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Original Scientific Article

COMPARATIVE STUDY OF IRON, MAGNESIUM AND ZINC AND DAILY INTAKES IN CERTAIN MEATS AND MEAT PRODUCTS

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Summary: Different meats (beef, pork, horse, pork kidney) and meat products (bolognese meat sauce, ham in casing, liverwurst, beans with cooked bacon, beef tripe, smoked pork neck, pancetta, sausage, cooked bacon) were collected in Croatian markets during 2012. The concentrations of Fe, Mg and Zn were determined and were in the ranges (mg/kg): Fe 1.24–63.9, Mg 86.2–333 and Zn 7.08–64.6. The highest element contents measured in different meats and meat products were (mg/kg): Fe 53.2 in pork kidney, Mg 263 in beef and Zn 51.7 in beef. The lowest mean levels were (mg/kg): Fe 6.33 in pork, Mg 173 in pork kidney and Zn 13.2 in different meat products. Significant differences for all three elements were observed between the food groups tested. The estimated mean daily intake (EDI) of Fe, Mg and Zn in different types of food contributing to the recommended dietary allowance (RDA) for women and men were in the ranges (%): Fe 0.07–1.33; Mg 0.09–0.17 and Zn 0.40–1.29. The results obtained in food groups tested for Fe levels is in agreement with literature values reported, though differences were found for Mg and Zn.

Key words: Fe, Mg; Zn; meat; meat products; ICP-OES; Croatia

Introduction

Essential elements such as Cu, Co, Fe, Zn, Mg Se and Mn are required for adequate physiological functions and should be available through dietary intake. Insufficient intake of Fe and Zn causes fatigue, poor growth, anaemia, rickets and impaired cognitive performance in humans (1). Furthermore, elements such as Cu, Zn, Fe, Se and Mn are key for the enzymatic systems that counteract free radicals in the organism. Iron plays a major role as an oxygen carrier in haemoglobin in blood, or myoglobin in muscle, and it is also required for many metabolic processes (2). Zinc has multiple biochemical functions and is present in a large number of proteins, and also as a physiological constituent of the oxidant defence system (3). Magnesium is needed for more than 300 biochemical reactions in the body. It helps maintain normal muscle and nerve function, keeps heart rhythm steady, supports a healthy immune system, and keeps bones strong (4).

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Meat and meat products are important source of proteins, trace elements and B vitamins and greatly contribute to the daily intakes of these micronutrients in the human diet in many parts of the world (5). It is well known that meat is the one of the richest sources of Zn in the total diet and it also provides sufficient amounts of Cu (6, 7). Also, meat represents the primary source of heme Fe, the iron form having the highest bioavailability (8, 9).

There has been a general decrease in the amount of red meat consumed in developed countries, primarily attributed to the reduction in beef consumption in the late 1990s (2). Furthermore, pork is the most widely consumed meat in the EU with continuous increasing consumption. Processed meat includes meat that has been preserved by methods other than freezing, such as salting, smoking, marinating, air-drying or heating, e.g. ham, bacon, sausages, cooked bacon, salami, corned beef and tinned meat. For example with regard to processed meat intake, Sweden, Norway and Germany have the highest intakes, primarily due to the amount of sausages they consume (10).

Trace element contents in meat and meat products depend on different factors, such as environmental conditions, type of pasture, feed composition, genetic characteristics of animals, rearing practices, slaughtering method and aging. Furthermore, technological treatments and cooking conditions are important for levels of trace elements in meat products (2, 11). Total Fe content is not changed after heat processing of meat, though the heme:non-heme iron ratio is modified with a decrease of heme iron concentration depending on the severity of the heat treatment utilized (9). In previous studies, low iron contents were established in pork, poultry and rabbit meats (6). A variation in Fe content was found among different species. However, the Fe content of the same type of meat may vary due to the age of the animal at the time of slaughter, the diet of the animal and husbandry practices (2).

The objective of this study was the assessment of Fe, Mg and Zn concentrations in the meat of different species, minced meat and different processed meats consumed in Croatia. Results were assessed by comparing estimates of dietary exposures with the recommended dietary allowances (RDA) recommended by Food and Nutrition Board of the Institute of Medicine (12).

