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ORIGINAL PAPER

Assessment of macro-, trace, and toxic element levels in beef and chicken bone broths*

Filiz Aksu[1], Duygu Tarhan[2], Sema Sandıkçı Altunatmaz[1], İbrahim Ertuğrul Yalçın[3], Deniz Aktaran Bala[1], Mehmet Erman Or[4]

[1] Department of Food Processing, Vocational School of Veterinary Medicine, Istanbul University-Cerrahpasa, Istanbul, Türkiye
[2] Department of Biophysics, School of Medicine, Bahcesehir University, Istanbul, Türkiye
[3] Department of Civil Engineering, Faculty of Engineering and Natural Sciences, Bahcesehir University, Istanbul, Türkiye
[4] Department of Internal Medicine, Faculty of Veterinary Medicine, Istanbul University-Cerrahpasa, Istanbul, Türkiye

Abstract

Bone broth is a product obtained by simmering beef or chicken bones, either on their own or with various aromatic spices, over an extended period, and it is sold in packaged form. In recent years, with the perception that it is a good source of minerals in terms of health and nutrition, the consumption of bone broth has increased. Despite the health benefits of these products, concerns exist regarding the risk of heavy metals. Producing bone broth at home is a difficult and laborious process. For this reason, commercially produced beef and chicken bone broths have been offered for retail sale in recent years. In this study, beef bone broth (n=10) and chicken bone broth (n=3), offered for retail sale, were purchased in their original packaging from various sales points in Istanbul or online in May–June 2024. Macro- and trace element (Ca, Cr, Cu, Fe, K, Mg, Mn, Na, P, Se, Zn) and toxic element (Pb, Al) analyses were performed on the samples using ICP-OES. The lowest and highest values (μg kg^{-1}) for Al, Cr, Cu, Fe, Mn, Se, Pb, Zn were as follows: Al (91.552; 120.739), Cr (1.215; 2.693), Cu (14.838; 21.129), Fe (176.429; 242.346), Mn (8.319; 14.265), Se (15.968; 21.618), Pb (6.335; 9.744), Zn (63.114; 91.286); the lowest and highest values (mg kg^{-1}) for Ca, K, Na, and P were determined as follows: Ca (148.079; 223.233), K (5.682; 6.960), Na (13.549; 17.274), P (90.442; 116.590). The nutritional content of the analyzed samples was evaluated based on a reference daily serving size of 250 mL. The evaluation showed that beef and chicken bone broths were not very good sources of nutrition for most of the analyzed mineral elements; they only partially contributed to nutrition in terms of Se (8.13%), Ca (4.53%), and P (3.72%). Considering the levels of toxic elements lead (Pb) and aluminum (Al), the risk level associated with their consumption is assessed to be low. Future research should utilize larger samples to compare production methods, examine cooking parameters affecting mineral and toxic element transfer into bone broth, and assess further toxic elements.

Keywords: bone broth, mineral element, toxic mineral element, heavy metal, lead

Filiz Aksu, PhD, Prof, Istanbul University-Cerrahpasa, Vocational School of Veterinary Medicine, Department of Food Processing, Food Technology, Istanbul, Avcilar, 34320, Türkiye, e-mail: filiz.aksu@iuc.edu.tr

