Journal of Elementology ISSN 1644-2296

Stasiak K., Roślewska A., Stanek M., Cygan-Szczegielniak D., Janicki B. 2017. *The content of selected minerals determined in the liver, kidney and meat of pigs*. J. Elem., 22(4): 1475-1483. DOI: 10.5601/jelem.2017.22.1.1314

ORIGINAL PAPER

THE CONTENT OF SELECTED MINERALS DETERMINED IN THE LIVER, KIDNEY AND MEAT OF PIGS*

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Abstract

The aim of the study was to determine the chemical composition of pig meat, liver and kidney in terms of mineral elements, and to establish the relationships between selected macro- and microelements. Twenty organically raised pigs [Złotnicka Spotted and F1 (Polish Large White × Polish Landrace)] were investigated. At the end of fattening (100-108 kg of body weight), the animals were slaughtered and the following tissues and organs were sampled from each pig: muscle *longissimus lumborum*, liver, and kidney. The samples were freeze-dried and digested in an Ethos Plus microwave system. Mineral content of the prepared samples was determined by means of a Unicam Solar 969 atomic absorption spectrometer. *Longissimus lumborum* muscle proved to be rich in macroelements as 1 kg of fresh tissue was found to contain as much as 282.34 mg magnesium, 3 668.41 mg potassium and 329.35 sodium. Among the analysed microelements (Zn, Cu, Mn and Fe), the presence of only zinc and iron (16.13 and 0.02 mg kg^{-1} of fresh tissue, respectively) was detected in the muscles. Liver samples were characterised by the highest levels of Zn (64.09 mg kg^{-1}), Mn (3.37 mg kg^{-1}) and Fe (0.48 mg kg^{-1}). The mean content of Cu in 1 kg of fresh tissue did not exceed 7.42 mg. The macroelements determined were Mg (180.89 mg kg^{-1}), K (3 082.04 mg kg^{-1}) and Na (744.25 mg kg^{-1}). Kidneys were most abundant in Cu (9.52 mg kg^{-1}) and Na (1 404.08 mg kg^{-1}). In addition, they also contained zinc (24.62 mg kg^{-1}), manganese (2.25 mg kg^{-1}), iron (0.11 mg kg^{-1}), magnesium (202.14 mg kg^{-1}) and potassium (2 541.63 mg kg^{-1}).

Keywords: minerals, pig, liver, kidneys, meat.

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* The study was supported by departmental sources.

INTRODUCTION

Meat and meat products are an excellent source of many valuable nutrients, such as high-value protein, B-complex and antioxidant vitamins, *n*-3 polyunsaturated fatty acid, and bioactive compounds (taurine, carnosine, creatine). They also contain many minerals without which no living organism can function. These minerals include the metals calcium, sodium, magnesium, potassium, iron, copper, manganese and zinc (Kunachowicz et al. 2005). Zinc is responsible for the proper growth and development of an organism (including the biosynthesis of the proteins) and it is necessary for the functioning of the respiratory, reproductive, and immune systems (Biesalski 2005). Iron is a component of haemoglobin and myoglobin, and is responsible for the transport of respiratory gases. Both Zn and Fe are absorbed from the food rich in animal protein better than from plant foods (Blicharski et al. 2013). Copper is involved in the oxidation-reduction processes, collagen metabolism and transport of iron (Gortat 2013). Manganese is an element responsible for the proper functioning the nervous system, and it is a component of the enzymes involved in the digestion and absorption of carbohydrates, lipids and proteins. Magnesium is involved in the transport of cations and anions and controls the permeability of the cell membranes (Jukna et al. 2013). Sodium is a basic element of body fluids and the main antagonist of potassium. Because the human body is unable to synthesise these minerals, they must be supplied by a diet in proper proportions and amounts.

Meat plays a very important role in human nutrition because of its high nutritional value. According to the Central Statistical Office in Poland (GUS in Polish) Poles consume an average of 69.5 kg of the meat (56.3% is pork) and 4.1 kg offals, the most common are the livers and kidneys (GUS 2015). The meat quality of slaughter animals and the mineral concentration thereof depend on several factors. The most important are species, sex, age and physiological status of the animals, continual innovations in breeding systems, changes in nutrition (e.g. diet composition), and housing conditions (Tomović et al. 2011). Exposure of animals to low levels of minerals may cause reproductive impairment, physiological abnormalities, and behavioural modifications (Nriagu et al. 2009). For animal welfare and considering the health of humans, who are at the top of the food chain, it is essential that dietary mineral deficiencies and excesses be prevented (Skibniewska et al. 2011).