Materials and methods

Sample collection

In total, 27 meat products were collected in Croatian markets during 2012: 4 minced meat products; 9 different meat products (bolognese meat sauce, ham in casing, liverwurst, beans with cooked bacon, beef tripe, smoked pork neck, pancetta, sausages, cooked bacon), 5 beef meat, 3 pork meat, 3 horse meat and 3 pork kidney samples. Following collection, samples were labelled and stored in polyethylene bags and frozen at -18°C prior to analysis.

Sample preparation

All reagents were of analytical reagent grade, HNO_3 and H_2O_2 (Kemika, Croatia). Ultra high purity water processed through a purification system NIRO VV UV UF 20 (Nirosta d.o.o. Water Technologies, Osijek, Croatia) was used for all dilutions. Plastic and glassware were cleaned by soaking in diluted HNO_3 (1/9, v/v) and by subsequent rinsing with double deionised water and drying prior to use. Calibrations were prepared with Fe, Mg and Zn standard solutions of 1 g/l (Perkin Elmer, USA). The stock solution was diluted in HNO_3 (0.5%).

Meat and meat product samples (0.5 g) were digested with 4 ml of HNO_3 (65% v/v) and 2 ml of H_2O_2 (30% v/v) in a microwave oven. A high-pressure laboratory microwave oven (Multiwave 3000, Anton Paar, Germany) was employed to perform the acid digestion of samples. The digestion program began at a potency of 500 W, then ramped for 1 min, after which samples were held for 4 minutes. The second step at a potency of 1000 W (ramp 5 min) was held for 5 minutes. The third step at a potency of 1400 W (ramp 5 min) was held for 10 minutes. A blank digest was carried out in the same way.

Digested samples were diluted to a final volume of 50 ml with double deionised water. Concentrations of Fe, Mg and Zn were determined on a wet weight basis as mg/kg. All samples were run in batches that included blanks, a standard calibration curve and two spiked specimens. Detection limits were determined as the concentration corresponding to three times the standard deviation of ten blanks. The quality of data was checked by an analysis of the recovery rate using certified reference material: dogfish liver (DORT-4, National Research Council, Canada). The reference material was treated and analysed under the same conditions as the samples.

Quantification of Fe, Mg and Zn

An inductively coupled plasma optical emission spectrometer with axial and radial viewing plasma configuration (ICP-OES Model Optima 8000, Perkin-Elmer, USA) operating at a 40 MHz free-running ratio-frequency and provided with an S 10 autosampler (Perkin-Elmer) was utilized. The nebulization system was equipped with a chemical-resistant concentric glass nebulizer coupled to a glass cyclonic spray chamber. A torch with an alumina-made injector was used. The polychromator, equipped with an Echelle grating, had a spectral range of 160–900 nm and a resolution of 0.009 nm at 200 nm. A UV-sensitive dual backside illuminated Charge-Coupled Device (CDD) array detector was used. The CDD array detector collects both the analyte spectra and nearby background spectra, allowing for simultaneous background correction and providing improved precision and analytical speed. The instrumental operating conditions used are shown in Table 1.

Determination of daily intake

The estimated daily intake (EDI) was calculated by the equation (13):

EDI = [(Mean of mg per kg of food) multiplied by (Daily Intake of food)] divided by [Adult body weights (60 kg)].

The contributions of each food items to the average dietary intake of elements were provided by comparison of mean values to RDA values expressed for females and males, with the assumption that the average adult woman and the average adult man consumed the same diet, i.e. the average typical diet of this population group.

Statistical analysis

Statistical analysis was performed using the Statistica 6.1 software (StatSoft Inc., Tulsa, USA). Concentrations were expressed as mean ± standard deviation, median, minimum and maximum values. One-way analysis of variance was used to test for differences in element levels in samples. In addition, determination of differences in concentrations of the element concentrations (Zn, Mg and Fe) between different food items were analysed using the *t*-test. Results were considered significant at $p < 0.05$.

