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Investigation of Elemental Contents in Wild Goat Meat (*Capra aegagrus aegagrus*)

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Abstract: This study focuses on *Capra aegagrus aegagrus*, a subspecies of wild goat listed as vulnerable by the International Union for Conservation of Nature. Hunting of males aged 8 years and older is allowed due to their low reproductive capacity. This study aimed to analyze essential and potentially toxic elements in meat of male *C. aegagrus aegagrus* from a high altitude protected area in Mersin using inductively coupled plasma-optical emission spectroscopy (ICP-OES). Thigh muscle samples from 18 males aged 10 years and older were analyzed. Phosphorus, potassium, and calcium were the most abundant macro elements in the samples, while sodium and magnesium were the lowest. Iron was the most abundant microelement, followed in decreasing order by zinc, copper, manganese, boron, selenium, cobalt, chromium, vanadium, and nickel. Among the potentially toxic metals, lead had the highest concentration. Arsenic, antimony, strontium, cadmium, aluminum, and barium were found in lower concentrations. Tin was not detected in the samples. High levels of potassium, phosphorous, and iron suggest nutritional benefits but potentially toxic elements must be monitored to ensure safety.

Keywords: Element, metal, muscles, vulnerable, wild goat.

Yaban Keçisi Etindeki (*Capra aegagrus aegagrus*) Element İçeriğinin Araştırılması

Öz: Bu çalışma, Uluslararası Doğa Koruma Birliği tarafından hassas olarak listelenen yaban keçisi alt türü *Capra aegagrus aegagrus*'a odaklanmaktadır. Üreme kapasitelerinin düşük olması nedeniyle 8 yaş ve üzeri erkeklerin avlanmasına izin verilmektedir. Bu araştırma, Mersin'deki yüksek rakımlı bir koruma alanından alınan erkek *C. aegagrus aegagrus* etindeki temel ve potansiyel toksik elementleri indüktif eşleşmiş plazma-optik emisyon spektroskopisi (ICP-OES) kullanarak analiz etmeyi amaçlamıştır. Yaşları 10 ve daha büyük olan 18 erkekten alınan uyluk kası örnekleri incelenmiştir. Örneklerde fosfor, potasyum ve kalsiyum en fazla bulunan makro elementler olurken, sodyum ve magnezyum en düşük seviyedeydi. Demir en fazla bulunan mikro elementti ve onu azalan sırayla çinko, bakır, manganez, bor, selenyum, kobalt, krom, vanadyum ve nikel değerleri izliyordu. Potansiyel toksik metaller arasında en yüksek konsantrasyon kurşun olarak tespit edilmiştir. Arsenik, antimon, stronsiyum, kadmiyum, alüminyum ve baryum daha düşük konsantrasyonlarda bulunmuştur. Örneklerde kalay tespit edilememiştir. Yüksek potasyum, fosfor ve demir seviyeleri besinsel faydalara işaret etmektedir, ancak güvenliği sağlamak için potansiyel olarak toksik elementlerin izlenmesi gereklidir.

Anahtar kelimeler: Element, metal, kaslar, hassas, yaban keçisi.

1. Introduction

The wild goat (*Capra aegagrus*) is the ancestor of the domestic goat (*Capra hircus*), a species economically vital to millions worldwide (Taheri et al., 2023). There are five subspecies of *C. aegagrus* globally, with *C. aegagrus* ssp. *aegagrus* found in Turkey. The other subspecies are *C. aegagrus* ssp. *blythi*, *C. aegagrus* ssp. *chialtanensis*, *C. aegagrus* ssp. *cretica,* and *C. aegagrus* ssp. *turcmenica* (Shackleton, 1997). *C. aegagrus aegagrus* is distributed across Armenia, Azerbaijan, Georgia, Iran, Iraq, Russia, Afghanistan, Pakistan, and parts of eastern Asia, including Sindh and Baluchistan. This wild goat is listed as vulnerable (VU) in the World Red List published by the International Union for Conservation of Nature (IUCN) (Gundogdu and Ogurlu, 2009). Adult males measure 120-140 cm in length and weigh 50-85 kg, whereas females are 60-80 cm long and weigh 35-60 kg. Both sexes have beards but only males possess a distinctive black girdle from the shoulders to the forelegs, back, and neck. Both sexes have backward-curved horns, with males' horns measuring 100-145 cm and females' 25-30 cm. The age of the goats can be determined by the annual growth lines and ridges on their horns (Paşalı, 2014).

