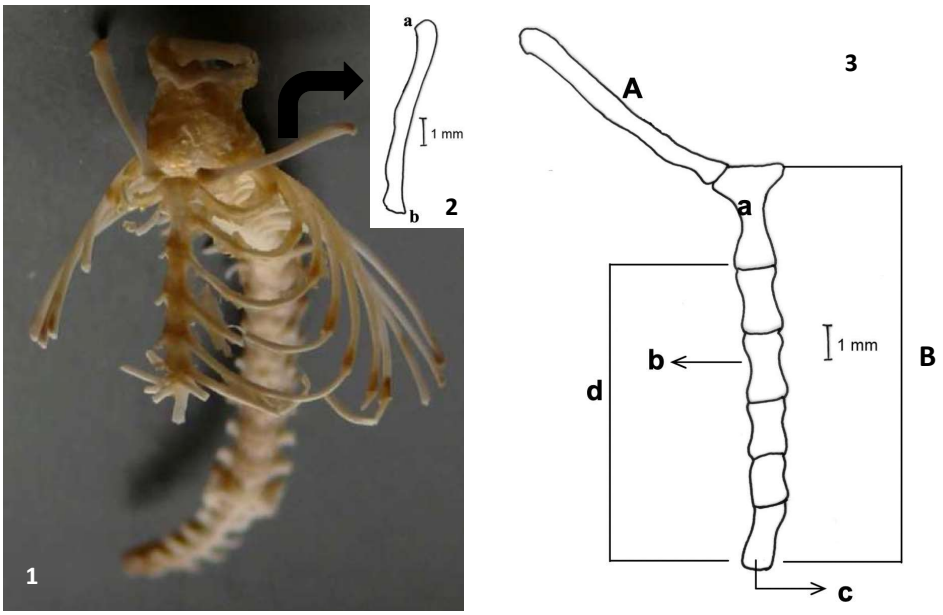

FIGURE 8. Thorax (**1**), clavicula (**2**); a) Extremites sternalis, b) Extremites acromialis, clavicula and sternum (**3**); A) Clavicula (collarbone), B) Sternum (breastbone), a) Manibrum sterni, b) Sternebrae, c) Processus xiphoideus, d) Corpus sterni of *M. avellanarius*.

Skeleton Appendiculare: Skeleton appendiculare of *M. avellanarius* consist of 120 bones (Table 4). Ossa membri thoracici (forelimb bones) have a total of 58 bones, comprising the cingulum membri thoracici, skeleton brachii, skeleton antebrachii and skeleton manus. The names and numbers of these bones are given in Table 4.

TABLE 4. Skeletal parts, names and numbers of bones in skeleton appendiculare in *M. avellanarius*

Division of the skeleton	Regions of appendiculare skeleton	Name of the bone		Number of bones	Regional number of bones
Skeleton Appendıculare	Ossa Membri Thoracici	Cingulum membri thoracici	Scapula	2	58
			Clavicula	2	
		Skeleton brachii (Humerus)		2	
		Skeleton Antebrachii	Radius	2	
			Ulna	2	
		Skeleton manus	Ossa capri	16	
			Ossa Metacarpilia	8	
			Ossa Digitorum Manus	24	
	Ossa Membri Pelvını	Os Coxae		2	62
		Skeleton femoris		2	
		Patella		2	
		Skeleton Cruris	Tibia	2	
			Fibula	2	
		Skeleton Pedis	Ossa Tarsi	14	
			Ossa Metatarsalia	10	
			Ossa Digitorum Pedis	28	
			Total	120	120

In *Muscardinus avellanarius*, the scapula exhibits a triangular morphology as depicted in Figure 9A-B. The fossa infraspinata is broader than the fossa supraspinata. From a lateral view, it was observed that the spina scapulae make up the processus hamatus, which protrudes like a hook at the acromion shoulder joint. Together with the scapula, a pair of clavicles are present in *M. avellanarius*, forming the cingulum membri thoracici (anterior limb girdle). The clavicle articulates with the scapula and sternum as shown in Figure 8-3.

The humerus bone is the thickest of the forelimb bones and articulates with the cingulum membrane thoracici (anterior limb girdle). It has been determined that the caput humeri of the humerus articulate with the cavitas glenoidalis of the scapula, as depicted in Figures 9C and 9D. In *M. avellanarius*, the skeleton antebrachia consists of two distinct long bones named the radius and the ulna. The radius is situated medially, as shown in Figure 4.36, while the ulna is situated laterally, as depicted in Figure 9E.

The forelimbs of *M. avellanarius* are adapted for climbing and have four toes. Due to the small size of the skeleton manus (forelimb skeleton) in this species, some of the bones were lost during the cleaning process, however, a total of 48 carpal, metacarpal and digitorum manus bones were identified.