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INTRODUCTION

Bone broth contains amino acids, minerals, and proteins such as collagen, as it is prepared by simmering various animal bones over an extended period. In recent years, its consumption has increased due to its immune system support, contribution to digestive system functions, and therapeutic effects (Mar-Solís et al. 2021). Bone broth obtained from beef and chicken bones is used in the preparation of various dishes, soups, and sauces. The development of the food industry has led to increased consumption of ready-to-heat products instead of home-cooked broths, which require long cooking times. Bovine bones contain bioactive peptides, a source of naturally occurring functional active components essential for bone cell regeneration, bone growth, and osteoporosis (Mar-Solís et al. 2021). Bone broth is reported to enhance immune system activity, support the digestive system, exhibit anti-inflammatory properties, and conrtibute to blood cell formation owing to its high mineral content (Ozturk and Kerimoğlu 2022). In addition, it is known for its skin and connective tissue regenerative and wound-healing properties in public health (Duman, Gençcelep 2021). Commercially produced and readily consumed products are preferred for flavoring and enhancing the nutritional value of meals. Bone broth soups are also preferred in the healing process of influenza infections and tissue and bone injuries (Ma et al. 2023). Besides, chicken broth is stated to be the most widely known medicinal soup in the world (Ke et al. 2011). It has been reported that fresh bone consists of an average of 25% water, 30% organic matter, and 45% inorganic matter. Inorganic matter constitutes 65% of the dry weight of the bone, with 95% being calcium and phosphorus, while sodium, magnesium, potassium, and fluoride are other inorganic components (Duman, Gençcelep 2021). The importance of micronutrients in nutrition and public health has been increasingly emphasized in recent years. These include calcium, iron, magnesium, essential amino acids, and connective tissue proteins and peptides. It is stated that minerals such as calcium, magnesium, and potassium can help in the production of blood cells, which play an important role in the body's healing mechanism (Chimegee, Dashmaa 2018). Indeed, one of the most important factors influencing consumption preferences for bone broth is the perception that it is a mineral-rich food. However, there are only a limited number of studies on this subject in Turkish and other international literature. It is reported that there is no standard production method for bone broth worldwide, and that it is produced by boiling marrow bones in open or closed pots in water for a long time. As a result, proteins, amino acids, glucosamine, chondroitin sulfate, collagen, vitamins, minerals, and other trace elements can be transferred into the bone broth (Duman and Gençcelep 2021). It is stated that the amounts of calcium and magnesium in bone broth are related to cooking times, and that cooking times of 8-12 h are required for the minerals to transfer to the bone broth (Kim 2006). Furthermore, research indicates that acidification during the bone broth production process increases the transfer of minerals from bone to water, but negatively impacts sensory perception (Hsu et al. 2017, Zou et al. 2021). Before retail sale, roughly 6-12% of the bone is separated and it is important to turn the bones into bone broth as a value-added product (Ozturk, Kerimoğlu 2022). Bone broth consumption is increasingly recommended as part of the paleolithic diet for intestinal and psychological syndrome disorders (such as autism, attention deficit hyperactivity disorder, dyslexia, dyspraxia, depression, and schizophrenia). However, it is stated that bones can sequestr lead, a heavy metal, which can subsequently be mobilized. Indeed, studies showing the presence of lead in bone broth and its potential to reach high concentrations emphasize that this issue should also be taken into consideration in its consumption (Monro et al. 2013). Lead, which is a heavy metals, can cause oxidative stress by damaging the immune system, particularly in humans and animals. Furthermore, studies indicate that lead exposure increases the risk of cancer. Lead is specifically stated to exert a triggering effect on breast cancer (Ebrahimi et al. 2020). Aluminum is a metal commonly found in environmental sources, particularly those with high levels of industrial waste. Humans and animals living in these areas can be heavily exposed to this metal. Literature highlights numerous health risks associated with aluminum exposure, such as oxidative stress, pro-inflammatory effects, immunosuppression, increased risk of breast cancer, and endocrine disruption (Igbokwe et al. 2019). This research was conducted to determine whether industrially produced bone broths of bovine and chicken origin are a good source of various macro- and trace elements, and whether they pose a negative impact on human health in terms of toxic elements (Pb and Al). Since lead and aluminum have a high propensity to bioaccumulate in bone tissue, we specifically analyzed these elements in this study.

MATERIALS AND METHODS

Methods of producing bone broth and obtaining samples

Bone broth samples used in the research were purchased at random from various stores in Istanbul, Türkiye. When buying the samples, the packaging was checked for the batch number, expiration date, any leaks, and if it was not bulging. The purchased samples were transported to the laboratory in a cold chain and stored at +4°C until analysis. A total of 13 commercially produced bone broth samples (10 beef bone broth samples, 3 chicken broth samples) were used in the analyses. According to manufacturer statements and literature information, commercially available bone broth is produced as follows: beef femur bones are generally used in the production of these products. Bones are divided into 100-150 g portions, washed three times by soaking them in 50°C water for 15 min to remove blood and fat particles. To enhance the flavor before boiling, bones are roasted in an oven for some time. Then, clean water is added to a boiling pot, and white vinegar (20 mL vinegar L^{-1} water) is used to acidify the water. Once the water reaches boiling point (100°C), pre-cooked bones are added, and the cooking process continues slowly (8-12 h) – Mar-Solís et al. (2021). During the cooking process, some companies may add aromatic vegetables and spices (bay leaf, cloves, garlic, onion, carrot, rosemary, celery stalks, peppercorns, thyme, parsley, salt) to the boiling water. After cooking, bone broth is cooled to room temperature within 3 h and then refrigerated at 4°C for 6 hours. It is filtered to remove bones and spices, then packaged and sold. The average shelf life before opening is stated as 4 months; after opening, it is recommended to keep it refrigerated and consume within 48 hours.

