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CRANIOMETRICAL ANALYSIS OF *CAPRA HIRACUS* AND *OVIS ARIES* FROM PUNJAB, PAKISTAN

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Abstract
There are roughly 37 goat breeds and 30 sheep breeds recognized in Pakistan. Goats (Capra circus) and sheep (Ovis aries) are two of the first hominid animals. These species thrive in diverse habitats, from temperate forests to deserts, and display different foraging behaviors; goats are browsers that prefer a variety of plants, while sheep primarily graze on grasses. Such dietary differences may influence the development and shape of their cranial structures. This study aimed to compare cranial parameters between the two species, utilizing 10 skulls five from each species collected from various regions of Punjab, Pakistan, and preserved in the Lab at the University of the Punjab Lahore (catalogued as G1-G5 for goats and S1-S5 for sheep). Using linear craniometry, 41 parameters were analyzed, and both descriptive and multivariate analyses (MANOVA) were performed to assess differences. Significant disparities were found in neurocranium breadth, skull length, nasal length, skull width, basal length, and facial width, with all these parameters being larger in sheep, except for skull base length, which was greater in goats. These cranial differences may result from anatomical variations, evolutionary lineages, hormonal influences, environmental factors, and genetic differences. This research provides essential baseline craniometric data for species, contributing valuable insights to existing literature and guiding future studies.

INTRODUCTION

Goat domestication dates back thousands of years; sheep domestication dates back much further, to between 11,000 and 9,000 BC, whereas goat domestication dates to between 6,000 and 7,000 BC (Amills et al., 2017; Alberto et al., 2018). Initially rose for their dairy products, including meat, milk, and skin, these animals were primarily developed in Southwest Asia (Caja, 1990). Cheese, discovered around 8,000 BC, emerged alongside sheep domestication, leading to its evolution into at least 1,000 varieties. Sheep and goats were chosen for domestication due to their manageable body size, social nature, early maturity, and higher reproduction rates, as well as the preservation challenges associated with meat (Clutton-Brock, 1990).

Globally, the goat population stands at approximately 556 million, predominantly in Asia (e.g., China, Pakistan and India) and Africa (Finnie et al., 2022). Meanwhile, the sheep population is about 512 million, with significant numbers in China, India, and several African countries. The differences between goats and sheep extend beyond simple management and nutrition; they include genetic distinctions such as chromosome counts, behavioral traits, and specific habitat preferences, with goats showing greater versatility in feeding habits (Mazinani et al., 2019; Miller et al., 2015).

In Pakistan, the livestock industry significantly contributes to the economy, representing 60.54% of the agricultural value and 11.22% of GDP. Domestic goats (*Capra hircus*) can be found in diverse habitats, thriving even in areas with thin growth that would not support other grazers. *C. hircus* prefers to be in groups and requires exercise, with a minimum space of 25 square feet per animal. Wild goats such as *Capra hircus* and West Asian ibex (*Capra aegagrus*) face threats from habitat destruction and poaching (Gall, 1996; Weinberg et al., 2008).

In Pakistan, goats are often found in mountainous areas and are adapted to harsh environments, commonly fed on natural vegetation and grains. Common breeds include Beetal, Kamori, and Barbari. In contrast, sheep are more commonly raised in plains, with breeds such as Kajli, Kaghani, and Lohi. Both goats and sheep are raised in a free-range system, providing important sources of income and nutrition for families in rural areas. Due to habitat degradation, wild goats in the area are classified as near threatened. Their mating season normally lasts from November to January, and they take around 170 days to gestate (Simpson et al., 2004; Deniskova et al., 2018; Wilson et al., 2012; Veen et al., 2009; Habel et al., 2013; Goupta et al., 1991; Stivens et al., 2012).

Globally, there are over 2.2 billion sheep and goats, of which 20.8% are farmed for dairy products. In 2016, milk from sheep and goats made up only 1.3% and 1.9% of the 799 million tonnes of milk produced worldwide; the main producers were cattle and buffaloes, with 83.1% and 13.1%, respectively. But in the previous fifty years, the production of goat and sheep milk has more than doubled; by 2030, production is predicted to rise by 9.7 million tonnes (+53%) and 2.7 million tonnes (+26%), respectively. Dairy goats (milk and meat) and sheep (milk, meat, and wool) have substantial total solids contents, but their fiber output is minimal (FAOSTAT, 2018). In subtropical-temperate parts of Asia, Europe, and Africa, especially in the Mediterranean and Black Sea regions, dairy farms raising goats (Capra circus) and sheep (Ovis aries) are mostly located (Caja, 1990).

