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Elemental Composition of Muscle Tissue of Various Beef Breeds Reared Under Intensive Production Systems

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ABSTRACT: Concentrations of major nutritional and trace elements (Ca, P, Mg, Na, K, Fe, Zn, Cu, Mn, Se, Co, Cr, Ni, Sr, Ba) and toxic heavy metals (Cd, Pb) were analyzed in the meat of Limousin, Red Angus and Salers bulls. Elements were determined using inductively coupled plasma emission atomic spectrometry. The conducted research showed that the meat of compared breeds differed in the concentrations of Cu, Zn, Fe, Se and K. The meat from Limousin bulls had significantly lower Zn ($P<0.001$) and Cu ($P<0.05$) contents than that of Red Angus and Salers bulls. Moreover, the meat of Red Angus bulls was characterized by a significantly ($P<0.001$) lower K content and significantly ($P<0.05$) higher Fe content compared to those in the Limousin and Salers bulls as well as significantly ($P<0.05$) higher Se content in comparison with the Salers bulls. No breed differences in the concentrations of Pb and Cd were found; however, the Pb concentration in meat was higher than the recommended standards. In the meat of all three breeds, the significant strong positive correlations were observed between the contents of Pb-Cd, Pb-Ni, Cd-Ni and K-P. The correlations between other elements within each of the breeds separately were also found.

Key words: Beef, Breeds, Tace elements, Heavy metals, Correlations

INTRODUCTION

Meat is known to be a source of trace elements but has, as well, been discussed in terms of accumulating heavy metals such as cadmium and lead (Gerber *et al.*, 2009). WHO has come to the conclusion that even low levels of lead and cadmium, can give rise to diseases in humans (WHO, 2000; WHO, 2001). This is produced by the capacity of these metals to accumulate in living organisms. It is well known that foods take up trace metals from soils, fertilizers, air, industrial processes, transportation and package materials. Heavy metals are mobile and easily taken up by plants in the environment (Chojnacka *et al.*, 2005; Demirel *et al.*, 2008). Since heavy metals are mobile and easily absorbed by plants in the environment, they are transmitted to the human body through nourishment. For these reasons, it is of the outmost importance to monitor the lead and cadmium content in dietary intakes (González-Weller *et al.*, 2006). In recent years, much attention has been focused on the concentration of heavy metals in meat, meat products and other food in order to check for the effects of those hazardous factors on human health (Abou-Arab, 2001; López-Alonso *et al.*, 2004, Gerber *et al.*, 2009; Ihedioha and Okoye, 2012). Considering that meat, as an essential component of the human diet, is a significant source of toxic metal exposure to humans, but also a valuable source of some essential elements (López-Alonso *et al.*, 2002; García-Vaquero *et al.*, 2011), it is important to explore trace element concentrations in the meat of various cattle breeds. Most frequently the content of heavy metals and elements has been examined in beef and veal from the animals fed on natural pastures (Miranda *et al.*, 2005; Giuffrida-Mendoza *et al.*, 2007; Cabrera *et al.*, 2010; Ramos *et al.*, 2012; Ihedioha and Okoye, 2012) or in industrial area (Farmer and Farmer, 2000; Koréneková *et al.*, 2002), alternatively in the meat purchased from the slaughterhouse or shop, originating from the animals whose age, breed, feeding method and intensity are often not known in detail (Williamson *et al.*, 2005; Gerber *et al.*, 2009). However, most beef consumed in Europe originates from the animals fattened intensively indoors, mainly from the bulls fattened to heavy body weight and the analyses of such beef are more significant for consumers. Besides, only few studies to date have compared the concentrations of

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toxic heavy metals and nutritional essential elements in the meat of different breeds of cattle, especially beef-type ones, which after weaning were kept together indoors and fattened intensively. Few comparisons of the content of some elements in meat considered Hereford and Braford breeds pasture-fed to 460 kg body weight (Cabrera *et al.*, 2010; Ramos *et al.*, 2012), Hungarian Grey and Holstein Friesian cattle fed extensively and intensively until 450-550 kg body weight (Holló *et al.*, 2007) as well as buffalo and Zebu-influenced cattle, calves fed on pasture with their dams and weaned at 7 months of age (Giuffrida-Mendoza *et al.*, 2007). There are no reports on the concentrations of toxic heavy metals and nutritional essential elements in the meat of various beef cattle breeds, such as Limousin, Red Angus or Salers, reared under intensive production systems and fed intensively to over 650 kg body weight.

So, it seems justified to compare the concentrations and the relationships between the levels of individual elements in the meat of Limousin, Red Angus and Salers bulls, kept in the same environment and fed identically, which allows finding breed differences in the concentration of elements and assimilability of heavy metals. Therefore, the aim of this study was the comparison of the concentrations of trace elements and toxic heavy metals in the meat of Limousin, Red Angus and Salers bulls kept together indoors and fattened intensively.