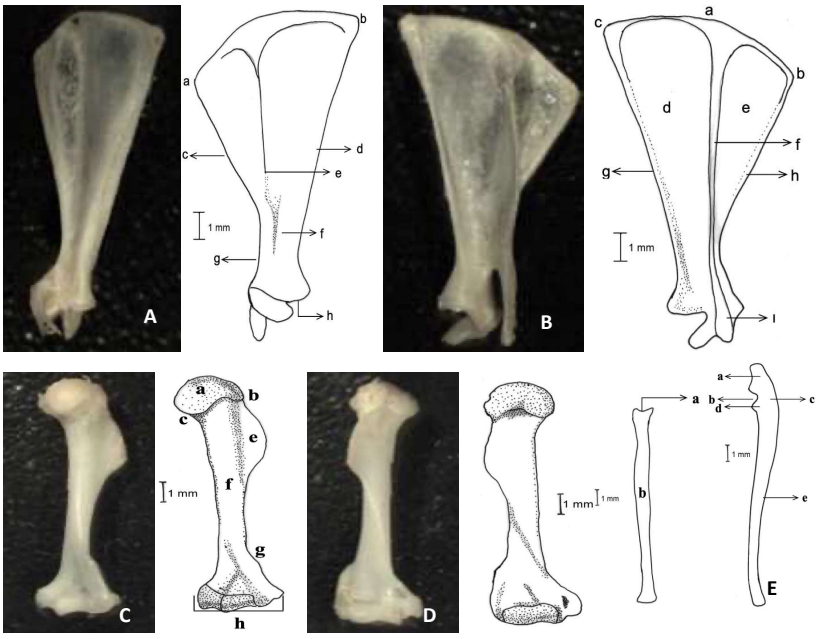

FIGURE 9. **(A)** View of right scapula from facies costalis; a) Angulus cranialis, b) Angulus caudalis, c) Margo cranialis, d) Margo caudalis, e) Fossa subscapularis, f) Angulus ventralis, g) Collum scapulae, h) Cavitas glenoidalis. **(B)** View of right scapula from facies lateralis; a) Margo dorsalis, b) Angulus cranialis, c) Angulus caudalis d) Fossa infraspinata, e) Fossa supraspinata, f) Spina scapulae, g) Margo caudalis h) Margo cranialis, i) Acromion. **(C)** Ventral view of the right humerus; a) Caput humeri, b) Tuberculum majus, c) Tuberculum minus d) Collum humeri, e) Tuberositas deltoidea, f) Corpus humeri, g) Sulcus m. brachialis h) Condylus humeri. **(D)** Dorsal view of the right humerus. **(E)** Radius; a) Fovea capites radii, b) Corpus radii; ulna a) Tuber olecrani, b) Processus anconeus, c) Olecranon, d) Incisura trochlearis, e) Corpus ulna of *Muscardinus avellanarius*.

Ossa membri pelvini: The specimens of *M. avellanarius* had os coxae formed by the fusion of three bones, as shown in Figure 10A. The ala ossis ilii was not large in the ilium, while the foramen obturatum was wide in the ischium. The corpus ossis ilii was long and the os pubis had a narrow structure.

The examination of the femur of *M. avellanarius* revealed that the caput ossis femoris and the trochanter major are not aligned, and there is no fovea capitis on the caput ossis femoris. The collum ossis femoris was observed to be thin, as shown in Figures 10B and C. The skeleton cruris corresponds to the skeleton

antebrachii on the front leg. In *M. avellanarius*, the hindlimb is composed of a fused tibia and fibula, as depicted in Figure 10D.

Due to the small size of the hindfoot skeleton in *M. avellanarius*, many of the bones were lost during the cleaning process, therefore not shown in the figures. However, tarsal, metatarsal and digitorum pedis bones were found to be 52 in total.