Mineral analyses

The amounts of calcium (Ca), chromium (Cr), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), phosphorus (P), selenium (Se), zinc (Zn), lead (Pb), and aluminum (Al) in bone broths were analyzed using ICP-OES (inductively coupled plasma optical emission spectrophotometry).

Samples were collected in sterile containers and transferred into 2 mL sterile tubes for laboratory processing. Until analysis, all samples were preserved at -20 °C to maintain stability. Before digestion, the samples were allowed to equilibrate to room temperature. An aliquot of 0.500 mL from each sample was then placed into teflon vessels suitable for a Berghof MWS-2 microwave digestion system. For mineralization, 8 mL of concentrated nitric acid (65%, Merck) was added to each vessel. The mixtures were subjected to microwave-assisted digestion to break down the organic matrix of the bone broth and release the dissolved elements. After completion of the digestion procedure, the solutions were passed through Whatman filter paper and transferred into sterile 50 mL tubes. The final volume of each digest was brought to 50 mL using ultrapure deionized water. The prepared solutions were subsequently analyzed for their elemental composition using inductively coupled plasma – optical emission spectrometry (ICP-OES; Perkin-Elmer Optima 7000 DV). The concentrations of Al, Ca, Cr, Cu, Fe, K, Mg, Mn, Na, P, Se, Pb, and Zn were quantified. Instrument calibration was carried out using a certified multi-element standard solution (1000 mg L^{-1}, Merck) to ensure analytical accuracy. Elemental concentrations were determined using a PerkinElmer Optima 7000DV inductively coupled plasma – optical emission spectroscopy (ICP-OES) system. During the analysis, the sample flow rate was set to 1.50 mL min^{-1}, the plasma gas flow rate to 17 L min^{-1}, the power to 1450 W, the flush time to 15 s, and the argon carrier flow rate to 0.2 L min^{-1}. Instrumental analytical parameters and validation data for determining element concentrations using the ICP-OES method are given in Table 1.

Table 1

Instrumental analytical parameters and validation data for ICP-OES determination of elemental concentrations

Element	Spectral line (nm)	LoD (μg kg^{-1})	LoQ (μg kg^{-1})	RSD (%)	R^2
Al	396.153	4.124	13.747	1.02	.999816
Ca	317.933	10.711	35.703	0.81	.999733
Cr	267.716	0.231	0.770	0.90	.999914
Cu	327.393	2.327	7.757	1.25	.999901
Fe	238.204	4.957	14.857	0.96	.999778
K	766.490	7.116	23.720	1.11	.999901
Mg	285.213	2.872	9.573	1.05	.999827
Mn	257.610	0.813	2.710	0.88	.999794
Na	589.592	8.846	29.487	1.03	.999830
P	213.617	13.685	45.617	0.85	.999854
Pb	220.353	2.006	6.687	0.79	.999798
Se	196.026	0.761	2.537	0.94	.999765
Zn	213.857	1.065	3.550	0.76	.999942

LoD – limit of detection, LoQ – limit of quantification, RSD – relative standard deviation, R^2 – determination coefficient

Evaluation of the nutritional effects of bone broth samples

The mineral elements obtained from bone broth, as indicated by (*) in Table 2, were calculated according to the reference values (Recommended Safe Level of Intake of Energy and Nutrients for Türkiye) given in the Dietary Guidelines For Türkiye published by the General Directorate of Basic Health Services, Food Safety Community Nutrition Department of the Ministry of Health of the Republic of Türkiye (Dietary Guidelines for Türkiye, 2004) for healthy male individuals aged 19-29. In Table 2, the nutritional contribution of an adult individual was calculated based on the assumption that they could consume 250 mL of bone broth per day.

Determining the hazard ratio (HR)

To assess the potential health risks of consuming bone broth, the Hazard Ratio (HR) was determined by dividing the amount obtained from 1000 mL of bone broth by the recommended daily intake in mg-μg. HR1 value indicates an increased likelihood of health risks associated with consuming the mineral, while an HR $\leq$ 1 value indicates that there are no health risks associated with consuming the mineral (Hsu et al. 2017).

