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MINERAL CONTENT OF MUSCLE TISSUE OF RAINBOW TROUT (*ONCORHYNCHUS MYKISS* WALBAUM)*

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Abstract

Fish are most often considered as a rich source of valuable fat, although sometimes the high quality of fish meat protein is also emphasized, but there is comparably little information on the mineral composition of fish meat. Chemical composition, caloric value and health safety of fish as food depend on many factors, of which the rearing conditions are most influential. Aside from environmental conditions, production technology is a major determinant of the quality and nutritional value of trout. In this study, the influence of a farming technology on the content of minerals in the muscle tissue of rainbow trout (*Oncorhynchus mykiss* Walbaum) netted in various Polish regions has been assessed. Fish were caught in autumn 2010 and 2011 and spring 2011, at 3 farms with a water flow-through system and 3 farms with water recirculation. The trout muscle tissue contained: 188.4 - 518.4 mg kg^{-1} of calcium, 306.9 - 338.1 mg kg^{-1} of magnesium, 464.0 - 718.2 mg kg^{-1} of sodium, 4.5 - 6.9 mg kg^{-1} of zinc, 2485.7 - 2823.6 mg kg^{-1} of phosphorous, 4261.2 - 4615.4 mg kg^{-1} of potassium, 3.0 - 9.4 mg kg^{-1} of iron and 0.09 - 11.74 mg kg^{-1} of copper. The farming technology influenced the content of calcium, sodium, zinc, iron and copper but had no effect on the content of magnesium, phosphorous and potassium in rainbow trout muscle tissue. Trout farmed in water recirculation systems contained higher amounts of

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most elements than the fish reared in water flow-through systems. The season of sample collection (date of netting) also affected the content of sodium, zinc, phosphorus, iron and copper. The fish farming site (localization of the farm) determined the content of most of the minerals except magnesium. Rainbow trout is a good source of phosphorous and potassium in a human diet, significantly covering the daily demand for the elements.

Keywords: rainbow trout, farming technology, FTS**,** RAS, minerals intake.

INTRODUCTION

Consumers value freshwater fish because of the standard quality proteins, high digestibility and fat composed of healthy fatty acids (Weichselbaum et al. 2013). Zabetakis (2013) emphasized the role of fish oils in a human diet and suggested that while food production should increase in volume, the quality of food needed to be improved as well. Fish are also a good source of such minerals as phosphorous, magnesium and selenium. Although fish meat's chemical composition, caloric value and health safety depend on many factors (feeding intensity, type and quality of used fodder, amount of natural food taken by the fish, type and place of breeding), the breeding conditions have the most considerable influence (Tkaczewska, Migdał 2012). Aside from environmental conditions, production technology is one of the most important factors determining the quality and nutritional value of the trout (Teodorowicz 2013).

Over the years, various systems of trout farming have been developed resulting from different natural environmental conditions and the influence of a fish farm's location (Martins et al. 2010). Trout farms in Poland are located mainly in the north of the country and in the south, in mountainous regions (Teodorowicz 2013). Trout ponds mimic the character of a river environment; the main demand is a strong flow of cold, clean, well-oxygenated water. Traditional trout farms use 200 to 400 liters of water per second, achieving production output from 40 to 200 tons of trout. The technology with flow-through water systems (FTS) is common in trout production, (Fallah et al. 2011).

In countries with limited water supplies, saving water is crucial (Bureau, Hua 2010). In an attempt to reduce costs, producers are more often inclined towards systems which allow multiple use of water, such as recirculation aquaculture systems (RAS) (Sindilariu et al. 2009). By re-using the same water over a dozen times, RAS systems allow for energy savings and, most importantly, they protect water supplies (Biegańska, Piątkowska 2012). Moreover, RAS systems prevent the unfavourable impact of trout production on the environment due to water pollution (Wik et al. 2009). Water is purified by physicochemical and biological processes (Martins et al. 2010). By controlling production parameters, it is possible to decrease the content of nitrites and ammonia and to maintain constant pH (Dalsgaard et al. 2013).

The RAS systems lack full legal regulations (Martins et al. 2010). *Commission Regulation (EC) No 710/2009* (2009), which sets specific rules concerning ecological production in the aquaculture sector, does not allow such systems as RAS in ecological production until sufficient studies have been completed. Such research is necessitated by the dynamic development of aquaculture and the limited supply of marine food resources (Dalsgaard et al. 2013). Earlier investigations describing both technologies compared the efficiency of both systems, fish welfare in various compactions, life cycles and production costs (Roque d'Orbcastel et al. 2009).