The aim of the study was to determine the chemical composition of pig tissues: muscle *longissimus lumborum*, liver and kidney, in terms of mineral elements, and to establish the relationships between selected macro- and microelements.

MATERIAL AND METHODS

Twenty organically raised pigs [Złotnicka Spotted and F1 (Polish Large White × Polish Landrace)] were investigated. Each group consisted of 10 animals (hogs and gilts in equal number). Animals were fed a diet containing 12.6 MJ ME and 156.2 g of crude protein. The diet consisted of 35% triticale/ lupin mixture, 20% rye, 10% barley, 10% wheat, 10% oat grain, 5% pea mixture, 5% rapeseed, and 5% vitamin-mineral mixture. The composition of the vitamin-mineral mixture is given in Table 1. At the end of fattening (100-108 kg of body weight), the animals were slaughtered (Zlotnicka Spotted aged 5.5-6 month, and PLW x PL aged 6.5 - 7 month). Twenty-four hours *post mortem*, the following tissues and organs were sampled from each pig: *m. longissimus lumborum*, liver, and kidney.

Table 1

Minerals and vitamins in 1 kg of mixture

Item	Content of mixture
Lysine (g)	5.8
Methionine + Cysteine (g)	3.8
Mineral and free phosphorus (g)	60
Threonine (g)	2,5
Tryptophan (g)	1,1
Fe (mg)	3 000
I (mg)	25
Cu (mg)	3 000
Se (mg)	10
Mg (mg)	8 000
Na (mg)	40 000
Ca (mg)	297 000
Vitamin A (j.m)	225 000
Vitamin. D_3 (j.m)	22 500
Vitamin E (mg)	900
Vitamin K (mg)	30
Vitamin B_1 (mg)	30
Vitamin. B_2 (mg)	60
Vitamin. B_6 (mg)	60
Vitamin B_{12} (μg)	150
Biotin (μg)	780
Niacin (mg)	300
Pantothenic acid (mg)	150
Folic acid (mg)	8

Upon delivery to the laboratory, samples were freeze-dried in a Lyovac GT2 lyophilizer (Finn-Aqua). To determine selected minerals (Na, K, Mg, Zn, Mn, Cu, Fe), 0.2 g of freeze-dried tissue was weighed, a mixture of HNO_3 and H_2O_2 at a 4:1 ratio was added and the sample was wet mineralised for 20 min in an Ethos Plus microwave mineraliser (Milestone) at 190°C. Mineralised samples were transferred to 50 cm^3 volumetric flasks and analysed using an Atomic Absorption Spectrometer (SOLAR 969, UNICAM, England). The content of mineral components was expressed in mg per kg of fresh tissue.

Statistical analysis was performed with Statistica 8.0. One-way analysis of variance (ANOVA) and the Scheffe test as a *post-hoc* procedure were used to compare the concentrations of Zn, Cu, Mn, Fe, Mg, Na and K in different tissues. Because two elements (Mn and Cu) were not detected in the muscle tissue, Student's *t*-test was used for comparison. The normality of data distribution was assessed by the Shapiro-Wilk test and the homogeneity of variance was verified with the Levene's test. Interrelationships between the analysed minerals were determined based on the Pearson's correlation coefficients. Differences were considered significant when $p < 0.05$.

RESULTS AND DISCUSSION

The content of selected macro- and microelements in the analysed pork tissues (expressed as mean value ± standard deviation) is shown in Table 2. *Longissimus lumborum* muscle proved to be rich in macroelements as 1 kg of fresh tissue was found to contain as much as 282.34 mg magnesium and 3 668.41 mg potassium. Sodium content did not exceed 329.35 mg kg^{-1}. In a comparison of our results with those published by Milczarek and Osek (2016), certain similarity can be observed (Mg – 245 mg kg^{-1}; Na –

Table 2

The content of selected minerals in pig *m. longissimus lumborum*, liver and kidney

Minerals (mg kg^{-1})	Tissue		
	muscle $\bar{x}$ ± SD	liver $\bar{x}$ ± SD	kidney $\bar{x}$ ± SD
Zn	16.13 ± 1.73	64.09 ± 19.99	24.62 ± 1.87
Cu	0	7.42 ± 1.47	9.52 ± 1.91
Mn	0	3.37 ± 1.91	2.25 ± 0.44
Fe	0.02 ± 0.01	0.48 ± 0.08	0.11 ± 0.02
Mg	282.34 ± 16.86	180.89 ± 25.77	202.14 ± 13.84
Na	329.35 ± 100.38	744.25 ± 180.25	1 404.08 ± 257.38
K	3 668.41 ± 258.28	3 082.04 ± 270.07	2 541.63 ± 210.28