RESULTS AND DISCUSSION

Table 2 presents the recommended daily intake (RDI) for various mineral elements in beef and chicken bone broth, the average values obtained from the analyzed samples, the percentage of daily requirements met depending on consumption (%), and the Hazard Ratio calculation values.

According to the findings of the study, the highest mineral amounts for 9 mineral elements (Ca, Cu, Fe, K, Mg, Na, P, Se, Zn) were identified in beef bone broth samples (n=10), while the highest amounts for 2 elements (Cr, Mn) were detected in chicken bone broth samples (n=3). In terms of toxic elements, the highest levels of Pb were obtained from beef bone broth, while the highest levels of Al were obtained from chicken bone broth. According to the research findings, the lowest mineral values for 10 mineral elements (Ca, Cr, Cu, Fe, K, Mg, Na, P, Se, Zn) were obtained from chicken bone broth (n=3), and for 1 mineral element (Mn) from beef bone broth (n=10). The lowest levels of toxic elements (Pb, Al) were obtained from chicken bone broth. When the recommended mineral levels for adult consumption are examined in Table 2, it is recognized that considering a daily consumption of 250 mL of bone broth, it meets 8.13% of the Se requirement, 4.53% of the Ca requirement, and 3.72% of the P requirement, while contributing between 0.12% and 1.62% for the other minerals examined. In terms of toxic elements (Pb and Al), it was found that the PTDI (Provisional Tolerable Daily Intake) values were below the limit values; when the Hazard Ratio was evaluated, data below HR≤1 were attained in the evaluation of all elements.

Table 2 shows the average values for mineral and toxic elements obtained from beef and chicken bone broths. The minimum, maximum, and average values gained from mineral and toxic elements are as follows, respectively: Ca (148.079; 223.233; 181.443 mg kg^{-1}); Cr (1.215; 2.693; 2.150 μg kg^{-1}); Cu (14.838; 21.129; 17.265 μg kg^{-1}); Fe (176.429; 242.346; 214.316 μg kg^{-1}); K (5.682; 6.960; 6.332 mg kg^{-1}); Mg (9.015; 11.345; 10.217 mg kg^{-1}); Mn (8.319; 14.265; 11.325 μg kg^{-1}); Na (13.549; 17.274; 15.525 mg kg^{-1}); P (90.442; 116.590; 104.370 mg kg^{-1}); Se (15.968; 21.618; 17.906 μg kg^{-1}); Zn (63.114; 91.286; 73.576 μg kg^{-1}); Al (91.552; 120.739; 106.687 μg kg^{-1}); Pb (6.335; 9.744; 8.563 μg kg^{-1}).

Commercially produced bone broth has become a preferred product, particularly in the nutrition of the elderly and children, due to the belief that it provides mineral and collagen support. Since the transfer of minerals from bones to water increases with cooking time, 8-12 h of cooking are required, making home production impractical in terms of cost and time. Modern food technology allows these products to be produced and packaged in industrial conditions, and then sold in packages that can be stored at room temperature until consumption. Bone broth is generally consumed to add flavor to various soups and dishes, to benefit from its healing properties in influenza infections, and in elderly nutrition to protect bone health. One of the most

Table 2

Mineral content in bone broths in relation to recommended daily intake, their hazard ratios, minimum, maximum and standard deviation