In orthodontics for more than a century, craniometry—the scientific measuring of the skull—has been crucial. Before X-ray technology, direct craniometric and anthropometric measurements were used for diagnosis. The cephalogram, introduced by Broadbent in 1931, became a standard diagnostic tool in orthodontics (Broadbent, 1931). Although many studies confirm the reproducibility of lateral cephalograms, fewer have evaluated the accuracy of three-dimensional cephalometric measurements due to limitations like distortion and magnification (Baumrind and Frantz, 1971). Cone beam computed tomography (CBCT) has been more common in orthodontics recently; a systematic review published in 2009 noted that the number of linked articles increased from 14 in 2007 to approximately 300 at that time (De Vos, Casselman, and Swennen, 2009). The cranium consists of various bones, and cranial measurements are crucial for understanding skeletal variations and population history. Ratios or percentages can be expressed using indices in anthropometric studies (Martin and Saller, 1957). Craniometry has historically supported Darwin's theory of evolution as presented in The Origin of Species in 1859 and encouraged ideologies that divide people based on race.

Materials and Methods:

The skulls of domestic sheep (*Ovis aries*) and goats (*Capra hircus*) were studied using a comprehensive methodology in order to quantify inter-species variance. With a focus on many aspects of the skull, such as dental morphology, facial structure, and other cranial parameters, the study employed the Linear Craniometry method as its main morphometric tool.

Skulls Collection:

Through a thorough investigation of butcher shops, ten skulls in total, five from domestic sheep (*Ovis aries*) and goats (*Capra hircus*) were gathered from different parts of Punjab, Pakistan. To facilitate a smooth collection process, permissions were obtained from relevant farms, agricultural research facilities, and abattoirs, ensuring compliance with local regulations. The skulls selected were representative of the target population, focusing on mature adults that were free from abnormalities or damage. Efforts were made to gather a diverse range of ages and sexes when possible. Prior to collection, discussions with owners or managers were conducted to secure permission and clarify the intent of the study, while also determining any associated costs and specific requirements for the collection process. Additionally, the specific breeds of goats and sheep to be studied were identified, acknowledging that variations in skull morphology may exist among different breeds.

Preparation and Categorizing of Skulls:

All skulls underwent a detailed preparation protocol for morphometric study. Initially, meat fibers and skin remnants were carefully removed using a knife and needle, followed by cutting through muscles and ligaments around the jaw joints. Thorough cleaning involved scrubbing with water, mild detergent, and a soft brush, after which the skulls were disinfected and soaked in a sanitizing solution. Tools used included gloves, a sharp knife, and containers for each skull, with an emphasis on hygiene to prevent contamination. Once cleaned, the skulls were air-dried in a well-ventilated area, avoiding direct sunlight. Boiling for 3-5 hours helped eliminate remaining soft tissues, followed by 24 hours of bleaching to remove odors. The skulls were then sorted by species, with each specimen labeled (e.g., S1 for sheep and G1 for goats) to prevent mix-ups. Mandibles and pre maxillas were also categorized similarly for accuracy in study.

Table 1: Craniometric parameters with Descriptions

SR#	PARAMETERS	DESCRIPTION
1	SKL	It is the length from the middle of the rostral edge of the incisive bone to the highest points of the parietal bones.
2	SKW	The separation of two zygomatic arches.
3	SKI	Skull length / skull breadth = 100.
4	SKBL	The length of the incisive bone's cranial edge from the center point to the dorsal margin midpoints of the foramen magnum.
5	CL	Length of the nuchal crest from its middle point to the frontonasal suture's center point.
6	CRW	The separation of both horn bases from one another.
7	CRI	Width of the skull times 100 divided by length of the skull.
8	WSH	From the highest level of the frontal bone to the lowest level of the mandible.
9	CRC	The cranial cavity was completely blocked with cotton to create a plug, and then the foramen magnum was completely filled with mustard grains. To find the volume in centimeters three, the mustard grains were put into a measuring cylinder.
10	FAL	The distance measured from the center of the incisive bone to the