C. aegagrus aegagrus typically lives for 15-20 years. The mating season spans 3-4 weeks from mid-November to mid-December during which males engage in fights.

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These wild goats are herd animals, led by an old female. Males and females stay together from the breeding season until birthing (Gundogdu and Ogurlu, 2009). Outside of the breeding season, old and strong males live alone or in small groups of 2-3, while females and young males up to three years old form herds in the summer. Births usually occur in May after a gestation period of around five months (Ildoromi et al., 2019). Wild goats seek shelter in nooks and caves in rocky, steep areas at altitudes of 1500 meters or higher. They prefer densely wooded areas for safety and feed on tree and shrub shoots, various grasses, leaves, twigs, and wild fruits. Active during the day, they forage from early morning until dusk, resting at noon in the shade of rocks, dens, or between trees (Abbasian et al., 2004).

In Turkey, *C. aegagrus aegagrus* is included in hunting tourism, where hunting is permitted for males aged 8 years and older with reduced reproductive ability as determined by the competent authority. Hunting of females and males under 8 years is prohibited (Paşalı, 2014). Despite its inclusion in hunting regulations, little is known about wild goats, with existing studies focusing primarily on their behavior. Naturally fed wild goats are considered healthier and their meat is preferred for its superior taste. Red meat from naturally raised animals is a crucial source of animal protein, essential for human nutrition and health due to its vitamins, minerals, antioxidants, and various nutrients.

There is growing interest in the role of micronutrients (essential trace elements and vitamins) in optimizing health and preventing or treating diseases. Trace elements are vital in animal nutrition, required in minimal amounts for basic metabolic processes (Byrne and Murphy, 2022). Deficiencies in trace elements can cause losses comparable to those from infectious and parasitic diseases as these elements significantly influence disease resistance (Çamaş et al., 1994; Taghipour et al., 2021). Therefore, determining the concentration of elements in the muscles of wild goats, which inhabit rocky areas at altitudes of 1500 meters and higher and feed on grass, leaves, twigs, and wild fruits, will provide important nutritional information both for the animals and humans consuming them.

Additionally, animals serve as biomonitors of their environment; thus, the concentrations of toxic metals such as lead, cadmium, aluminum, and arsenic detected in these animals can indicate environmental contamination with these metals. These toxic metals have been reported to inhibit the absorption of other minerals and may indirectly cause mineral deficiencies (Gupta et al., 2021). Furthermore, as these animals are also consumed by humans, this poses an additional risk of human poisoning.

Assessing trace elements is thus crucial for determining nutrient deficiencies or toxicities within a population. There is currently insufficient information on the concentrations of essential elements and toxic metals in wild goats protected in the Cehennem Creek region of Turkey. The aim of this study is to investigate the concentrations of essential and toxic elements in the muscles of wild goats hunted as part of hunting tourism in Cehennem Creek, Mersin province and to use these goats as biomonitors for heavy metal environmental toxicity.

2. Material and Method

This study was conducted on the muscles of wild goats (*C. aegagrus aegagrus*) living in the Çamlıyayla-Cehennem Creek Wildlife Development Area in Mersin, Turkey and hunted as part of hunting tourism. The habitat of these wild goats is shown on the map in Figure 1. This area was granted special protection status by the competent authority in 2006, maintaining its natural structure away from settlements and industrial facilities. It is located at an altitude of at least 3000 meters above sea level. Permitted activities in the region include forestry, beekeeping, sheep and goat husbandry, ecotourism, and hunting tourism. Covering 27,610 hectares, this area is situated in the Mediterranean Region of southern Anatolia, east of the Central Taurus Mountains, at the foot of the Bolkar Range Mountains.