MATERIALS & METHODS

The research material comprised meat samples from 14 bulls of Limousin breed, 14 bulls of Red Angus breed and 15 bulls of Salers breed. The animals were kept on a commercial farm in north-western Poland, which occupies an area surrounding the town of Stargard from the south, east and north. Bulls born in March and April 2010 remained with their dams until October, being fed entirely on maternal milk and grazing during this period. After weaning, the bulls were kept together indoors and fattened intensively to approximately 24 months of age and the mean body weight of approximately 650 - 700 kg. The fattening bulls were fed concentrate (0.5 kg/animal), crushed barley (3 kg/animal), maize silage (15 kg/animal) and hay *ad libitum*. Bulky feed and barley fed to the animals were produced on the farm.

Samples of the *longissimus lumborum* muscle were collected from the same site between the 12th and 13th rib of the right side of each carcass 24 h post-slaughter, packaged and stored at -20^{o}C in polypropylene containers filled to a maximum capacity with the research material in order to minimize the amount of air coming into contact with the sample. The elements (Ca, P, Mg, Na, K, Fe, Zn, Cu, Mn, Se, Co, Cr, Ni, Sr, Ba, Cd, Pb) in the analyzed material were determined by inductively coupled plasma optical emission spectroscopy (ICP OES; Optima 2000 DV, Perkin Elmer, USA) after mineralization in a microwave oven (Microwave, Anton Paar, Austria). Weighed amounts of meat of approximately 0.6 g were placed in a quartz pressure reaction vessel, to which 5.0 mL 65% HNO_3 (Suprapur, Merck) and 0.5 mL 30% H_2O_2 (Suprapur, Merck) were added. After closing, the vessels were placed in the microwave oven equipped with temperature and pressure regulators in each quartz reactor. The mineralization was carried out according to the “Meat” procedure recommended by the manufacturer [0 – 5 min – a linear gradient of 100 - 600W, 6 – 10 min – 600 W (constant), 11 – 20 min – 1000 W or lower after reaching a threshold value (75 MPa or 300^{o}C), 21 – 35 min – cooling down vessels]. The cooled mineralisate was quantitatively transferred to a 10 mL volumetric flask. In the solutions prepared in this way, the microelements were determined directly, whereas macroelements (Na, K, Ca, Mg and P) were assayed in the solutions obtained from a 100-fold dilution of the original solution. A certified multi-element standard (ICP multielement standard solution VIII, Merck) served as a reference solution. Reference solutions were supplemented with acids used for mineralization at the same concentration as in the mineralized samples. In order to further minimize any errors connected with the introduction of a sample to the plasma and other physical disturbances in argon plasma, the analyses were carried out according to the method of internal standard by introducing yttrium (Y) to the solutions of samples and standards at a concentration of 0.5 mg/L Y. The possible spectral interferences were corrected using the MSF mathematical model (Perkin Elmer). All measurements of emitted radiation intensity were performed choosing a longer axial optical path (along plasma) in the spectrometer.

The limit of detection was as follows: Ca 0.05 µg/L; P 4 µg/L; Mg 0.04 µg/L; Na 0.5 µg/L; K 1 µg/L; Fe 0.1 µg/L; Zn 0.2 µg/L; Cu 0.4 µg/L; Mn 0.1 µg/L; Se 4 µg/L; Co 0.2 µg/L; Cr 0.2 µg/L; Ni 0.5 µg/L; Sr 0.05 µg/L; Ba 0.03 µg/L; Cd 0.1 µg/L and Pb 1.0 µg/L.

The correctness of the analytical procedure was tested by determining the analyzed elements in the reference material Seronorm (Trace Elements Serum, Sero AS) (n=3) together with the samples. The results agreed within ±10 % of the certified values. The analytical procedure was also checked by the analysis of the blank samples. Blank digests (n=4) were run with a series of meat samples, and no major interferences were found in the quantitative element analysis. Statistical analysis of the data was performed using Statistica software (StatSoft Inc., version 10.0). Prior to analyses, the data were investigated to determine their distribution using the Shapiro-Wilk W test. The concentrations of elements were log-transformed to attain or approach a normal distribution of the data. Significance of differences was tested using one-way ANOVA and Duncan's multiple range test. The relationships between the levels of individual elements in the meat of the examined breeds were calculated using the Pearson's correlation coefficients.

RESULTS & DISCUSSION

The content of mineral elements and toxic heavy metals in the meat of Limousin, Red Angus and Salers bulls is given in Table 1. The meat of Limousin bulls was characterized by significantly lower contents of Zn ($P<0.001$) and Cu ($P<0.05$) than those in the meat of Red Angus and Salers bulls. Moreover, in the meat of Red Angus bull calves, a significantly ($P<0.001$) lower K content and a significantly ($P<0.05$) higher Fe content were found in comparison with the meat of Limousine and Salers bulls. Also, a significantly higher ($P<0.05$) Se content was observed compared with that in the meat of Salers bulls. The content of the remaining elements in the meat of the investigated cattle breeds was very similar.