		frontonasal suture.
11	**FAW**	The separation between the orbital rims' caudal extents.
12	**FAI**	Face length / facial width (X 100).
13	**ML**	The separation between the frontonasal suture and the parietofrontal suture.
14	**MAW**	The distance between the orbit's rim and the interfrontal suture. .
15	**PML**	The longest segment of the premaxilla
16	**PMW**	The premaxilla's maximum width.
17	**LAL**	The distance measured between the lacrimal and maxilla bone junction and the frontolacrimal suture.
18	**LOW**	The distance measured between the lacrimal and malar bone junction and the frontolacrimal suture.
19	**NAL**	The distance measured between the rostral end of the internasal suture and the central point of the frontonasal suture.
20	**NAW**	The length of the nasal bones or the separation between the naso-maxillary sutures.
21	**NAI**	Nasal length / nasal breadth = 100.
22	**PAL**	The distance that separates the caudal nasal spine of the palatine bone from the rostral mid-sutured line of the incisive bone
23	**PAW**	The separation at the palatine bone's horizontal plate behind the final molar tooth.
24	**TOP**	A single occipital condyle maximum width.
25	**TLPP**	The paracondylar process thickest region is encircled by the circumference.
26	**LPP**	The distance measured from the Para condylar process tip to the squamous occipital bone junction .
27	**OCH**	Distance between the occipital condyle's base and the sagittal crest's beginning..
28	**OCT**	The underside protuberances of the occipital bone in vertebrates, known as the occipital condyles, serve as points of articulation with the superior facets of the atlas vertebra.

29	**ICW**	Width of the occipital condyles between their lateral edges.
30	**IPCW**	Maximum width between the paracondylar processes' ventromedial ends. .
31	**FMH**	The distance measured between the ventral and dorsal rim midpoints of the foramen magnum. .
32	**FMW**	The two occipital condyles are separated by this distance.
33	**FMI**	Foramen magnum width / foramen magnum height X 100
34	**PRH**	Parietal bone maximum height.
35	**PRW**	Maximum parietal bone width .
36	**FRL**	Length of the frontonasal suture and parietofrontalsuture.
37	**FRW**	The separation of the orbit's dorsocaudal edge from the interfrontal suture.
38	**SOFD**	Distance between the two supraorbital foramina.
39	**OHD**	The distance measured horizontally between the orbital rim's caudal and rostral borders
40	**OVD**	The distance measured perpendicularly between the orbit's infraorbital and supraorbital borders.
41	**BL**	The occipital condyles at the level of the jugular process and the cranial alveolar end of the jaw make up the basal length.

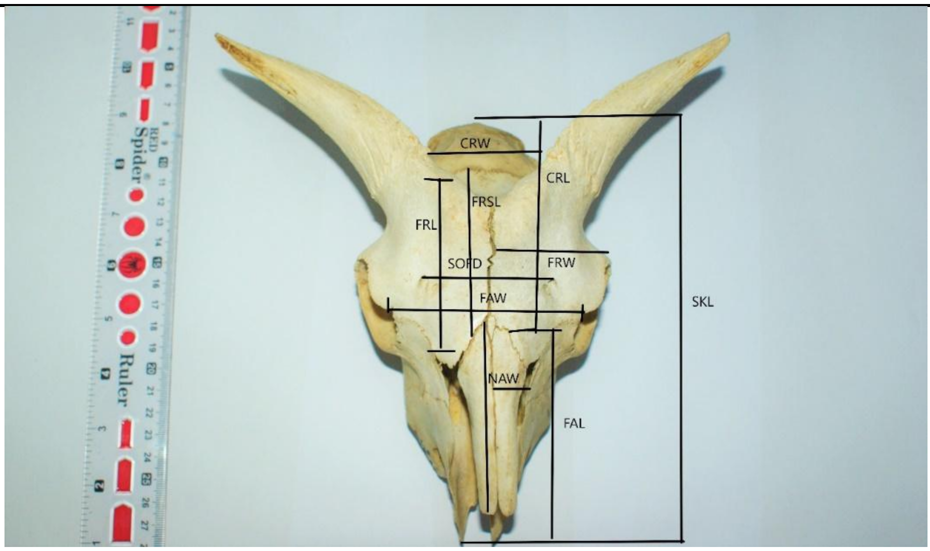

Figure 1: Measurements of skull (Dorsal View)