All studies were carried out as part of the Çamlıyayla-Cehennem Creek Wild Animals Capture, Monitoring, Inventory, and Management and Development Plan Construction Project initiated by the 7th Regional Directorate of the General Directorate of Nature Conservation and National Parks of the Ministry of Agriculture and Forestry (tender no: 2017/165207). The tradition of nomadic animal husbandry continues intensively in this area. Thigh muscle samples (approximately 50 g) were collected from 18 male wild goats aged 10 years and older, hunted during the 2018 and 2019 hunting seasons. Tissue samples were collected after the goats were hunted by hunters in the area. The samples were placed in separate glass jars, transported to the laboratory under a cold chain, stored at -21°C until analysis, and analyzed within one week.

The metals sought in thigh muscles were divided into 3 classes; (1) macro elements [calcium (Ca), phosphorous (P), potassium (K), magnesium (Mg), sodium (Na) (2) micro elements [boron (B), iron (Fe), zinc (Zn), manganese (Mn), cobalt (Co), chromium (Cr), copper (Cu), molybden (Mo), nickel (Ni), selenium (Se), vanadium (V)] (3) potentially toxic elements [aluminum (Al), arsenic (As), barium (Ba), cadmium (Cd), lead (Pb), antimony (Sb), tin (Sn) and strontium (Sr)] (World Health Organization, 1996).

Metal analyses were performed according to the United States Environmental Protection Agency (USEPA, 1998) method. Muscle samples were thawed at room temperature, minced thoroughly, and then dried. One gram of the dried, minced muscle was weighed directly into the clean Teflon digestion vessels at 1 mg sensitivity, homogenized with 8 mL of 65% HNO_3 and 2 mL of 30% hydrogen peroxide, and left for 20 minutes. The samples were then decomposed in a 1000-Watt microwave oven (MWS-2, Berghof Brand, Eningen, Germany) with medium pressure vessels using the program shown in Table 1.

Table 1. Microwave oven temperature program used for the decomposition of muscle samples

Step	Temperature (°C)	Power (W)	Time (mins)
1	200	70%	35
2	200	70%	20
3	100	40%	10