The average concentrations of P, Mg, Zn, Cu, and Mn in the examined meat were generally comparable to those reported by other studies, whereas the Ca concentration was higher and the contents of Fe, Se, K and Na were lower or similar to the lowest values obtained in these studies (Giuffrida-Mendoza *et al.*, 2007; Holló *et al.*, 2007; Gerber *et al.*, 2009; Cabrera *et al.*, 2010; Ramos *et al.*, 2012). The average concentration of Ca in meat, ranging in the present study from 157.6 to 163.1 mg/kg, was significantly higher in comparison with other previously published reports. According to Kotula and Lusby (1982), the Ca content in the longissimus muscle of Aberdeen Angus steer was 33.5 mg/kg. In the study by Giuffrida-Mendoza *et al.* (2007) the Ca content in wet tissue in the longissimus dorsi muscle of Zebu-influenced cattle and water buffalo ranged from 33.1 to 35.4 mg/kg, whereas in Holló *et al.* (2007), it ranged between 32.7 and 49.9 mg/kg in Hungarian Grey and Holstein Friesian bulls.

The concentrations of Na (ranging from 455.8 to 472.9 mg/kg) and K (ranging from 2377 to 2488.3 mg/kg) in meat were lower than those obtained in the study by Giuffrida-Mendoza *et al.* (2007) and Holló *et al.* (2007), in which the Na content ranged from 554 to 799 mg/kg, whereas that of K varied between 3108 and 3623 mg/kg.

The present investigation shows that Limousin, Red Angus and Salers meat contains lower Fe and Se levels in comparison with other previously published reports. The average concentration of Fe in meat ranged in the present study from 13.7 to 17 mg/kg. In the study by Kotula and Lusby (1982), the Fe content ranged from 20.8 mg to 38.8 mg/kg wet tissue in five different muscles. In the report of Lombardi-Boccia *et al.* (2005), the Fe level in the five evaluated meat cuts ranged from 18.0 mg to 23.7 mg/kg wet tissue. Williamson *et al.* (2005) found that the Fe content in the raw meat from Denmark, United Kingdom, Australia and the USA was between 16 mg and 24 mg/kg wet tissue, whereas Gerber *et al.* (2009) reported that sirloin and rib eye purchased from the butchers in Switzerland and the USA, had Fe content between 16 and 25 mg/kg wet meat. Purchas and Busboom (2005) compared Fe content in the meat of Angus cross heifers pasture-finished in New Zealand to Angus cross heifers feedlot-finished in the USA. The pasture-finished animals from New Zealand showed a level of 22.3 mg/kg wet tissue, which was significantly higher than that in the feedlot-finished animals from the USA, which showed a level of 16.5 mg/kg wet tissue. In the study by Cabrera *et al.* (2010) and Ramos *et al.* (2012), Fe content ranged between 30 and 45 mg/kg wet meat and between 35 and 40 mg/kg wet meat for the Hereford and Braford breeds, respectively.

The average concentration of Se in meat ranged in the present study from 0.045 to 0.049 mg/kg. Previously published reports show a level of Se in Longissimus dorsi and Psoas major muscles of 0.106 mg and 0.095 mg/kg wet tissue, respectively (Daun *et al.*, 2001). Gerber *et al.* (2009) found that sirloin and rib eye purchased from the butchers in Switzerland and the USA had the Se content of 0.09 - 0.44 mg/kg wet meat. In the study by Cabrera *et al.* (2010), Se content ranged from 0.42 to 1.20 mg/kg wet meat and from 0.49 to 1.3 mg/kg wet meat in the Hereford and Braford breeds, respectively. The selenium content of several meat cuts in Norway amounted to 0.04 - 0.07 mg/kg wet weight, the short-loin and strip loin having the lowest and richest values, respectively (NORFOODS, 2006; Ramos *et al.*, 2012). Williamson *et al.* (2005) found that the raw meat from Denmark, United Kingdom, Australia and the USA had Se levels of 0.065 mg, 0.070 mg, 0.10 mg and 0.308 mg (per kg wet tissue), respectively. The Se concentration in skeletal muscle is more related to geographic origin than to mineral supplementation, i.e. feeding practices (Hintze *et al.*, 2001; 2002). It has been clearly determined that the meat from America has a much higher Se concentration than the meat from Europe (Franke *et al.*, 2005).