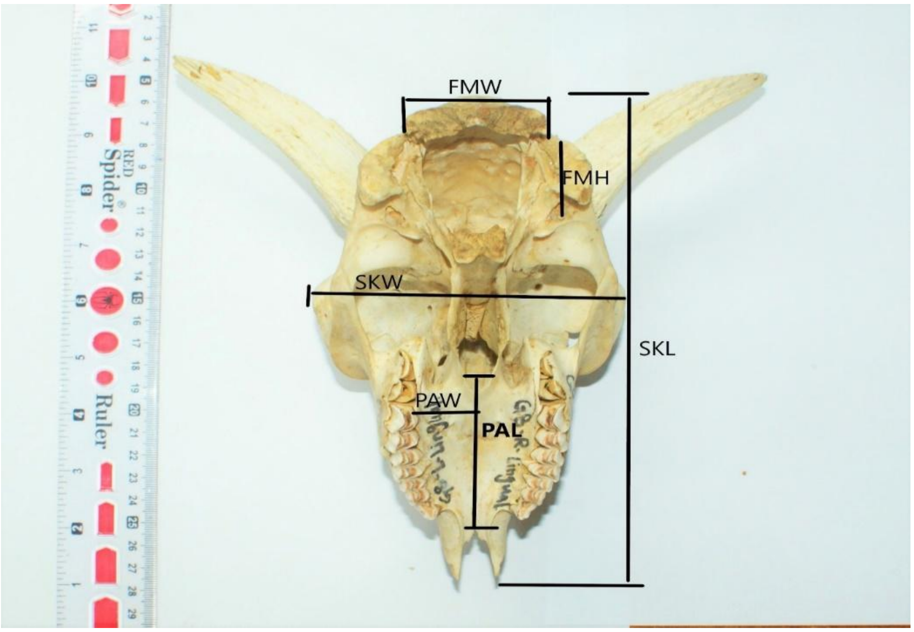

Figure 2: Skull measurements (Ventral View)

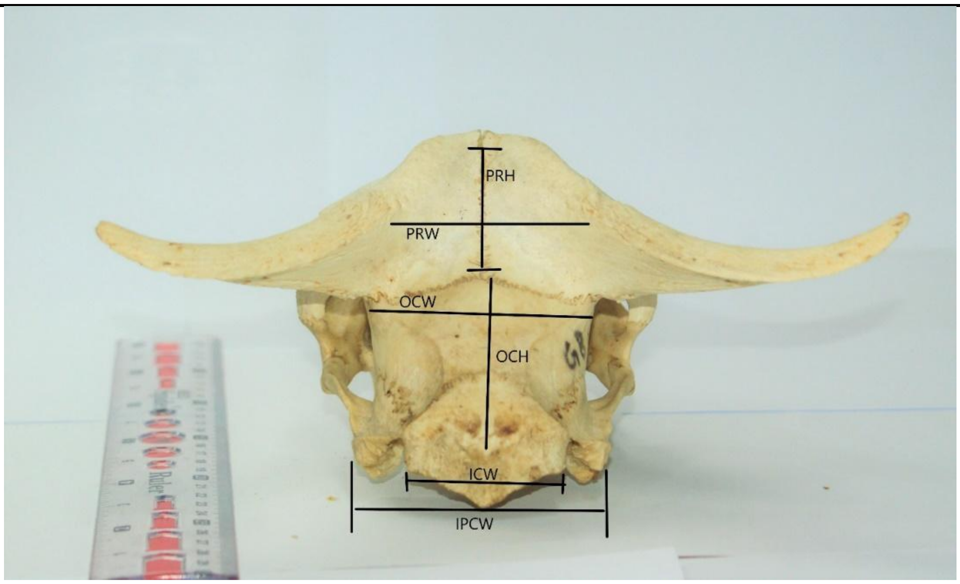

Figure 3: Skull view measurements (Nuchal View)

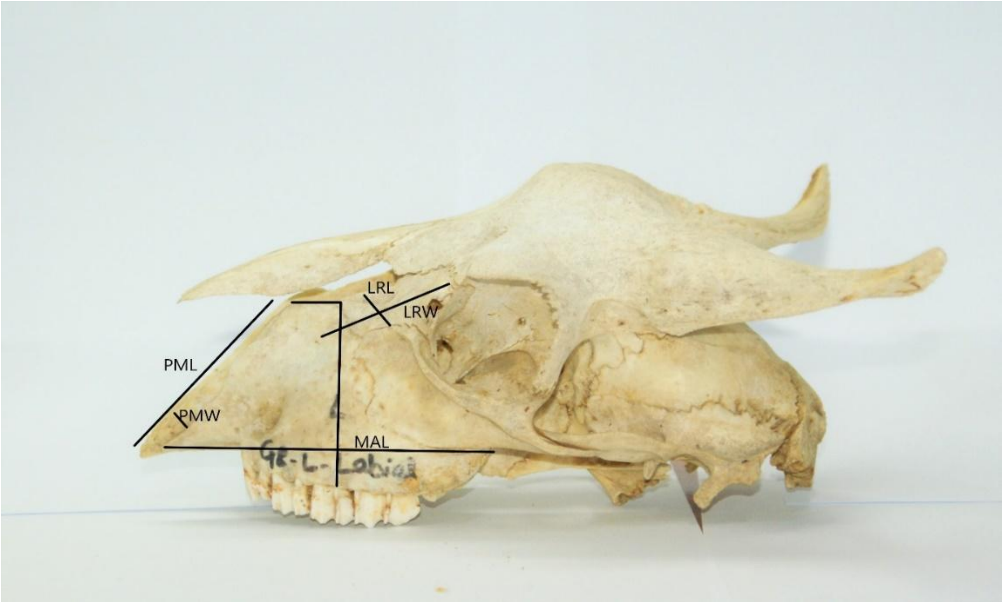

Figure 4: Skull measurements (Lateral View)