Table 1: Operating conditions for Optima 8000 ICP-OES

Parameter	Value
Plasma viewing mode	Axial
Read time	1–5 s
Measurement replicates	3
RF incident power	1300 W
Plasma argon flow rate	8 L/min
Nebulizer argon flow rate	0.55 L/min
Auxiliary argon flow rate	0.4 L/min
Sample uptake rate	1 mL/min
Inner diameter of the torch injector	2.0 mm
Nebulizer type	Concentric glass (Meinhard)
Spray chamber type	Glass cyclonic spray chamber

Results and Discussion

The accuracy of results were checked and showed good accuracy with the recovery rate for tested elements (%): Fe 99.6, Mg 104.9, Zn 106.9. The limits of detection (LODs, mg/kg) of elements in meat samples were: Fe 0.005, Mg 0.008 and Zn 0.0015. The mean content of these elements are presented in Table 2. Analysis of variance showed significant differences between the tested food groups for all three elements tested ($p < 0.001$).

Selected food items represent only a portion of the food items that contribute to the average daily intake of essential elements. Also, consumption of meat or meat products is dependent on culture and availability and varies considerably between individuals (14). In a recent study of dietary exposure in different countries, it was concluded that the food groups that most contributed to the intake of Zn were meat and poultry, followed by breads, cereals and dairy products (7, 14, 15, 16). It is generally known that iron rich foods are those of animal origin, while those of plant origin are rich in non-heme iron (17). Cereals and legumes often contain a high amount of inhibitors to mineral absorption, such as phytates and polyphenols, which inhibit which inhibit zinc and/or non-heme iron and creating insoluble complexes in the intestines. Therefore the bioavailability of these micronutrients from these foods is often poor (18). The food groups that contributed the most for Mg intake were fish and fish products, cereals and cereal products and meats and offal (19, 20).

Regarding the requirements of essential elements for a number of physiological functions, their deficiencies may play a negative role in children's development, pregnancy and elderly health in humans and animals (3, 21, 22). The US Food and Nutrition Board of the Institute of Medicine is in charge of estimation of nutritional deficiency problems and toxicity and establishing the quantities of various nutrients by setting the recommended dietary allowance (RDA), the estimated average requirement (EAR), the adequate intake (AI) and the tolerable upper intake level (UL) for essential trace elements (12). The recommended dietary allowance (RDA) and the adequate intake (AI) for the prevention of disease and as the sufficient recommended adequate intake of elements for females/males are (mg/kg): for Fe 18/8; for Mg 310/400 and for Zn 8/11 (12).

Table 3 shows the estimated daily intake (EDI) for Fe, Mg and Zn based on the concentrations found in this study calculated by taking into account the average consumption of 120 (g/day per adult) for meat and meat products in Croatia (23). The EDIs for Fe in the meat of tested species and pig kidney ranged from 0.0127 to 0.1064 mg/day, thus contributing 0.07–0.59% and 0.16–1.33% of the RDA values of 18 mg/day for adult women

Table 2: Contents of Fe, Mg and Zn (mg/kg) in meat and meat products collected from Croatian markets

		Fe[1]	Mg[2]	Zn[3]
Meat and meat product	N	Mean ± SD (ranges)	Mean ± SD (ranges)	Mean ± SD (ranges)
Meat product	4	7.20 ± 2.35 [a] 4.27-9.92	212 ± 30.9 [a] 173-256	13.4 ± 2.97 [abc] 10.7-18.1
Processed meat products	9	7.05 ± 6.85 [b] 1.24-23.5	195 ± 76.4 86.2-333	13.2 ± 5.01 [bcc] 7.08-24.4
Meat				
Pork	3	6.33 ± 2.76 [c] 3.40-8.88	220 ± 38.1 182-258	22.2 ± 9.31 [a] 12.1-30.4
Beef	5	24.9 ± 2.72 [abcc] 20.6-27.7	263 ± 29.7 [ab] 227-309	51.7 ± 14.3 [acc] 36.3-64.6
Horse	3	22.4 ± 2.02 [abcd] 20.1-23.9	213 ± 38.5 179-255	41.3 ± 18.4 [bcc] 24.9-61.3
Kidney, pork	3	53.2 ± 14.7 [abccd] 36.5-63.9	173 ± 20.7 [b] 153-194	26.8 ± 10.4 [ab] 19.4-34.1