Minerals	Recommended Daily Intake (RDI)	Mineral contents in current study (mean)	Daily value (%) (for 250 mL consumption)	HR (hazard ratio)	Min.	Max.	SD
Calcium Ca)*	1000 mg	181.443 mg kg^{-1}	4.53	≤1	148.079	223.233	19.864
Chromium (Cr)*	33 µg	2.150 µg kg^{-1}	1.62	≤1	1.215	2.693	0.431
Copper (Cu)*	900 µg	17.265 µg kg^{-1}	0.47	≤1	14.838	21.129	1.562
Iron (Fe)*	10 000 µg	214.316 µg kg^{-1}	0.53	≤1	176.429	242.346	19.630
Potassium (K)	3800 mg	6.332 mg kg^{-1}	0.40	≤1	5.682	6.960	0.388
Magnesium (Mg)*	400 mg	10.217 mg kg^{-1}	0.63	≤1	9.015	11.345	0.662
Manganese (Mn)*	2300 µg	11.325 µg kg^{-1}	0.12	≤1	8.319	14.265	1.353
Sodium (Na)	2000 mg	15.525 mg kg^{-1}	0.19	≤1	13.549	17.274	1.029
Phosphorus (P)*	700 mg	104.370 mg kg^{-1}	3.72	≤1	90.442	116.590	7.145
Selenium (Se)*	55 µg	17.906 µg kg^{-1}	8.13	≤1	12.355	21.618	2.132
Zinc (Zn)*	11 000 µg	73.576 µg kg^{-1}	0.16	≤1	63.114	91.286	6.895
Toxic elements	Provisional tolerable daily intake (PTDI)	Toxic mineral contents in current study (mean)	Daily value (%)	HR (hazard ratio)	min.	max.	SD
Lead (Pb)	250 µg	8.563 µg kg^{-1}	-	≤1	6.335	9.744	0.831
Aluminum (Al)	7000 µg	106.687 µg kg^{-1}	-	≤1	91.552	120.739	8.168