So far, the concentrations of Co, Cr and Ni in bovine meat have been determined only in few studies and the reports on the Ba and Sr contents are

Table 1. Content of mineral elements and toxic heavy metals in the meat (mg/kg of fresh meat) of Limousin, Red Angus and Salers bulls

Elements	Limousin					Red Angus					Salers					*P* value
	Mean	GM	SEM	Min.	Max.	Mean	GM	SEM	Min.	Max.	Mean	GM	SEM	Min.	Max.	
Ca	157.6	156.4	5.08	110.8	190.8	163.1	162.1	5.00	133.7	191.4	157.9	155.8	6.91	120.8	222.7	0.751
P	2053.8	2051.2	29.18	1923.1	2320.0	1968.6	1967.2	20.70	1859.8	2081.5	2037.1	2034.6	27.14	1878.7	2287.4	0.063
Mg	272.6	272.5	2.16	258.6	284.7	266.5	266.3	2.95	245.3	284.1	272.2	272.0	2.51	258.1	291.4	0.185
Na	463.3	462.5	7.63	425.1	510.5	472.9	472.7	3.90	449.5	502.7	455.8	455.1	6.94	405.7	499.8	0.176
K	2488.3^{A}	2486.9	22.97	2325.6	2619.6	2377.0^{AB}	2375.8	21.11	2307.7	2553.6	2475.3^{B}	2474.3	18.77	2336.9	2640.1	<0.001***
Fe	14.1^{a}	13.5	1.26	8.8	26.3	17.0^{ab}	16.7	0.88	12.9	24.9	13.7^{b}	13.6	0.475	10.3	17.7	0.033*
Zn	33.9^{AB}	33.7	1.14	28.2	42.5	39.4^{A}	39.2	0.87	32.9	43.9	39.7^{B}	39.4	1.161	30.6	46.3	<0.001***
Cu	0.521^{ab}	0.518	0.0159	0.434	0.625	0.618^{a}	0.609	0.0305	0.442	0.847	0.610^{b}	0.603	0.0266	0.477	0.877	0.017*
Mn	0.059	0.058	0.0039	0.030	0.085	0.070	0.068	0.0039	0.051	0.096	0.066	0.064	0.0040	0.044	0.092	0.212
Se	0.047	0.047	0.0010	0.040	0.052	0.049^{a}	0.048	0.0010	0.043	0.056	0.045^{a}	0.044	0.0008	0.039	0.052	0.013*
Co	0.014	0.014	0.0004	0.012	0.017	0.014	0.014	0.0004	0.011	0.016	0.014	0.013	0.0004	0.011	0.016	0.572
Cr	0.075	0.075	0.0016	0.068	0.086	0.071	0.071	0.0010	0.065	0.079	0.077	0.076	0.0020	0.065	0.089	0.062
Ni	0.206	0.206	0.0031	0.192	0.224	0.203	0.203	0.0028	0.182	0.227	0.203	0.203	0.0028	0.189	0.222	0.731
Sr	0.131	0.129	0.0069	0.080	0.160	0.141	0.139	0.0071	0.109	0.207	0.136	0.134	0.0069	0.099	0.174	0.588
Ba	0.010	0.007	0.0021	0.000	0.023	0.012	0.009	0.0020	0.001	0.028	0.014	0.010	0.0027	0.002	0.034	0.528
Pb	0.208	0.207	0.0035	0.181	0.230	0.206	0.205	0.0032	0.190	0.230	0.201	0.201	0.0031	0.183	0.220	0.381
Cd	0.020	0.020	0.0004	0.018	0.023	0.021	0.021	0.0003	0.018	0.023	0.020	0.020	0.0003	0.018	0.022	0.275

GM geometric mean, SEM standard error mean, Min. minimum values, Max. maximum values
The same lower case letters denote statistically significant differences, $P<0.05$. The same upper case letters denote statistically significant differences, $P<0.001$

practically non-existent. The Co and Cr concentrations in meat were similar to those reported by López Alonso *et al.* (2004) and amounted to 0.015 and 0.076 mg/kg, respectively. In the study by Koréneková *et al.* (2002), the Ni concentration in the muscle of cattle reared in the vicinity of a metallurgic industry from three regions in Slovakia ranged between 0.15 and 0.35 mg/kg. Cd and Pb are environmental pollutants toxic to humans and animals (Cai *et al.*, 2009). Cd and Pb are nonbiodegradable and their accumulation in the environment raises agricultural and public health concerns (Olsson *et al.*, 2005; De Vries *et al.*, 2007). Unfortunately, the Pb content in the meat of bulls of the studied breeds was two times higher than the permissible concentration of 0.1 mg/kg in the beef meat given by the standards of the European Commission Regulation (2006) establishing the highest permissible levels of some pollutants in foodstuffs.