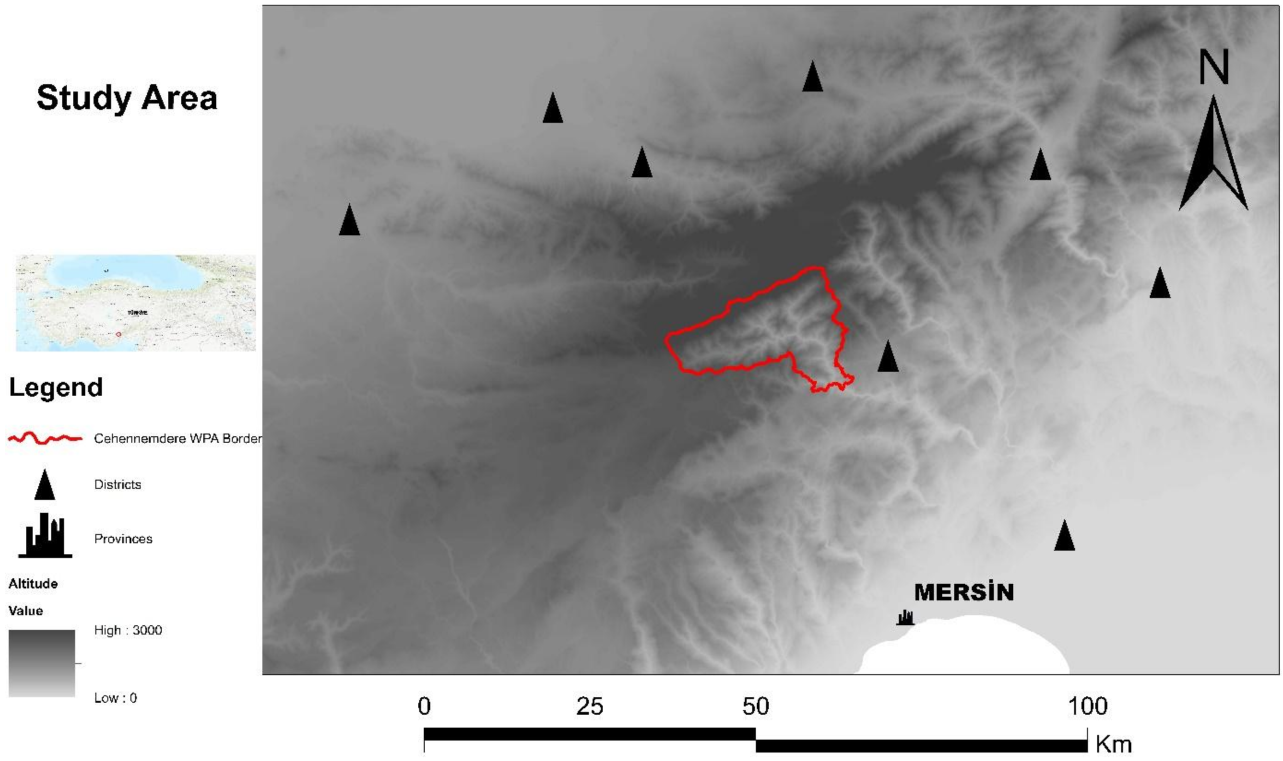

Figure 1. Habitat of sampled wild goats (*C. aegagrus aegagrus*)

All chemicals used in the analysis were of analytical or superior grade and fresh ASTM Type 1 grade ultrapure water was used throughout the study. Blank samples were used to account for the potential trace elements in the digestion chemicals. After digestion, vessels were cooled to room temperature, and digested samples filtered through Whatman No. 4 ashless filter paper and diluted to 15 mL with ultrapure water. Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) was then applied using the ICP-OES-Spectroblue series (SPECTRO Analytical Instruments GmbH, Kleve, Germany) (USEPA, 1998). The instrumental conditions for the ICP-OES measurements are summarized in Table 2. The method was calibrated using a 10-level calibration curve (concentration versus CPS) that was diluted with a 1% aqueous nitric acid solution from a primary multi-element standard (Multimix IV, Merck, Darmstadt, Germany). Quality control was checked against a certified reference material (Merck, Darmstadt, Germany).

Table 2. Inductively Coupled Plasma-Optical Emission Spectroscopy instrument conditions.

Parameters	Value
Plasma Power	1435 W
Pump Speed	30 rpm
Coolant Flow	13 L/min
Auxilary Flow	0.80 L/min
Nebulizer Flow	0.75 L/min
Number of replicates	3
Integration time (s)	3 s
Sample uptake rate (μL/min) (speed)	0.3 rps

The wavelengths used in ICP-OES, correlation coefficients, and calculated detection limits (DL) are provided in Table 3. All macro and micro element concentrations were expressed in mg/100 g dry matter (DM) and potentially toxic elements were expressed in μg/kg DM.

3. Results

The elements detected in the thigh muscles of wild goats and their minimum and maximum levels were given in Table 4. The highest macro elements found in the thigh muscles of wild goats were P, followed by K and Ca, with the lowest levels being Na and Mg (Table 4).

Microelement concentrations in wild goats were highest in Fe, followed in descending order by Zn, Cu, Mn, B, Se, Co, Mo, Cr and V, and lowest in Ni (Table 4).