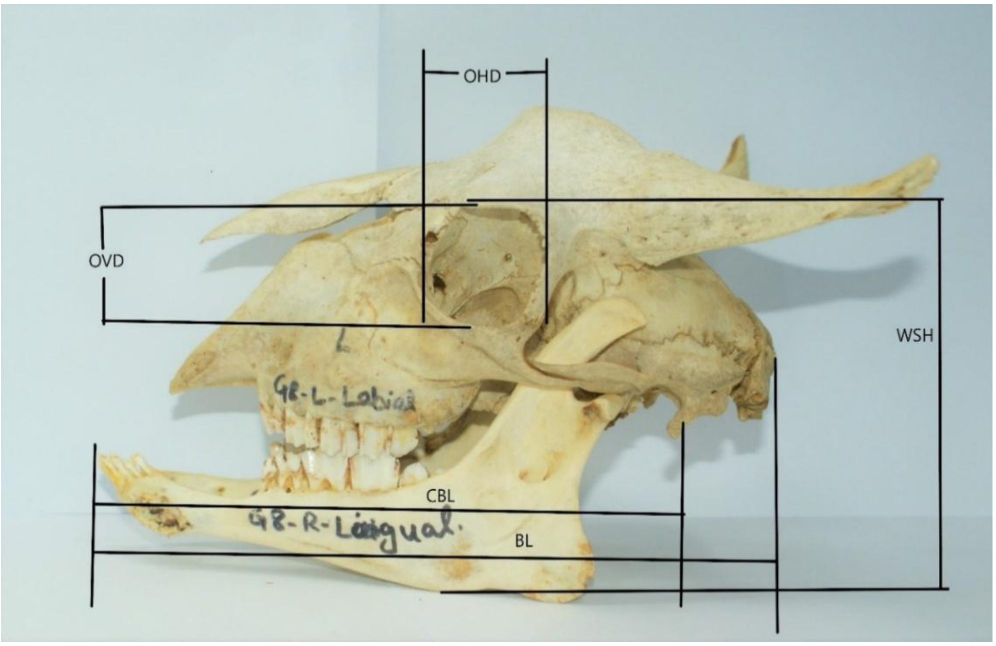

Figure 5: Lateral view schematic depiction of a goat's skull, including mandible

Results and Discussion:

Measurements of linear craniometrics have been made using the skulls of domestic goats (*Capra hiracus*) and sheep (*Ovis aries*). For the skull, face, cranium, mandible, and maxilla, a total of 41 parameters were employed; these are shown in tables 2 and 3, respectively. Moreover, a graph (Fig. 6) is provided that illustrates many metrics and demonstrates notable variations between the two species. The two species differed from one another in almost all physical linear measurements.

IBM SPSS Statistics 20 was the program we utilized for statistical analysis. The mean, standard deviation, and standard error were used to express the specimens' descriptive statistics. The Multivariate Analysis of Variance (MANOVA) test was employed in this research thesis to assess and compare the craniometric differences between both species Analyzing several dependent variables (such as craniometric measures) simultaneously while taking into account their intercorrelations is made possible by MANOVA, a multivariate version of the Analysis of Variance (ANOVA) test. This makes a thorough analysis of the general pattern of variation in these species' cranial morphology possible. By using MANOVA, it becomes possible to determine whether there are statistically significant differences in the combination of craniometrical variables between both species, rather than focusing solely on individual measurements. This approach helps to give insight in the interrelationships and covariation among the measured cranial traits, providing a more holistic understanding difference in their skull morphology. The detailed results are revealed in table,3).