Vertically, letters show statistically significant differences: 1 between: meat and meat products: [a] ($p < 0.001$); meat and different products: [b] ($p < 0.001$); meat: [c] ($p < 0.001$), [d] ($p < 0.01$); [2 a] ($p < 0.05$), [b] ($p < 0.001$); [3 a] ($p < 0.05$), [b] ($p < 0.01$), [c] ($p < 0.001$)

and 8 mg/day for adult men, respectively. For meat products and different products, EDIs values were only 0.014 mg/day, contributing 0.08% and 0.18% of the RDA values for women and men. For Mg, EDIs for different meat, pig kidney and both groups of meat products ranged from 0.39 to 0.53 mg/day, thus contributing in range 0.09–0.17% of the RDA of 310 mg/day for females and 400 mg/day for males. The similar EDIs of 0.026 mg/day for Zn in meat products and different products were measured, contributing less than 0.35% of the RDA of 8 mg/day for females and 11 mg/day for males. For meat and pig kidney, EDIs values were only in the range 0.044 to 0.103 mg/day, contributing 0.56–1.29% and 0.40–0.94% of the RDA values for women and men, respectively.

The results obtained for three elements were compared with the literature data. Concentrations of Fe, Mg and Zn in different types of meat and products obtained in different countries in recent years are presented in Table 4.

Table 3: Estimation of daily intakes (EDIs) of Fe, Zn and Mg through consumption of meat and meat products and comparison to RDA values

Element	Fe		Mg		Zn	
Food	EDI (mg/kg BW/day)	Contribution of mean to RDA[a] (%)	EDI (mg/kg BW/day)	Contribution of mean to RDA[a] (%)	EDI (mg/kg BW/day)	Contribution of mean to RDA[a] (%)
Meat product	0.0144	0.08 (F) 0.18 (M)	0.42	0.14 (F) 0.11 (M)	0.0268	0.34 (F) 0.24 (M)
Processed meat products	0.0141	0.08 (F) 0.18 (M)	0.39	0.13 (F) 0.10 (M)	0.0264	0.33 (F) 0.24 (M)
Meat						
Pork	0.0127	0.07 (F) 0.16 (M)	0.44	0.14 (F) 0.11 (M)	0.0444	0.56 (F) 0.40 (M)
Beef	0.0498	0.28 (F) 0.62 (M)	0.53	0.17 (F) 0.13 (M)	0.1034	1.29 (F) 0.94 (M)
Horse	0.0448	0.25 (F) 0.56 (M)	0.43	0.14 (F) 0.11 (M)	0.0826	1.03 (F) 0.75 (M)
Kidney, pork	0.1064	0.59 (F) 1.33 (M)	0.35	0.11 (F) 0.09 (M)	0.0536	0.67 (F) 0.49 (M)

a RDA for female (F) and male (M): Fe 18 mg/day (F), 8 mg/day (M); Mg 310 mg/day (F), 400 mg/day (M); Zn 8 mg/day (F), 11 mg/day (M)

Table 4: Overview of the Fe, Zn and Mg contents in different meat products in previous studies

	Country Meat and meat products (reference)					
Element (mg/kg)	Denmark	France	Italy	Spain	UK	Turkey
Fe	BM 24 (2) PM 7 (2)	M 12.7 (19) O 60.8 (19)	BM 18-23.7 (6) PM 4.2-7 (6) HM 22.7 (6)		BM 18 (2) PM 7 (2)	M 1.36 (25) S 1.56; 1.07 (25)
Mg		M 286 (15) O 305 (15) M 309 (20) O 292 (20)		M 224 (26)		
Zn	BM 47 (2) PM 36 (2)	M 36.20 (7) M 36.76 (15) O 31.12 (15)	BM 39.4-47.5 (6) PM 9.8-22.8 (6) HM 19.5 (6)	PK 30.5 (27) M 42.3 (26)	BM 41 (2) PM 21 (2)	M 1.11 (25) S 0.49; 0.6; 1.59 (25)

BM- bovine, muscle; PM-pig, muscle; HM- horse, muscle; PK-pig, kidney; M-meat (without specification); O-offal (without specification); S-sausages