4. Discussion

In a study (Dey et al., 2019) conducted with 16 Black Bengal goats without specifying age and sex, it was reported that Cu concentrations in the thigh muscle (0.84 mg/100 g) were quite close to the Cu concentrations found in our study, while Mn (0.86 mg/100 g) and Zn (9.09 mg/100 g) concentrations were quite high. However, the Mg concentration reported in the same study (0.051 mg/100 g) was considerably lower than the Mg concentration found in our study (81.32 mg/100 g). This may be explained by the fact that wild goats are more mobile than domestic goats. As it is known, Mg is an important element affecting muscle mass, muscle strength and performance (Castiglioni et al., 2024). On the other hand, Cu, Fe and Mn concentrations found in a study (Ivanović et al., 2016) in Serbian white goats and Balkan goats were considerably lower than the concentrations found in our study. The same situation was found in the concentrations of Mn, Fe, Zn and Cu detected in the muscles of male goats bred as crossbred in Poland. Thus, it is understood that goats may show different mineral compositions according to their feeding habits and breed (Niedziółka et al., 2010).

Table 3. Wavelengths used in ICP-OES, correlation coefficients and calculated detection limit.

Element	Wavelenght (nm)	Correlation Coefficient (r^2)	Detection Limit (µg kg^{-1})
Aluminium	167.1	0.99978	0.06
Antimony	217.6	0.99982	1.80
Arsenic	189.0	0.99970	1.64
Barium	233.5	0.99990	0.03
Boron	249.7	0.99975	6.43
Cadmium	226.5	0.99987	0.01
Calcium	393.4	0.99845	2.14
Chromium	267.7	0.99954	0.08
Cobalt	228.6	0.99924	0.05
Copper	324.7	0.99966	0.63
Iron	238.2	0.99986	0.10
Lead	220.4	0.99973	0.16
Magnesium	285.2	0.99994	1.60
Manganese	257.6	0.99988	0.03
Molybdenum	202.1	0.99982	0.09
Sodium	589.6	0.99859	4.75
Nickel	221.6	0.99982	0.58
Phosphorous	213.6	0.99845	11.2
Potassium	766.5	0.99683	0.38
Selenium	204.1	0.99950	0.62
Strontium	421.6	0.99974	0.03
Tin	242.9	0.99983	0.80
Vanadium	309.3	0.99981	0.31
Zinc	202.6	0.99966	1.52

In contrast to wild goats, Alpine and Saanen kids exhibited the highest levels of K, followed by Na and P, with the lowest levels of Mg and Ca (Mioč et al., 2000). The influence of breed and sex on macro mineral concentration in muscles is minimal, although breed and sex significantly affect K and Mg levels (Park, 1990). Compared to wild goats, the muscles of young kids contain significantly lower levels of P and K, approximately equal levels of Mg and Na, and higher levels of Ca. Kid meat is noted for its high nutritional value due to its protein content, low fat content, and abundance of macro and microelements (Popov-Reljić et al., 1995). The high concentration of K in wild goat muscle tissue is noteworthy because K is essential for maintaining fluid balance, nerve function, and muscle contractions (Vaudin et al., 2022). Additionally, the Ca concentration suggests that wild goat meat could contribute to dietary Ca intake that is crucial for bone health (Tokysheva et al., 2022). The P level aligns with the requirement for ATP production and bone structure (Calvo and Lamberg-Allardt, 2015). The moderate Na content provides essential electrolyte balance without excessively contributing to the recommended Na intake limit (WHO, 2012). Mg is vital for enzyme activity and muscle function (Grober et al., 2015). Several factors, such as sex, age, cooking and processing methods, breed, and management systems, have been reported to influence Ca levels in goat meat. Goat meat contains more Ca than chicken and mutton and less P than beef. It has also been reported that cooked goat meat has much higher Na and Mg content than beef (Sheridan et al., 2003; Osman and Mahgoub, 2012).

Table 4. Element concentrations detected in wild goat thigh muscles (n:18).