Table 2: Standard deviation, mean, and standard error of both species expressed descriptively

SR#		SKULLID	Mean	Std. Deviation	N
1.	SKL	GOAT	15.9400	1.94628	5
		SHEEP	17.4400	.45607	5
2.	SKW	GOAT	9.5200	1.12561	5
		SHEEP	9.6400	.73689	5
3.	SKI	GOAT	59.8800	5.47604	5

		SHEEP	55.2200	3.88549	5
4.	**SKBL**	GOAT	13.2400	1.03344	5
		SHEEP	12.9400	4.83405	5
5.	**CRL**	GOAT	7.8400	2.05134	5
		SHEEP	8.6200	1.05688	5
6.	**CRW**	GOAT	4.7200	1.21532	5
		SHEEP	4.9000	.80000	5
7.	**CRI**	GOAT	60.7600	7.57813	5
		SHEEP	57.5220	11.77773	5
8.	**WSH**	GOAT	10.0200	1.05688	5
		SHEEP	9.4000	1.30000	5
9.	**CRC**	GOAT	940.0000	45.27693	5
		SHEEP	988.0000	108.94953	5
10.	**FAL**	GOAT	8.5800	.87579	5
		SHEEP	9.9000	.96177	5
11.	**FAW**	GOAT	5.9580	.87924	5
		SHEEP	6.3200	.61290	5
12.	**FAI**	GOAT	57.2420	30.99738	5
		SHEEP	172.1200	239.30829	5
13.	**MAL**	GOAT	7.6200	.63797	5
		SHEEP	7.9000	.82158	5
14.	**MAW**	GOAT	4.5560	.59454	5
		SHEEP	5.0900	.41304	5
15.	**PML**	GOAT	4.7200	.55408	5
		SHEEP	4.8600	1.10815	5
16.	**PMW**	GOAT	.2700	.09028	5
		SHEEP	.4260	.13126	5
17.	**LAL**	GOAT	2.8980	.43689	5
		SHEEP	3.0300	.23473	5
18.	**LRW**	GOAT	1.0220	.22208	5
		SHEEP	1.0960	.08849	5
19.	NAL	GOAT	4.4600	1.34648	5
		SHEEP	4.5600	1.92172	5
20.	**NAW**	GOAT	1.1920	.30874	5
		SHEEP	1.2520	.25791	5
21.	**NAI**	GOAT	72.5000	99.55509	5
		SHEEP	151.8600	278.78724	5
22.	**PAL**	GOAT	5.8000	1.00250	5
		SHEEP	5.8000	.33912	5
23.	**PAW**	GOAT	1.4140	.19870	5
		SHEEP	1.7300	.17176	5
24.	**TOC**	GOAT	1.5200	.37014	5
		SHEEP	1.5200	.37683	5
25.	**TLPP**	GOAT	.4800	.48166	5
		SHEEP	.5400	.18166	5
26.	**LPP**	GOAT	2.2200	.82885	5

		SHEEP	2.9200	.44944	5
27.	**OCH**	GOAT	5.1800	.74632	5
		SHEEP	5.6200	.75961	5
28.	**OCW**	GOAT	4.4560	1.00316	5
		SHEEP	5.1320	.59843	5
29.	**ICW**	GOAT	4.2600	.80187	5
		SHEEP	4.6200	.50695	5
30.	**IPCW**	GOAT	6.0420	.61386	5
		SHEEP	6.5720	.55400	5
31.	**FMH**	GOAT	2.2600	.49295	5
		SHEEP	2.7000	.36742	5
32.	**FMW**	GOAT	2.1400	.61074	5
		SHEEP	2.6600	.56833	5
33.	**FMI**	GOAT	94.0200	8.25179	5
		SHEEP	99.1000	19.51371	5
34.	**PRH**	GOAT	2.8000	.42426	5
		SHEEP	3.8400	1.17388	5
35.	**PRW**	GOAT	3.7800	1.02811	5
		SHEEP	4.7860	.40802	5
36.	**FRL**	GOAT	7.2980	.95051	5
		SHEEP	7.1180	1.50232	5
37.	**FRW**	GOAT	4.1420	.44494	5
		SHEEP	4.6300	.27973	5
38.	**SOFD**	GOAT	4.1120	.21776	5
		SHEEP	4.0600	.32825	5
39.	**OHD**	GOAT	3.3080	.17641	5
		SHEEP	3.5080	.12775	5
40.	**OVD**	GOAT	2.8860	.13686	5
		SHEEP	7.9880	11.29945	5
41.	**BL**	GOAT	16.7400	2.14546	5
		SHEEP	17.6600	1.43805	5

Table 3: Results of MANOVA for all craniometric measurements also indicating significant values of both species