* RDI – Dietary Guidelines for Türkiye, 2004

important reasons for choosing to consume bone broth is to receive mineral support. Indeed, inorganic components make up 65% of the dry weight of bone, with 95% of this being calcium and phosphorus, while the remainder consists mainly of sodium, magnesium, potassium, and fluoride (Duman et al. 2021). Macrominerals, particularly calcium and magnesium, have important functions in the skeletal system, and their deficiencies lead to problems associated with osteoporosis and cardiovascular diseases (Swaminathan 2003, Pickering 2021). The mineral with the highest expected benefit from bone broth is calcium (Ca), but this study showed that consuming a 250 mL serving provided an average of 45.36 mg which only met 4.53% of the daily requirement. Milk is one of the richest sources of calcium. The amount of Ca in milk is 300 mg $(240\ mL)^{-1}$, and consuming a similar amount can meet 31% of the daily requirement (Miller et al. 2001). Compared to milk, bone broth consumption provides only a negligible amount of Ca, indicating that it is not a good source of this mineral. In a study similar to ours conducted in Korea, commercially produced bone broths were found to contain an average of 7.6 mg (250 g^{-1}) of Ca and 2.6 mg (250 g^{-1}) of Mg, indicating that beef bone broths have low Ca and Mg content. The results of our study are consistent with that study (Choi et al. 2025). The mineral levels of bone broths vary depending on many parameters, including animal breed, species, cooking methods, bone type, region where the animal was raised, and the pH of the solvent. In terms of cooking methods, our research revealed that commercial bone broth samples were produced using high-temperature, long-duration cooking techniques, as stated by the producers. A study investigating the effects of different cooking methods on bone broth indicated that boiling was the best method, particularly for the transfer of minerals like K, Ca, Mg, and Na into the liquid medium. In the relevant study, the amounts of mineral elements K (566 μg g^{-1}), Ca (15.76 μg g^{-1}), Mg (33.48 μg g^{-1}), and Na (298 μg g^{-1}) were determined from chicken bone broth made by boiling method (Zou et al. 2021). In our study, the average amounts of K (6.403 mg kg^{-1}), Ca (165.226 mg kg^{-1}), Mg (10.026 mg kg^{-1}), and Na (15.104 mg kg^{-1}) were determined from chicken bone broths (n=3). When comparing the research data, it is observed that our results regarding K, Mg, and Na are lower than those of the researchers, while Ca is noticeably higher. This suggests that the low Na and high Ca levels may provide an advantage in terms of chicken broth, which is generally recommended for patient nutrition. The difference between the studies is thought to be due to the different chicken breeds used (Silkie chicken in the relevant study). In our country, broiler chickens are generally used in the production of chicken broth. It has been reported that calcium, magnesium, and iron minerals were detected in concentrated bone broths obtained using beef bones at levels of (85.3; 46.7 and 23.3 mg (100 g^{-1}) respectively. Based on these data, it has been stated that consuming concentrated beef bone broth can meet 8.5% of the daily calcium requirement, 21.2% of the magnesium requirement, and 12.9% of the iron requirement (Chimegee et al. 2018). In the relevant study, the ratio of data obtained from a 100 g quantity of concentrated beef bone broth to daily consumption was evaluated. Our research data, however, were evaluated at a 250 mL consumption level, and the ratios to meeting daily needs were given. When these data are compared, it is understood that consuming 1000 g of concentrated beef bone broth meets more than 100% of the daily requirement for Mg and Fe, and 85% for Ca. However, in the beef bone broth we studied (n=10), the average levels of Ca (186.308 mg kg^{-1}), Mg (10.275 mg kg^{-1}) and Fe (219.548 μg kg^{-1}) were detected, and it was observed that consuming 250 mL met 4.65%, 0.64%, and 0.54% of the daily requirement, respectively. The significant differences between the two studies are attributed to the fact that the data in the relevant research were obtained from concentrated beef bone broths. It has been stated that mineral elements at the levels of Na (356.7 mg kg^{-1}), Mg (7.4 mg kg^{-1}), K (76.179 mg kg^{-1}), Ca (20 mg kg^{-1}), P (23.6 mg kg^{-1}), Fe (4.2 mg kg^{-1}), and Zn (0.2 mg kg^{-1}) were obtained from beef bone broth samples prepared without the addition of any aromatic substances (Sarı 2023). According to the findings of our study, the average mineral element values determined from beef bone broths (n=10) were Na (15.651 mg kg^{-1}), Mg (10.275 mg kg^{-1}), K (6.345 mg kg^{-1}), Ca (186.308 mg kg^{-1}), P (105.407 mg kg^{-1}), Fe (219.548 μg kg^{-1}), and Zn (74.520 μg kg^{-1}). When our research data are compared with the relevant research data, it is seen that the values obtained are lower for Na, K, Fe, and Zn; and higher for Mg, Ca, and P. These differences are thought to be due to variations in the type of animal used in broth extraction, bone type, cooking time, and acidity levels. In a study investigating the effect of time on the transfer of essential and toxic elements from beef bones into bone broth, it was stated that some elements increased (Cr, Fe, Mg, Ca) and others decreased (Pb, Cu, Zn, Al) depending on the time (Hsu et al. 2017). In this study, element values at an 8-hour cooking time were used as a reference because they were consistent with our research samples. According to the relevant research results, the following element values were determined: Pb (2.98 ± 1.22 μg kg^{-1}), Cr (4.50 ± 1.82 μg kg^{-1}), Cu (14.4 ± 3.51 μg kg^{-1}), Fe (187 ± 33.2 μg kg^{-1}), Zn (90.3 ± 38.3 μg kg^{-1}), Al (327 ± 156 μg kg^{-1}), Mg (53.3 ± 15.7 mg kg^{-1}), Ca (371 ± 75.4 mg kg^{-1}). According to the results of our research, the average element values of Pb (8.849 μg kg^{-1}), Cr (2.270 μg kg^{-1}), Cu (17.479 μg kg^{-1}), Fe (219.548 μg kg^{-1}), Zn (74.520 μg kg^{-1}), Al (107.120 μg kg^{-1}), Mg (10.275 mg kg^{-1}), Ca (186.308 mg kg^{-1}) were determined from the beef bone broth samples (n=10). When compared with this research, the elements found in our study can be ranked as follows: high (Pb, Cu, Fe) and low (Cr, Zn, Al, Mg, Ca). The relevant study indicated that, contrary to expectations, the levels of macro-minerals such as Ca and Mg in bone broth were not very high, and the amounts per serving represented only a small percentage of the daily recommended intake. Furthermore, the risk factors for the toxic elements (Pb, Al) analyzed in our study were found to be low, similar to the results for heavy metals like Pb and Cd analyzed in the relevant study, suggesting that the risks associated with consuming heavy metals and toxic elements from bone broth are minimal. Aluminum and lead are toxic metals for many organisms, including humans, and while they can accumulate in many organs of the human body, the central nervous system is the primary target for both metals (Verstraeten et al. 2008). It is thought that these types of toxic elements can contaminate food, particularly from environmental sources, and food contamination is frequently investigated. Various studies have indicated that environmentally induced lead contamination can adhere to and then be mobilized from animal bones. In this regard, when the lead levels in chicken broths were investigated, 2.3 μg L^{-1} of lead was detected in broths produced from boneless chicken meat, and 7.01 μg L^{-1} of lead was detected in bone broths produced using chicken bones, and these values were stated as high for chicken broth (Monro et al. 2013). In our study, lead was detected in an average of 7.612 μg kg^{-1} from chicken broths (n=3). Our research result is similar to the result of the relevant research. However, according to the Turkish Food Codex Contaminants Regulations (2023), the maximum lead limit values in many different food categories are expressed in the range of 0.010-2.0 mg kg^{-1}. Although there is no specific limit value for lead in bone broths, since the detected lead value was below 0.010 mg kg^{-1}, which is given for various foods in the Turkish Food Codex Contaminants Regulation, it is thought that broth is not in a high-risk category in terms of Pb, contrary to what was stated by Monro et al. (2013). Mineral analyses of beef bone broth (mg (100 mL^{-1}) revealed the following amounts; Ca (6.4160), Mg (1.8460), P (2.0370), Na (12.5840), K (1.9610), Fe (0.0430), Cu (0.0310), Zn (0.0970), Mn (0.0022), Co (0,0004) (Mar-Solís et al. 2021). Researchers have reported that, similar to our study, they found HR values of ≤1 for all mineral elements and that consuming these minerals through bone broth does not pose a risk. When various research results are evaluated generally, it is seen that achieving a standard mineral composition in bone broths is difficult. The most important factors contributing to these differences are different extraction methods, mineral transfers due to acidification, animal breed and species, types of bones used, the environmental conditions in which the animals were raised, and the spices and other flavoring components added to the bone broth.