Element	Concentrations	Minimum	Maximum
Macro elements (mg 100 g^{-1} Dry Matter)			
Calcium	587.91±65.9	518.41	724.67
Magnesium	81.32±7.9	67.89	99.50
Sodium	260.97±37.22	200.01	330.34
Phosphorous	1656.65±253.1	1298.69	2124.58
Potassium	1157.58±131.2	907.26	1399.83
Micro elements (mg 100 g^{-1} Dry Matter)			
Boron	0.35±0.05	0.25	0.46
Chromium	0.04±0.02	0.01	0.077
Cobalt	0.08±0.03	0.06	0.11
Copper	0.90±0.08	0.76	1.03
Iron	50.67±13.8	35.44	75.13
Manganese	0.50±0.01	0.20	0.69
Molybdenum	0.05±0.006	0.43	0.06
Nickel	0.02±0.01	0.01	0.06
Selenium	0.13±0.04	0.09	0.20
Vanadium	0.04±0.002	0.01	0.06
Zinc	4.10±0.6	2.96	5.1
Potentially toxic elements (µg kg^{-1} Dry Matter)			
Aluminium	4.97±1.2	1.21	17.14
Antimony	35.92±6.3	25.10	47.72
Arsenic	59.39±17.6	25.12	93.78
Barium	4.22±0.8	2.50	5.71
Cadmium	29.21±8.7	15.92	44.59
Lead	654.67±157.3	298.98	898.47
Strontium	29.41±8.8	2.99	45.47
Tin	<DL	-	-

In a study conducted in Alpine and Saanen kids, it was reported that the highest level of Zn was found in the muscles, followed by Cu and Fe and the lowest level was Mn (Mioč et al. (2000). Thus, it is seen that breed and age have a significant effect on micronutrient concentrations in muscles of goats.

Fe is an element particularly associated with anemia. Goat meat can be a good source of heme iron, which has higher bioavailability compared to non-heme iron from plant sources (Park and Attaie, 1988). Zn concentration in wild goat muscle is important because zinc is vital for immune function and cellular metabolism (Prasad, 2013). Zn concentration in wild goats has been shown to be higher than in beef (Hoffman et al., 2003). Cu is an essential trace element for mammals. Besides its role in Fe metabolism, the need for Cu stems from its role in numerous biological processes, including antioxidant defense, neuropeptide synthesis, and immune function (Bost et al., 2016). Co level is essential for vitamin B12 synthesis (Spataru, 2024). The Fe level in cooked goat meat is almost the same as in cooked beef but about twice as high as in chicken meat (Osman and Mahgoub, 2012).

In a study conducted in Omani and Somali goats, V level in muscles was found to be 0.003 and 0.03 mg/100 mg DM, Cr level was found to be 0.01 and 0.11 mg/100 g, and Mo level was found to be 0.13 and 0.16 mg/100 mg DM, respectively (Osman and Mahgoub, 2012). V level in wild goats was close to Somali goats, Cr level was higher than Omani goats but lower than Somali goats and Mo level was lower than both goats. This situation can be explained by race, age, and nutritional status.

According to our knowledge, there is no study on B in goat meat. However, boron is considered as an essential mineral for humans and animals by the World Health Organization (World Health Organization, 1998). In a study, it was found that 70 mg/kg B was added to the feed and fed to male goats for 6 months without affecting growth but there was a significant increase in serum Mg concentrations of male goats fed with B at 24th week (Ibrahim et al., 2023).

Although V is widely used in industrial plants, no harmful effects have been observed in animals or humans. As an analogue of P, it interferes with P metabolism, mimics growth factors, and is involved in cell proliferation, repair and angiogenesis. It is also used in the treatment of diabetes as it has insulin-like effects. The concentration of V in soil and plants, including vegetables, is known to increase near industrial activities (Altaf et al., 2021). However, since there are no industrial facilities near wild goats, it was thought that this could come from other sources.