Sr. No	Dependent Variable	Sum of Squares of Type III	DF	Average Square	F	Sig.
1	SKL	5.625[a]	1	5.625	2.815	.042*
2	SKW	.036[b]	1	.036	.040	.046*
3	SKI	54.289[c]	1	54.289	2.408	.159
4	SKBL	.225[d]	1	.225	.018	.039*
5	CRL	1.521[e]	1	1.521	.571	.471
6	CRW	.081[f]	1	.081	.077	.03*

7	**CRI**	26.212[g]	1	26.212	.267	.619
8	**WSH**	.961[h]	1	.961	.685	.432
9	**CRC**	5760.000[i]	1	5760.000	.828	.390
10	**FAL**	4.356[j]	1	4.356	5.149	.043
11	**FAW**	.328[k]	1	.328	.570	.036*
12	**FAI**	32992.387[l]	1	32992.387	1.133	.318
13	**MAL**	.196[m]	1	.196	.362	.564
14	**MAW**	.713[n]	1	.713	2.721	.138
15	**PML**	.049[o]	1	.049	.064	.807
16	**PMW**	.061[p]	1	.061	4.794	.060
17	**LAL**	.044[q]	1	.044	.354	.568
18	**LRW**	.014[r]	1	.014	.479	.508
19	**NAL**	.000[s]	1	.000	.000	.023*
20	**NAW**	.009[t]	1	.009	.111	.747
21	**NAI**	15745.024[u]	1	15745.024	.359	.565
22	**PAL**	.000[s]	1	.000	.000	1.000
23	**PAW**	.250[v]	1	.250	7.238	.027
24	**TOC**	.000[s]	1	.000	.000	1.000
25	**TLPP**	.009[w]	1	.009	.068	.801
26	**LPP**	1.225[x]	1	1.225	2.756	.135
27	**OCH**	.484[y]	1	.484	.854	.383
28	**OCW**	1.142[z]	1	1.142	1.675	.232
29	**ICW**	.324[aa]	1	.324	.720	.421
30	**IPCW**	.702[ab]	1	.702	2.054	.190
31	**FMH**	.484[ac]	1	.484	2.561	.148
32	**FMW**	.676[ad]	1	.676	1.943	.201
33	**FMI**	64.516[ae]	1	64.516	.287	.606
34	**PRH**	2.704[af]	1	2.704	3.471	.099
35	**PRW**	2.530[ag]	1	2.530	4.136	.076
36	**FRL**	.081[ah]	1	.081	.051	.827
37	**FRW**	.595[ai]	1	.595	4.311	.072
38	**SOFD**	.007[aj]	1	.007	.087	.775
39	**OHD**	.100[ak]	1	.100	4.216	.074
40	**OVD**	65.076[al]	1	65.076	1.019	.342
41	**BL**	2.116[am]	1	2.116	.634	.044*

*Significant values ($p<0.05$)