In the study by Abou-Arab (2001), López-Alonso *et al.* (2004), Miranda *et al.* (2005), Gerber *et al.* (2009) and Ihedioha and Okoye (2012), the Pb concentration in the meat of cattle was much lower and ranged from 0.008 to 0.09 mg/kg. Heavy metal contamination in meat has been reported also in different countries and regions, the most often from different industrial areas (Farmer and Farmer, 2000; Koréneková *et al.*, 2002; Nwude *et al.*, 2010). In the study by Farmer and Farmer (2000), the Pb level in the muscles of cattle reared around a metal production centre in eastern Kazakhstan ranged from 0.61 to 0.77 mg/kg, whereas that of Cd was between 0.02 and 0.42 mg/kg. In the study by Koréneková *et al.* (2002), the concentration of Pb and Cd in the muscles of cattle reared in the vicinity of a metallurgic industry from three regions in Slovakia ranged from 0.386 to 0.671 mg/kg and from 0.023 to 0.126 mg/kg, respectively. Nwude *et al.* (2010) reported even higher Pb concentration in the meat of Nigerian raised cattle, which amounted to 0.67 - 2.75 mg/kg.

The main sources of lead of anthropogenic origin are metallurgical, glass and dyeing industry as well as motorization. Other anthropogenic sources of heavy metals include the addition of manures, sewage sludge, fertilizers and pesticides, which may affect the uptake of heavy metals by modifying the physicochemical properties of the soil such as pH, organic matter and bioavailability of heavy metals in the soil (Sharma *et al.,* 2008).

The Pb content in the meat from bulls of the investigated breeds exceeding permissible standards could have been caused by several factors. Great significance can be attributed to the location of the farm's soils and grasslands around the town and the intensive agricultural production on the farm, characterized by the significant use of fertilizers and pesticides in crop production and mechanization of feeding, which could have contributed to an increased Pb concentration in the environment and feed of animals. Several comparisons of the mineral composition of meat from various cattle breeds showed differences, similarly as in the present study, in the contents of Cu, Zn, Fe and K as well as those of Mn, Ca and Na (Giuffrida-Mendoza *et al.*, 2007; Holló *et al.*, 2007; Cabrera *et al.*, 2010; Ramos *et al.*, 2012). Cabrera *et al.* (2010) and Ramos *et al.* (2012) determined the content of Se, Cu, Zn, Fe and Mn in various meat cuts: tenderloin (*m. psoas major*), eye of rump (*m. gluteus medius*), striploin (*m. longissimus dorsi*), eye round (*m. semitendinosus*), tri-tip (*m. tensor fasciae latae*), rib-eye roll (*m. longissimus dorsi*, *mm. multifidi*), 3 rib plate-flank on (*m. obliquus internus abdominis*, *m. obliquus externus abdominis*, *m. transversus abdominis* and *m. rectus abdominis*) and in unaged and aged meat (14 days) from the *psoas major*, *gluteus medius* and *longissimus dorsi* muscles of Hereford and Braford breed steers fed pasture. In the study by Ramos *et al.* (2012), Hereford steers had a significantly lower Cu content and a higher Fe content in meat, whereas in the study by Cabrera *et al.* (2010), the lower Mn content was found. Holló *et al.* (2007) compared the concentrations of Ca, P, Mg, K, Na, Cu, Zn and Fe in *longissimus* muscle of Hungarian Grey and Holstein Friesian bulls. The Na and Ca content in Hungarian Grey beef was lower compared to Holstein Friesian muscle. Giuffrida-Mendoza *et al.* (2007) determined the differences in macro- and micro-mineral content (Ca, P, Mg, Na, K, Fe, Cu, Zn and Mn) of *longissimus thoracis* muscle of water buffalo and Zebu-influenced cattle produced under extensive savannah conditions. The contents of Fe, Cu, Zn and Mn were significantly higher, whereas those of K were lower in buffalo meat.