CONCLUSIONS

Analysis of commercially produced and sold beef and chicken bone broths revealed that, based on a daily consumption of 250 mL portions, they contribute to nutrition at the levels of Se (8.13%), Ca (4.53%), and P (3.72%), while other investigated mineral elements contribute between 0.12% and 1.62%. Therefore, it has been determined that bone broth consumption does not meet expectations for high mineral levels and, contrary to popular belief, is a product with low nutritional value in terms of minerals. Since various mineral elements (Ca, Cr, Cu, Fe, K, Mg, Mn, Na, P, Se, Zn) and toxic mineral elements (Pb, Al) have HR (hazard ratio) values of ≤1, it is considered that consumption of these minerals and toxic elements does not pose a risk. In light of the results obtained from this research, it is recommended that future studies utilize wider sample groups for comparative analyses of distinct production methods, examine the impact of cooking parameters on the transfer of minerals and toxic elements into bone broth, and comprehensively assess other toxic elements.

Author contributions

F.A – supervision, investigation, writing, review, editing, original draft preparation, funding acquisition; S.S.A. – writing, review, funding acquisition; D.A.B. – review, funding acquisition; D.T. – methodology, formal analysis, funding acquisition; İ.E.Y. – methodology, formal analysis, funding acquisition; M. E. O. – review, editing, funding acquisition. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors of this study declare that there are no conflicts of interest.

REFERENCES

Castrica, M., Andoni, E., Quattrone, A., Koleci, X., Ozuni, E., Zalla, P., Postoli, R., Menchetti, L., Bilgiç, B., Tarhan, D., Yalcin, I. E., Dova, I., Fehri, N. E., Or, M. E., Munga, A., Beqiraj, D., Curone, G., Agradi, S. (2025) 'Livestock animal hair as an indicator of environmental heavy metals pollution in central Albania', *Animals*, 15(13), 1898, available: https://doi.org/10.3390/ani15131898

Chimegee, N., Dashmaa, D. (2018) 'The daily value of micronutrients in newly produced beef and horse concentrated bone broths', *Mongolian Journal of Agricultural Sciences*, 23(01), 30-34, available: https://mongoliajol.info/index.php/MJAS/article/view/1018

Choi, M., Kim, M. (2025) 'Nutritional evaluation of beef-bone broth products: focus on calcium, phosphorus, and magnesium content', *Journal of Elementology*, 30(1), 115-127, available: https://doi.org/10.5601/jelem.2024.29.3.3399

Dietary Guidelines for Turkey (2004). The Ministry of Health of Turkey, General Directorate of Primary Health Care, Food Safety Department, Community Nutrition Division.