It has been reported that Cr in goat diets has no effect on carcass characteristics of goats but may improve meat quality with higher protein content, leaner and healthier fatty acids for human consumption (Lalhriatpuii et al., 2024). Cr is known as glucose tolerance factor. It is known to potentiate insulin activity by stimulating insulin receptors on the cell membrane, thereby enabling cells to take up glucose, which maintains blood glucose levels (Zhao et al., 2022). In this study, Cr concentrations in muscles were very close to the Cr concentrations found in Bengal goats by Lalhriatpuii et al (2024). This indicates that there is no difference in Cr concentrations in muscles between wild goats and domestic goats.

The mean Mo concentration detected in wild goat meat (0.05 mg/100 mg DM) was lower than the mean Mo concentration in red deer muscle (0.42 ± 0.07 mg/100 g wet weight) (Skibniewski et al, 2015). Since the Mo concentration measured in this study was lower than those observed in other free-living ruminant species and lower than those found in farmed ruminants, it should be stated that wild goat meat is not a good source of Mo for human dietary requirements.

When evaluated in terms of potentially toxic metals, it is seen that Pb is the highest in goat muscles followed by As, Sb, Sr, Cd, Al, and Ba in decreasing order and Sn metal is not found.

Among the potentially toxic elements, Pb levels (654.67 ± 157.3 ppb) raise concerns given that chronic exposure to lead is associated with neurological and developmental disorders (Bjørklund et al., 2024; Shibeeb et al., 2024). The As levels (59.39 ± 17.64 ppb) also warrant attention, as arsenic exposure can contribute to various health issues like skin lesions and cancer (Tchounwou et al., 2023). Despite the presence of these elements, the concentrations of Sn were below the detection limit and Cd (29.21 ± 8.7 ppb) remains within acceptable limits (European Food Safety Authority., 2012). In the Turkish Food Codex Contaminants Regulation, MRL values in goat meat are given as 200 µg/kg for Pb and 50 µg/kg for Cd. No MRLs were set for other metals in goat meat. Thus, based on the lead concentration detected in wild goat meat according to the legislation in Turkey, it should be stated that health problems may be encountered in people consuming this type of meat.

The levels of Sr (29.41±8.8 µg/kg) observed in goat thigh muscle are noteworthy as strontium is not typically associated with adverse health effects at these concentrations (Curtis et al., 2021). Conversely, the presence of Ba (4.22±0.8 µg/kg) and Al (4.97± 1.4 ppb) at elevated levels suggests potential environmental contamination sources that could affect muscle mineral composition (Pi et al., 2019). Monitoring these levels in wild goat meat is crucial to ensure they remain within safe consumption limits and align with food safety standards set by health organizations like the EFSA and WHO.

Comparing the elemental composition of wild goat muscle tissue to other meats like beef, pork, and chicken, goat meat often has lower fat and cholesterol content while being rich in essential nutrients (Suman and Joseph, 2010). Its high Fe and Zn content makes it a good option for individuals requiring higher intake of these minerals. However, regular monitoring of potentially toxic elements is crucial to ensure safety, particularly in regions with high industrial activity or environmental pollution that could increase contamination (Korish et al., 2020).

5. Conclusion

The analysis of elemental concentrations in wild goat muscle tissue offers valuable insights into the nutritional composition of wild goat meat and its potential health implications. The data obtained can be contextualized within nutritional guidelines and compared to other commonly consumed meats. Additionally, assessing the levels of potentially toxic elements ensures the meat's safety for consumption. In summary, wild goat muscle tissue is a rich source of macro and microelements essential for human health. The high levels of K, P, and Fe make it particularly beneficial. However, it is crucial to monitor the concentrations of potentially toxic elements to ensure they remain within safe consumption limits. Further research comparing the elemental profiles of different cuts and cooking methods would provide additional valuable insights into optimizing the nutritional benefits of goat meat.

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