Breed effects for efficiency in metabolizing especially Cu are well documented (Smart and Christensen, 1985; Littledike *et al.*, 1995; Ward *et al.*, 1995; Du *et al.*, 1996). In an experiment by Du *et al.* (1996), Holstein and Jersey primiparous cows and growing heifers were supplemented with either 5 or 80 mg of copper per kilogram dry matter. At the end of the 60-day experiment, the hepatic Cu concentration, plasma Cu concentration, and ceruloplasmin oxidase activity clearly showed a genetic difference in Cu absorption and post-absorption metabolism between Holstein and Jersey breeds. Jerseys had higher liver copper concentrations relative to Holsteins across both treatments. Furthermore, liver copper concentrations increased more rapidly and were higher in the Jerseys compared to Holsteins supplemented with 80 mg of copper per kilogram dry matter. Overall serum ceruloplasmin oxidase activity was higher in Jerseys than in Holsteins. Additionally, Jersey cows and heifers had higher liver Fe and lower liver Zn concentrations than did Holstein cows and heifers at the end of the experiment. No differences in plasma Fe and Zn appeared between breeds. These data indicate that Jerseys and Holsteins metabolize Cu, Zn, and Fe differently. In the study by Gooneratne *et al.* (1994) bile Cu concentration and bile Cu excretion were higher in Simmental cattle than in Angus cattle. Ward *et al.* (1995) conducted a study in which Angus and Simmental steers were placed in metabolism crates to monitor apparent absorption and retention of copper. At the end of the experiment, plasma copper concentrations, apparent absorption, and retention of copper were higher in Angus steers. The authors indicate that Simmental cattle may have a higher copper requirement than Angus cattle and that these different requirements may be related to the differences in copper absorption from the gastrointestinal tract between breeds. Furthermore, it has also been suggested that these breed differences in copper metabolism may not be due solely to differences in absorption, but also to the manner in which copper is utilized or metabolized post-absorption. Simmental steers had also lower serum and liver Cu concentrations and serum ceruloplasmin activity than Angus throughout the study by Mullis *et al.* (2003). Smart and Christensen (1985) reported that Hereford-sired cows had greater plasma Cu concentrations during gestation than did Simmental-sired cows. The genetic difference may be related to the efficiency of dietary Cu absorption, the excretion of endogenous Cu, or the amount of feed intake. Gooneratne *et al.* (1994) suggested that the differences in endogenous Cu excretion also contributed to the genetic differences in the retention of hepatic Cu. Littledike *et al.* (1995) compared the mineral status of Angus, Braunvieh, Charolais, Gelbvieh, Hereford, Limousin, Red Poll, Pinzgauer, and Simmental breeds consuming similar diets. In adult cattle, liver Cu was higher for the Limousin breed than for all others, except for Angus. Liver Zn concentrations were higher for Limousin than for Pinzgauer, but no other breed differences were observed. Serum Ca concentrations were higher for Angus, Red Poll, and Limousin than for Simmental, and Red Poll had higher concentrations of serum Ca than did Braunvieh. Serum Mg concentrations were higher for Angus than for Hereford. Concentrations of serum Ca were positively correlated with serum concentrations of Cu, Zn, and Mg, but negatively correlated with liver Fe.

In few studies, an effect of breed on the efficiency of Se metabolism was also shown. In an experiment by Sprinkle *et al.* (2006), Brahman cross (Brahman × Salers or Brahman × Hereford) cows were more efficient in metabolizing Se, having greater whole blood Se than either composite cows (25 % Hereford, Angus, Gelbevieh, and Senepol or Barzona) or Hereford cows. Langlands *et al.* (1980) reported that Brahman cattle in Australia had greater blood Se than Brahman cross, Africander, Africander cross, Brahman-Africander × Hereford-Shorthorn cross, or Hereford × Shorthorn cross cattle. In evaluating specific sire breeds, they also reported that Brahman × Hereford crosses had greater Se than Hereford × Hereford, Friesian × Hereford, and Simmental × Hereford genotypes.

An interesting aspect of the present study is the interaction between toxic heavy metals and major nutritional and trace elements in meat, because the nutritional function of meat is important for health. Although toxic and trace element interactions have been very well studied in internal organs (mainly liver and kidney) from animals receiving naturally high polluted or experimentally dosed diets (López-Alonso *et al.*, 2004; Nriagu *et al.*, 2009), little attention was paid to muscle (García-Vaquero *et al.*, 2011), where most research effort has been focused on carcass performance or nutritional composition.

In the meat of Limousin, Red Angus and Salers bulls, the following significant, very strong and strong positive correlations (Table 2) were noted: Pb-Cd (r=0.84, r=0.72, r=0.65, respectively), Pb-Ni (r=0.89, r=0.78, r=0.72, respectively), Cd-Ni (r=0.77, r=0.89, r=0.74, respectively) and K-P (r=0.54, r=0.57, r=0.59, respectively). Moreover, in the meat of Limousin and Red Angus bulls, significant strong positive correlations were observed between the Cr content and the contents of Pb (r=0.75 and r=0.68), Cd (r=0.82 and r=0.68) and Ni (r=0.65 and r=0.79) as well as between the Fe and Mn contents; however, in the latter case, this correlation was positive in the Red Angus meat (r=0.68) and negative in the Limousin meat (r=-0.65). In the meat of Red Angus and Salers bulls, significant positive correlations were also noted between the contents of Pb and Na (r=0.77 and r=0.61, respectively), Mg and P (r=0.74 and r=0.78, respectively), Cu and Mn (r=0.67 and r=0.71, respectively), whereas in the meat of Limousin and Salers bulls such correlations were observed between the Cu and Mn contents (r=0.58). Besides, in the meat of Limousin bulls, we found significant positive correlations between the contents of Pb-Ca, Pb-Sr, Cd-Sr, Co-Sr, Co-Ca, Mn-K, Fe-Cr and a negative correlation between the Fe and K contents. In the meat of Red Angus bulls, significant positive correlations were also noted between the contents of Cd-Co, Cu-Fe, Cu-Na, Cr-Na and Mn-Ba and negative ones were shown between the contents of Se and Zn as well as K and Ba, while in the meat of Salers bulls, significant positive correlations were obtained for the contents of Pb-Co, Cd-K, Cd-Na, Ni-Co, Ni-K, Ni-Na, Mn-Zn and Mg-K.