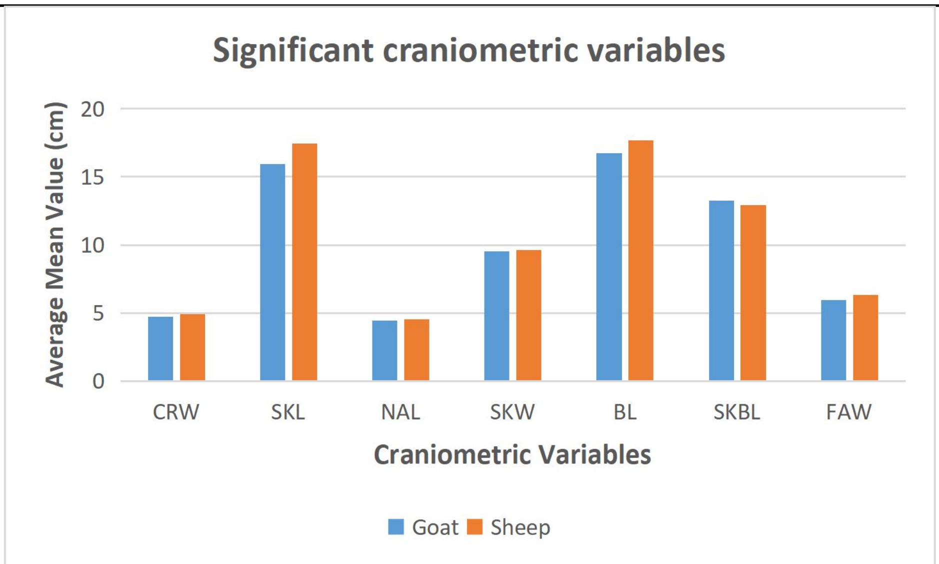

Figure 6: Graphical representation of Significant Craniometrical Variables

DISCUSSION

Comparison between different skull parts and facial parts of goats and sheep indicate complex differences with one being slightly larger than the other in one length and vice versa. The length of the mandible was slightly larger in sheep than in goats. While the face bone length, height of mandible, palatine length, lacrimal bone length, and length of Maxilla showed moderate differences again sheep being larger than goat. The length of the premaxilla showed a marked difference between the two with sheep being larger than goat. Overall, there is a lot of difference in various parts of measurements between the two species which showed inter-species variation with sheep beings lightly large than goat generally (Yudin et al., 2017). Goats and sheep often inhabit different environments and exhibit distinct foraging behaviors. Goats are known for their browsing habits, preferring a wide variety of plants, shrubs, and trees, while sheep are more inclined towards grazing on grasses. These varying feeding patterns could lead to differences in the development and shape of their cranial structures to accommodate different jaw movements and muscle attachments. The nutritional requirements of goats and sheep may differ due to their distinct feeding habits. Goats are generally considered browsers and have evolved to extract nutrients from a broader range of plants, some of which might be more fibrous or harder to digest. In contrast, sheep are primarily grazers and have adaptations for efficiently extracting nutrients from grasses. These different diets may influence cranial morphology to support their specialized feeding habits. However, there had been found significance in few parameters as shown in the table. (Table 3) and their values were less than 0.05. It has been confirmed by many comparisons of these two species of goat and sheep which retain their differences with a certain significant value in seven parameters. These parameters are neurocranium breadth, skull length, nasal length, skull width, basal length, skull base length, and facial width. . The values of all these parameters were greater in *Ovis aries* as compared to *Capra circus* except skull base length which was more in case of Ovis aries. The measurement differences in craniometry between goats and sheep can be attributed to several factors, including inherent anatomical variations and the specific breeding characteristics of each species. Goats (Capra hircus) and sheep (Ovis aries) belong to different genera within the same family, Bovidae. They have distinct evolutionary lineages, and over time, they have developed different characteristics to adapt to their specific environments and feeding habits. (Zeuner, 1963). Goats and sheep encompass various breeds, each with its distinct characteristics. Breeding practices have selectively emphasized certain traits over generations, resulting in differences in skull morphology, skull size, and skull shape. Human intervention through selective breeding can also contribute to differences in craniometric measurements between goat and sheep skulls. Selective breeding for specific traits over generations can lead to variations in skull morphology within each species.For example, some sheep breeds have been bred for specific wool types, while goats may have been bred for meat, milk, or fiber production, leading to variations in skull size and shape. Horns play a significant role in skull measurements. While both goats and sheep can have horns, the size, shape, Goat horns are usually longer, more curved, and oriented backward and upward. Sheep horns, on the other hand, tend to be shorter, less curved, and often spiral in shape (Nadler et al., 1973). There are often differences between male and female skulls within a species. This sexual dimorphism can manifest in variations in size, shape, or specific cranial features. If the measurements are taken from different sexes of goats and sheep, this could contribute to the observed differences. It's important to note that craniometric measurements can also be influenced by individual variation within each species. Therefore, while general trends and differences may exist, there can still be overlap and variation within populations of goats and sheep. Genetic variations between goat and sheep populations can influence the morphology of their skulls. Genetic factors control the development and growth of different anatomical features, including the size and shape of the skull. Goats and sheep have adapted to different environmental conditions, and these adaptations can affect their skull morphology. For example, goats are known for their agility and climbing abilities, which require strong jaw muscles and a more robust skull compared to sheep, which are primarily grazers (Yalcin et al,. 2009) Within a species, there can be natural variations in skull size and shape among individuals. Additionally, craniometric measurements can also differ depending on the age of the animal, as the skull undergoes growth and development during its lifetime. It's important to note that while there are general trends in the craniometric measurements of goat and sheep skulls, there can still be considerable overlap between individual specimens. Therefore, relying solely on craniometric measurements may not be sufficient for accurate species identification, and other morphological or genetic characteristics should be considered as well.

Conclusion: This study was done to report the difference between goat (*Capra hiracus*) and Sheep (*Ovis Aries*) by Craniometric analysis of measurements. Each of the two species' skulls had 41 different cranial parameters assessed. To determine the differences in the skulls of the two species, this study used both multivariate analysis (MANOVA) and descriptive analysis. Many of the parameters showed non significant difference, however a significant difference in the following parameters was observed (for example, facial width, basal length, skull base length, nasal length, skull width, and neurocranium breadth). The values of all these parameters were greater in (*Ovis aries)* as compared to *Capra circus* except skull base length which was more in case of (*Ovis aries).*

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