465 mg kg^{-1}, K – 3 910 mg kg^{-1} fresh tissue). The muscle of gilts of native Polish pig breeds (PLW and PL) contained more Mg (approx. 50 mg), Na (approx. 140 mg) and K (approx. 1 400 mg) in 1 kg of fresh tissue (Mieńkowska-Stępniewska et al. 2007). When analysing the mineral composition of the meat depending on a production system, our results turned out to be 3-fold lower than those reported by Zhao et al. (2016), and the production system (organic vs. conventional) of [Duroc × F1 (Landrace × Yorkshire)] pigs was found to have no significant effect on the macroelement content of their meat. Among the determined microelements (Zn, Cu, Mn and Fe), only the presence of zinc and iron was found in the analysed muscles. The zinc content of the muscles (16.13 mg per kg of fresh tissue) is similar to that reported by Rekiel, Surdacki (1985) analysing the mineral composition in the muscle tissue of domestic pig breeds and their hybrids. Of concern in the context of other reports is the low level of iron (0.02 mg kg^{-1} of fresh tissue) and the lack of copper and manganese in the muscles. The observed discrepancies can be attributed to the use of different grower diets (Milczarek, Osek 2016) or to different breeds of the animals (Tomović et al. 2010, López-Alonso et al. 2012).

The major source of zinc, manganese and iron in the human diet is pork liver. Its zinc content was four times as high as in the *longissimus lumborum* muscle. A similar amounts of zinc (approx. 57 mg kg^{-1}) was contained in livers of pigs examined by Żmudzki et al. (1992). The content of manganese (3.366 mg), which was determined in 1 kg of fresh tissue, was similar to the values published by other authors (Tomović et al. 2010, López-Alonso et al. 2012). In turn, a similar copper content to that obtained in our study was reported by Korsrud et al. (1985). According to these authors, the majority of pork livers (65% of all samples), contain from 2 to 10 mg of this element per kg of fresh tissue. Compared to some earlier reports on the mineral content of pork liver, the mean concentration of iron determined in the liver is low. Nevertheless, the liver's iron concentration is 20-fold higher than that determined in the muscles. The results obtained for the content of macroelements (magnesium, potassium and sodium) correspond with the findings reported for different breeds of crossbred pigs (Tomović et al. 2011) and for the breed Swallow-Belly Mangalica (Tomović et al. 2015) as well as the wild boar (Długaszek, Kopczyński 2011).

Unlike muscle and liver samples, pork kidneys were characterised by the highest content of copper (9.516 mg kg^{-1}), and the zinc content did not exceed 25 mg per kg of fresh tissue. This supports the findings of López-Alonso (2012), who found 27.1 mg of zinc and 4.34 mg of copper in the kidneys of crossbred pigs (White Belgium × [Landrace × Large White]). A slightly higher content of these elements was found in the samples of wild boar kidneys: Zn – 32.46 mg kg^{-1} and Cu – 5.64 mg kg^{-1} (Amici et al. 2012). According to literature reports, a high level of dietary zinc reduces the copper content of tissues (Skibniewska et al. 2011). On the other hand, a low zinc concentration contributes to the accumulation of copper. The kidney samples that we analysed contained four-fold less iron than the liver samples, which is also confirmed by López-Alonso (2012). In turn, the amounts of manganese were similar to the data reported by Tomović et al. (2010). Of the macroelements, kidneys were most abundant in sodium (twice as much as in the liver and four times as much as in the *longissimus lumborum* muscle). The results were similar to those achieved by Tomović et al. (2015) who analysed the mineral composition in the offals of pigs which belonged to the breed Swallow-Belly Mangalica.