López-Alonso *et al.* (2002, 2004) also found in the muscle of cattle a positive correlation between the concentrations of Pb and Cd (r=0.229), Cu and Zn (r=0.375), Cu and Fe (r=0.295), Cu and Mn (r=0.576) and Fe and Mn (r=0.352). However, contrary to present results, they found significant positive correlations between Pb and Zn (r=0.155), Ca and Fe (r=0.24) and a negative one between Cd and Cu (r=-0.106). García-Vaquero et al. (2011), evaluating the associations

Table 2. Pearson's correlation coefficients between the meat concentrations of different mineral elements

	P	Mg	Na	K	Fe	Zn	Cu	Mn	Se	Co	Cr	Ni	Sr	Ba	Pb	Cd
Limousin																
Ca	0.05	0.45	0.27	0.28	-0.06	0.13	0.12	0.20	-0.05	0.57*	0.25	0.46	0.55	-0.01	0.62*	0.48
P		0.49	-0.38	0.54*	-0.45	0.39	0.45	0.16	-0.45	-0.14	-0.24	-0.40	-0.44	-0.54	-0.19	-0.26
Mg			-0.25	0.45	-0.10	0.24	0.40	0.06	0.13	0.35	0.33	0.27	0.12	-0.57	0.40	0.28
Na				-0.41	0.12	-0.19	-0.22	0.13	0.08	0.34	0.00	0.27	0.50	0.33	0.14	0.24
K					-0.59*	0.48	0.24	0.53*	-0.03	0.22	-0.11	-0.16	-0.38	-0.17	-0.03	-0.24
Fe						-0.07	0.20	-0.65*	0.15	0.08	0.57*	0.17	0.46	0.31	0.23	0.46
Zn							0.57*	0.37	0.16	0.09	0.07	-0.39	-0.54	-0.28	-0.31	-0.25
Cu								0.18	0.10	0.22	0.20	-0.46	-0.11	-0.02	-0.21	0.07
Mn									0.37	0.19	-0.16	-0.09	-0.41	-0.09	-0.18	-0.16
Se										0.30	0.35	0.31	-0.21	-0.16	0.10	0.20
Co											0.37	0.32	0.60*	0.09	0.42	0.29
Cr												0.63*	0.42	0.31	0.73**	0.83***
Ni													0.58*	0.03	0.89***	0.77***
Sr														0.46	0.72**	0.68*
Ba															0.15	0.37
Pb																0.84***
Red Angus																
Ca	0.05	0.31	0.52	0.25	-0.22	-0.29	-0.15	-0.36	0.31	0.26	0.32	0.14	0.13	0.15	0.43	0.11
P		0.74**	0.34	0.57*	0.28	-0.19	0.27	-0.03	0.08	-0.23	0.12	0-.18	-0.45	-0.11	-0.01	-0.36
Mg			0.47	0.45	0.33	-0.14	0.25	0.09	0.14	0.04	0.00	0.00	-0.03	0.00	0.30	-0.05
Na				0.07	0.51	-0.09	0.64*	0.06	0.25	0.32	0.67**	0.49	0.26	0.26	0.77***	0.44
K					-0.32	-0.17	-0.35	-0.50	0.23	0.00	0.12	-0.12	-0.38	-0.62*	-0.18	-0.18
Fe						0.18	0.88***	0.68**	-0.33	0.02	0.22	0.24	0.29	0.28	0.50	0.24
Zn							0.18	0.09	-0.60*	0.26	-0.48	-0.40	-0.17	-0.07	-0.36	-0.16
Cu								0.67**	-0.22	-0.05	0.27	0.20	0.34	0.46	0.50	0.14
Mn									-0.33	-0.30	-0.13	0.08	0.52	0.62*	0.23	0.01
Se										-0.07	0.42	0.45	-0.06	0.00	0.24	0.25
Co											0.31	0.48	-0.01	-0.28	0.34	0.59
Cr												0.79***	0.16	0.03	0.68**	0.66*
Ni													0.34	0.11	0.78***	0.89***
Sr														0.38	0.50	0.45
Ba															0.35	-0.02
Pb																0.72**
Salers																
Ca	-0.05	0.08	0.34	0.05	0.16	0.08	-0.16	0.05	-0.33	0.21	-0.02	0.28	0.77**	0.49	0.29	0.30
P		0.78***	0.18	0.59*	-0.25	-0.23	-0.03	0.02	0.42	0.13	0.27	0.24	0.03	-0.26	0.26	-0.08
Mg			0.25	0.59*	-0.45	-0.38	-0.26	-0.16	0.27	0.11	-0.06	0.35	0.33	-0.27	0.40	0.12
Na				0.38	0.29	-0.27	-0.17	-0.04	-0.13	0.14	0.20	0.71**	0.42	0.61*	0.61*	0.61*
K					-0.45	-0.42	-0.35	-0.06	0.48	0.31	0.10	0.56	0.32	0.16	0.45	0.55
Fe						0.40	0.50	0.38	-0.20	-0.42	0.25	0.03	0.01	0.47	-0.03	-0.13
Zn							0.58*	0.67**	-0.09	-0.15	0.10	-0.10	-0.01	-0.04	-0.16	-0.34
Cu								0.71**	0.38	0.06	0.43	0.05	-0.22	-0.25	0.02	-0.39
Mn									0.15	0.14	0.61*	0.22	-0.11	0.11	0.15	-0.08
Se										0.28	0.36	0.32	0.25	-0.35	0.03	-0.06
Co											0.55	0.52*	0.18	-0.18	0.56*	0.47
Cr												0.44	-0.18	0.27	0.15	0.33
Ni													0.47	0.27	0.72**	0.74**
Sr														0.44	0.31	0.36
Ba															0.05	0.48
Pb																0.65**