The concentrations of Fe in different type of meat and meat products ranged from 1.24 to 63.9 mg/kg. Among different meat products, a minimal mean Fe of 6.33 mg/kg level was measured in pork meat and maximal in liverwurst (23.5 mg/kg). Significantly higher Fe concentrations were found in pork kidney than those in meat products, different meat products, pork, beef and horse ($p<0.001$, all). However, significantly lower Fe levels were determined in meat products, different meat products and pork than in beef and horse meat ($p < 0.001$, all). The high levels of Fe measured in kidney may be explained by the role of the kidney in iron homeostasis. It is known that a significant amount of serum iron is available for glomerular ultrafiltration, and also that most of the filtered iron is reabsorbed by the renal tubules (24). The Fe contents reported in this study are in general agreement with the literature values reported for meat of different species (6, 19, 25). There are limited data regarding element levels in processed meat. In the very scarce data regarding element levels in meat products such as sausages, Fe concentrations lower than those measured in the present study were determined in Turkey (25).

The concentrations of Mg ranged from 86.2 to 333 mg/kg. The highest Mg concentration was found in the product beans with cooked bacon (333 mg/kg). Significantly higher Mg concentrations were determined in beef meat than in processed meat products and pig kidney ($p<0.05$; $p<0.001$). Relatively few data on the Mg content in meat products were available. Magnesium levels measured in meat samples in this study were lower that recently reported levels in France (15, 20) but similar to values from Spain (26). Also concentrations obtained in pig kidney were lower than those determined in offal samples from France (15, 20).

The concentrations of Zn were in the range 7.08–64.6 mg/kg. The highest zinc concentration was determined in smoked pork neck (24.4 mg/kg) in the group of processed meat products. Accordingly, the main findings were significantly higher Zn levels in: beef and horse meat than in meat products ($p<0.001$, both) and processed meat products ($p<0.001$, both); beef meat than in pig kidney ($p<0.05$); pig kidney than those in meat products ($p<0.05$) and processed meat products ($p<0.001$).

The concentrations of Zn in beef and pork meat presented are similar to results from other countries (2, 7, 15, 27, 28). However, results measured in horse meat were more than twice those from Italy (6). Also, Zn levels measured in both groups of meat products were more than 10-times higher than those measured in Turkey (25).

In conclusion, the results obtained for Fe levels are in agreement with literature values reported, while some differences were found for Mg and Zn.

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PRIMERJALNA ŠTUDIJA VNOSA ŽELEZA, MAGNEZIJA IN CINKA TER DNEVNIH VNOSOV NEKATERIH VRST MESA IN MESNIH IZDELKOV

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Povzetek: V letu 2012 so na hrvaških trgih zbrali različne vrste mesa (govedina, svinjina, konjsko meso, ledvice svinj) ter mesnih izdelkov (bolonjska omaka, šunka v ovoju, jetrne klobase, fižol s kuhano slanino, goveji vampi, dimljena svinjska vratovina, panceta, klobase in kuhana slanina). Ugotovili so koncentracije Fe, Mg in Zn in so bile naslednje (v mg/kg): Fe 1,24 – 63,9; Mg 86,2 – 333 in Zn 7,08 – 64,6. Najvišje vsebnosti elementov v različnih vrstah mesa in mesnih izdelkov so bile (mg/kg): Fe 53,2 v svinjskih ledvicah, Mg 263 v govedini in Zn 51,7 tudi v govedini. Najnižje vrednosti so bile v mg/kg: Fe 6,33 v svinjini, Mg 173 v svinjskih ledvicah in Zn 13,2 v različnih mesnih izdelkih. Med različnimi skupinami živil so pri vseh treh elementih opazili statistično značilne razlike. Ocenjeni povprečni dnevni vnos (EDI) Fe, Mg in Zn v različnih vrstah živil, ki prispevajo k priporočenemu vnosu hrane (RDA) za ženske in moške, je bil v naslednjih razponih (odstotki): Fe 0,07 - 1,33; Mg 0,09 - 0,17 in Zn 0,40 - 1,29. Rezultati, pridobljeni v skupinah živil, testiranih za raven Fe, se ujemajo s podatki iz literature, za Mg in Zn pa so bile ugotovljene razlike.

Ključne besede: Fe; Mg; Zn; meso; mesni izdelki; ICP-OES; Hrvaška