Duman, M., Gençcelep, H. (2021) 'Kemik Suyu Üretimi ve Sağlık Üzerine Etkileri', 3. Tarım Gıda Etiği Kongresi Kitabı, 1.Basım, Ankara, p. 271

Ebrahimi, M., Khalili, N., Razi, S. et al. (2020) 'Effects of lead and cadmium on the immune system and cancer progression', *Journal of Environmental Health Science Engineering,* 18, 335-343, available: https://doi.org/10.1007/s40201-020-00455-2

Güneş, B.G., Uçmak, Z.G., Koenhemsi, L., Tarhan, D., Yalcın, I.E., Or, M.E., Halaç, B., Ak, S. (2025) 'Element status and inflammatory response in dogs with pyometra', *Journal of Trace Elements Medicine and Biological*, 90, 127696, available: https://doi.org/10.1016/j.jtemb.2025.127696

Hsu, D., Lee, C., Tsai,W., Chien, Y. (2017) 'Essential and toxic metals in animal bone broths', *Food & Nutrition Research*, 61(1), 1347478, available: https://doi.org/10.1080/16546628.2017.1347478

Igbokwe, I.O., Igwenagu, E., Igbokwe, N.A. (2019). 'Aluminium toxicosis: a review of toxic actions and effects', *Interdisciplinary Toxicology*, 12(2), 45-70, available: https://doi.org/10.2478/intox-2019-0007

Ke, L., Zhou, J., Lu, W., Gao, G., Rao, P. (2011) 'The power of soups: Super-hero or team-work?', *Trends in Food Science and Technology*, 22(9), 492-497, available: https://doi.org/10.1016/j.tifs.2011.06.004

Kim, M.S. (2006) 'The effect on the nutrition value of beef leg and rib bone soup by boiling time', *Journal of the Korean Society of Food Culture*, 21(2), 161-165, available: https://doi.org/10.7318/KJFC.2006.21.2.161

Ma, C., Tian, X., Li, Y., Guo, J., Wang, X., Chen, S., Wang, W. (2023) 'Using high-temperature cooking for different times for bone soup: physicochemical properties, protein oxidation and nutritional value', *Journal of Food Composition and Analysis*, 122, 105467, available: https://doi.org/10.1016/j.jfca.2023.105467

Mar-Solís, L.M., Soto-Domínguez,A., Rodríguez Tovar,L.E., Rodríguez Rocha, H., GarcíaGarcía, A., Aguirre-Arzola, V.E., Zamora-Ávila, D.E., Garza-Arredondo, A.J., Castillo-Velázquez, U. (2021) 'Analysis of the anti-inflammatory capacity of bone broth in a murine model of ulcerative colitis', *Medicina*, 57, 1138, available: doi.org/10.3390/medicina57111138

Miller, G.D., Jarvis, J.K., McBean, L.D. (2001) 'The importance of meeting calcium needs with foods', *Journal of the American College of Nutrition*, 20(2), 168-185, available: https://doi.org/10.1080/07315724.2001.10719029

Monro, J. A., Leon, R., Puri, B. K. (2013) 'The risk of lead contamination in bone broth diets', *Medical Hypotheses*, 80(4), 389-390, available: https://doi.org/10.1016/j.mehy.2012.12.026

Ozturk, M. U., Kerimoğlu, B. Ö. (2022) 'Characterization of industrial bone broths formulated with various meat and non-meat ingredients', *Gıda*, 47(6), 1092-1103, available: https://doi.org/10.15237/gida.GD22074

Pickering, M.E. (2021) 'Cross-talks between the cardiovascular disease-sarcopenia-osteoporosis triad and magnesium in humans', *International Journal of Molecular Sciences*, 22(16), 9102, available: https://doi.org/10.3390/ijms22169102

Sarı, H. (2023) 'Kasaplık Hayvanlardan Üretilen Kemik Suyu Tozlarının Depolama Stabiliteleri Üzerine Adaçayı ve Zencefil İlavesinin Etkisi', *Selçuk Üniversitesi Fen Bilimleri Enstitüsü Doktora Tezi*, Konya.

Swaminathan, R. (2003) 'Magnesium metabolism and its disorders', *The Clinical Biochemist Reviews,* 24(2), 47-66, available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1855626/

Turkish Food Codex Contaminants Regulations (2023). Official Gazette, No 32360.

Verstraeten, V.S., Aimo, L., Oteiza, P. (2008) 'Aluminium and lead: molecular mechanisms of brain toxicity', *Archives Toxicology*, 82, 789-802, available https://doi.org/10.1007/s00204-008-0345-3

Zou, J., Xu, M., Zou, Y., Yang, B. (2021) 'Chemical compositions and sensory characteristics of pork rib and silkie chicken soups prepared by various cooking techniques', *Food Chemistry,* 345, 128755, available: https://doi.org/10.1016/j.foodchem.2020.128755