between non-essential (As, Cd, Hg, Pb and Sn) and essential (Co, Cr, Fe, Mn, Mo, Ni, Se and Zn) elements in different muscle samples, found strong relationships, especially between the main essential elements. Like in the present study, the authors reported strong positive correlations between Pb-Co (r=0.603), Pb-Ni (r=0.470), Ni-Co (r=0.764), Cu-Fe (r=0.929), Cu-Mn (r=0.924) and Fe-Mn (r=0.917), however, they also observed negative ones between Pb-Cr (r=-0.455), Cu-Zn (r=-0.597), Mn-Zn (r=-0.553) and Se-Zn (r=-0.537). Contrary to the present study, no significant correlation between Cd and the remaining analyzed elements was found, whereas many significant correlations between other elements were noted, which in the present study were statistically non-significant.

The largest number of significant correlations between toxic and essential elements is found in the kidneys followed by liver (Tomza-Marciniak *et al.*, 2011), which according to Lopez Alonso et al. (2004), is a reflection that these organs play the main role in trace element metabolism.

In the opinion of García-Vaquero *et al.* (2011), in the situations of an adequate mineral status, trace element concentrations in the muscle are dependent on their own internal metabolism. To maintain the mineral homeostasis in the muscles and other tissues, an organism has developed different mechanisms such as metallothioneins, chaperones and other metal transporters; with a particular significance of divalent metal transporter 1 (DMT1), involved in the traffic of divalent metals such as Fe, Zn, Cd, Cu, Co, Ni and Pb into the cells (Gunshin *et al.*, 1997; Mackenzie *et al.*, 2007) and ubiquitously expressed in all tissues including kidney, brain and cardiac muscle (Ke *et al.*, 2003). The fact that some of the essential metals do not follow the same intermuscular distribution pattern could be related to metal interactions or antagonisms to maintain a correct mineral balance (García-Vaquero *et al.*, 2011).

Correlation analysis confirms the differences in trace mineral metabolism between the studied breeds. For example, the correlations between Fe and Mn are noteworthy. In the meat from Red Angus bulls, significant, high and positive correlations between these elements were recorded (0.67), and in the meat from Limousin bulls these correlations were significant and negative (-0.65), whereas in the meat from Salers bulls they were weak and statistically non-significant (0.18).

CONCLUSION

The present study showed that the meat of Limousin, Red Angus and Salers bulls differed in the concentrations of Cu, Zn, Fe, Se and K. The meat from Limousin bulls had significantly lower Cu and Zn contents than that of Red Angus and Salers bulls. Moreover, the meat of Red Angus bulls was characterized by a significantly lower K content and significantly higher Fe content compared to those in the Limousin and Salers bulls as well as significantly higher Se content in comparison with the Salers bulls. The Se and Fe contents in the meat of the investigated breeds were lower than those previously reported, which also indicates their lower content in the feed and environment. No breed differences in the concentrations of heavy metals such as Pb and Cd were found; however, the Pb concentration in meat was higher than the recommended standards, which shows its higher concentration in the environment and feed. It should be emphasized that under the conditions of intensive forage production, feeding and management (application of fertilizers and pesticides and feeding mechanization), the Pb content in beef may be elevated, which is of great importance for consumers. Special attention should be paid to the possible sources of Pb in the environment of animals and to their elimination. Limousin, Red Angus and Salers bulls remained in the same environment and were identically fed, which allows us to suppose that the differences obtained between these breeds in the content of the examined elements in meat are caused by differences of metabolic background.

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