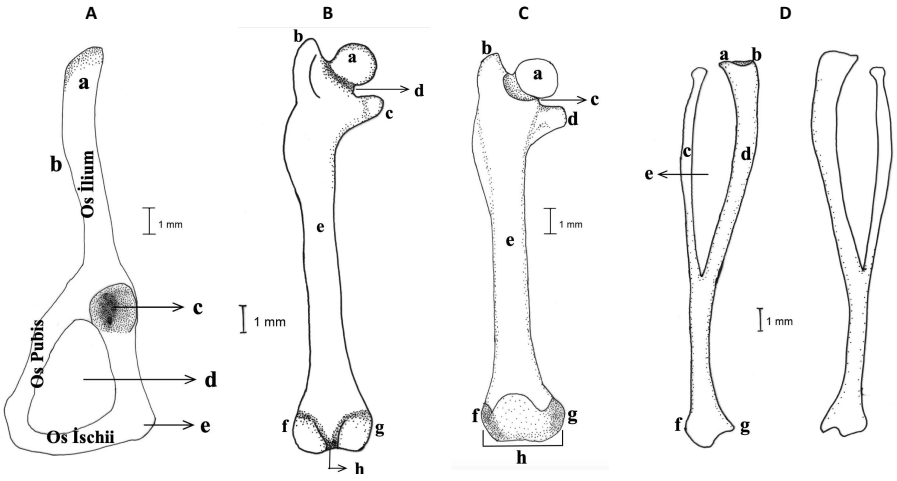

FIGURE 10. **(A)** Os coxae: a) Ala ossis ilii, b) corpus ossis ilii, c) Acetabulum, d) Foramen obturatum, e) Tuber ischiadicum. **(B)** Dorsal view of Os femoris: a) Caput ossis femoris, b) trochanter major, c) trochanter minor, d) Collum ossis femoris, e) corpus ossis femoris, f) condylus lateralis, g) condylus medialis, h) fossa intercondylaris. **(C)** Ventral view of Os femoris: a) Caput ossis femoris, b) trochanter major, c) collum ossis femoris, d) trochanter minor, e) corpus ossis femoris, f) condylus lateralis, g) condylus medialis, h) trochlea ossis femoris. **(D)** Skeleton cruris: a) Condylus lateralis, b) condylus medialis, c) fibula, d) corpus tibia, e) spatium interosseum cruris, f) malleolus lateralis, g) malleolus medialis.

Os glandis (Baculum): The os glandis of *M. avellanarius* is shown in Figure 11. The proximal part of the os glandis shaped like a spoon, and narrows distally, resembling an awl in appearance. The proximal ventral part of the os glandis has a slight depression, and the dorsal part appears to be raised. The measurements of the os glandis are listed in Table 5.

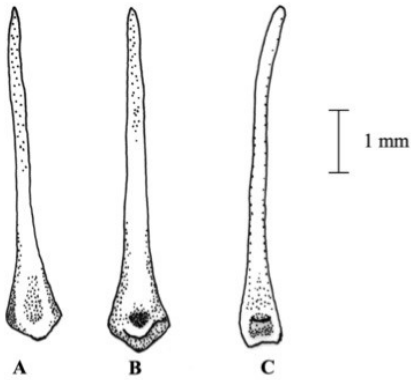

FIGURE 11. View of the os glandis (baculum) in *M. avellanarius* from **A)** dorsal, **B)** ventral, and **C)** lateral.

TABLE 5. Measurements of os glandis

Characters	Number	Min. – Max. (mm)	Mean (mm)	Standard deviation
Total length	5	5,72 - 6,05	5,94	0.16
Proximal width from the ventral	7	0.66 - 1.1	0.97	0.15
Proximal width from the lateral	7	0.44 - 1.21	0.75	0.23

4. DISCUSSION

Andreescu and Andreescu [38] recorded a total of 54-56 vertebrae in *M. avellanarius*, including 7 cervical vertebrae, 13 thoracic vertebrae, 6 lumbar vertebrae, 3 os sacrum and 25-27 caudal vertebrae. The number of vertebrae and regions of the vertebral column stated by Andreescu [38] were consistent with the findings of this study, and the number of vertebrae in the vertebrae caudales was found to be 25.

The British Museum's mammal collection catalogue [39] states that the vertebral column is comprised of 5 regions with 7 cervical vertebrae, 13 thoracic vertebrae, 6 lumbar vertebrae, 2 sacral bones, and 24 caudal vertebrae. However, this study found that while the vertebral counts in the various regions were consistent with the Turkish samples, the number of sacral bones was determined to be 3 and the number of caudal vertebrae was found to be 25.

The length of the upper and lower molar rows, as well as the variations in the premolar and molar roots, were found to be consistent with the findings reported by Kıvanç [18,19].

Hrabe [40] reported baculum length (BL) as approximately 6 mm and baculum base width (BaW) as 0,5 mm. Hrabe [40] also reported that the anterior of os glandis (baculum) is awl-shaped and the cross-section is circular. In their study of the phallus and the baculum of European edible dormice, Simson [41] reported that the baculum length of a single *Muscardinus* specimen from Italy was 4.84 mm, and the baculum base width was 0.86 mm. In this study, the overall length of the os glandis was found 5.94 mm on average, and the base part was 0.97 mm on average, which was in agreement with Hrabe [40] however was larger than those reported by Simson [41].

This study is a pioneer one that conducted a macro-anatomical analysis of the entire skeletal structure and determined the number of bones in the whole skeleton of *Muscardinus avellanarius* species living in Türkiye for the first time. In addition, bones that hold taxonomic value such as humerus, femur, radius-ulna, scapula, os coxae were defined and necessary information was provided to compare these bones with other species.

Author Contribution Statement EEK and EK experimental design and performance, EEK and HME-manuscript writing. HME-manuscript drawing. All authors have read and approved the manuscript.

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