The statistical analysis confirmed only three statistically significant correlations between the elements present in the *longissimus lumborum* muscle (Table 3). Magnesium content had a beneficial effect on the concentration of

Table 3

Coefficients of correlation (r_{xy}) between the content of selected elements in pig *m. longissimus lumborum*

Elements	Zn	Fe	Mg	Na
K	0.5001	0.3437	0.7361*	0.4600
Na	0.0465	0.1575	0.1397	
Mg	0.5777*	0.7090*		
Fe	0.4549			

* significant coefficient at $p \leq 0.05$

zinc (r_{xy} = 0.578) and potassium (r_{xy} = 0.736). In addition, increased magnesium concentration in the muscles increased the content of iron (r_{xy} = 0.709), which has an effect on the colour of meat (Ren Guang-zhi et al. 2008). Similar relationships: between Fe-Mg (r_{xy} = 0.6 at $p < 0.01$) and between Mg-K (r_{xy} = 0.78 at $p < 0.001$), were reported by Tomović et al. (2014*b*), who analysed the mineral composition in the meat of Swallow-Belly Mangalica pigs. Because the muscle tissue was found to contain no copper, its effect on sodium (Jukna et al. 2013) and zinc could not be established (Ren Guang-Zhi et al. 2008). In turn, the lack of manganese in the muscles precluded the confirmation of positive correlations, and thus the synergistic effect of Mn on K, Mg and Fe (Tomović et al. 2014*a*).

Most correlations were found between the elements determined in the liver (Table 4). These relationships occurred between Cu and Mn (r_{xy} = 0.655) and between Cu and Mg (r_{xy} = 0.753, $p < 0.05$). The positive, statistically significant coefficient of correlation obtained in our study between the concentration of Zn and Cu (r_{xy} = 0.807), does not confirm the antagonistic action of both elements. Thus far, lower coefficients for the interactions between Zn and Cu were established by Nriagu et al. (2009): r_{xy} = 0.198 at $p < 0.05$ for cow livers. Analysis of the interactions between the determined elements showed the presence of positive correlations between the content of magnesium and the amounts of zinc, sodium and potassium. Our analysis showed no statistically significant relationship between Mg and Mn, as opposed to Długaszek and Kopczyński (2011), who examined the livers of wild boars.

Table 4

Coefficients of correlation (r_{xy}) between the content of selected elements in pig liver

Elements	Zn	Cu	Mn	Fe	Mg	Na
K	0.5272	0.3774	0.2838	0.3922	0.7712*	0.6307*
Na	0.6265*	0.5230	0.3171	0.5811*	0.7934*	
Mg	0.8079*	0.7534*	0.3891	0.5220		
Fe	0.5210	0.5318	0.3211			
Mn	0.5297	0.6546*				
Cu	0.8071*					

* significant coefficient at $p \leq 0.05$

The synergistic action of sodium and potassium (r_{xy} = 0.631 at $p < 0.05$), and a positive effect of sodium on the zinc and iron content of the liver were also confirmed.

Analysis of intra-group correlations for the kidney showed only one statistically significant ($p < 0.05$) relationship between the iron and manganese content (Table 5). The literature on cattle is abundant with information abo-

Table 5

Coefficients of correlation (r_{xy}) between the content of selected elements in pig kidney

Elements	Zn	Cu	Mn	Fe	Mg	Na
K	0.1498	0.0341	0.2909	0.2611	0.1305	0.3129
Na	0.5683	0.2642	-0.2053	-0.4524	-0.0529	
Mg	0.0706	-0.1482	0.0830	0.4137		
Fe	-0.5161	0.2153	0.6038*			
Mn	-0.2408	0.2097				
Cu	-0.0714					

* significant coefficient at $p \leq 0.05$

ut relationships between the elements found in kidneys. The most often reported are the statistically significant correlations between Zn and Cu (López-Alonso et al. 2004, Nriagu et al. 2009) and the correlations (non-significant but with high coefficients) of Cu with Fe and Mn; of Zn with Mn and Fe; and of Fe with Mn (López-Alonso et al. 2004). The mechanisms of the latter relationship are not fully understood. According to Garrick et al. (2003), the correlation may suggest the presence of common transporters that control the uptake and trafficking of these metals, and this in turn is related to maintaining normal body homeostasis.

CONCLUSIONS

The performed determinations showed that pork liver is the best source of zinc, iron and manganese, the elements necessary for normal body development and function. Most copper is found in the pig kidneys. The poorest in microelements was the *longissimus lumborum* muscle, which had the highest content of magnesium and potassium.

The analyses demonstrated the presence of 13 relationships between the elements studied: 3 for muscle, 9 for liver, and 1 for kidney. Among these, only two statistically significant correlations occurred in both the muscle and liver: between Mg content and K and Zn content. Obtaining nine correlations associated with the liver indicates that this organ is involved in the process of metal accumulation.

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