In Poland, rainbow trout is farmed in both FTS and RAS systems. The aim of this study was to assess the influence of a farming technology on the content of minerals in the muscle tissue of fish netted in various Polish regions.

MATERIAL AND METHODS

Sample collection and preparation

In the autumn of 2010, 2011 and in the spring of 2011, 40 specimens of rainbow trout (*Oncorhynchus mykiss* Walbaum 1792) were netted in each of six fish farms from different regions of Poland: 3 farms (Nos 1, 2 and 3) with flow-through systems (FTS) and 3 farms (Nos 4, 5 and 6) using the recirculation aquaculture system (RAS). At the site of netting, the fish were anaesthetized, sacrificed, washed, gutted, re-washed and packed in plastic bags and boxes with ice. The chilled fish were taken to a laboratory. For chemical analysis, samples of muscle tissue in the form of approx. 5-cm-wide segments were dissected from the middle part of a fillet (from the dorsal to the abdominal side). The skin and bones were removed. Next, a sample from each fish was comminuted and mixed separately, packed into a plastic bag and stored at -25°C until analysis.

Mineral analyses

Portions (1 g) of each meat sample were mineralized in a Muffle Furnaces FCF 7 SM microwave oven (Czylok, Poland) at 450°C. Th residue was dissolved in 4 ml (65%) of nitric acid (Suprapur Merck, Germany) and transferred to a 25 ml volumetric flask, adding ultra-pure de-ionized water (Millipore, Baltimore, USA) to the 25 ml mark. Concentrations of calcium, magnesium, sodium, zinc, potassium, iron and copper were determined by atomic absorption spectrophotometry. A Perkin-Elmer atomic absorption spectrometer 1100 B equipped with a deuterium lamp for background correction was used. Phosphorous concentrations were determined by optical emission spectrometry with plasma induction (Varian ICP-OES Vista MPX). Average values from 3 replicates <10% were submitted to interpretation and analysis of the results.

Statistical analysis

Statistical analyses were conducted with the STAT statistical software Statistica 10 Program (StatSoft Poland, Cracow, Poland). Significant differences were determined at $p \leq 0.05$. The homogeneity of variances was examined using the Levene's test. The test of significance between the number of averages was performed using non-parametric analysis of multiple comparisons of means (the Kruskal-Wallis test). The Spearman's correlation coefficients were used to determine the strength and significance of the correlation between the mineral content, production technology and the trout culture conditions.

RESULTS AND DISCUSSION

Mineral content of muscle tissue of rainbow trout

The samples of muscle tissue of the rainbow trout contained from 188.4 to 518.4 mg kg^{-1} of calcium, depending on the origin (Table 1). There is a wealth of data on the content of minerals in rainbow trout tissues originating from various breeding farms. Fallah et al. (2011) studied the composition of fillets of farmed and wild rainbow trout from Iran and determined 360 mg kg^{-1} of the element in farmed fish and 660 mg kg^{-1} in fillets of wild fish. In raw fillets of rainbow trout, Gokoglu et al. (2004) recorded an average of 632 mg kg^{-1} of calcium.

The results presented in the article are much higher than those determined by Polak-Juszczak (2007) for other species of fish new to the Polish market: oilfish – 59.3 mg kg^{-1}, pangasius catfish – 73.9 mg kg^{-1}, African catfish – 105.8 mg kg^{-1}, Nile perch – 178.0 mg kg^{-1}. Łuczyńska et al. (2011) also determined a lower Ca content in fish bought on Polish markets: salmon – 90 mg kg^{-1} and rainbow trout – 137 mg kg^{-1}.

The samples of muscle tissue of rainbow trout contained from 306.9 to 338.1 mg kg^{-1} of magnesium (Table 1). A higher Mg content (330-350 mg kg^{-1}, depending on fish diet) in rainbow trout was determined by Apines-Amar et al. (2004) in a study of acid-chelated trace elements as fish dietary supplements. Gokoglu et al. (2004) also found a higher magnesium content in raw rainbow trout fillets (409 mg kg^{-1}). Brucka-Jastrzębska and Kawczuga (2011) found a different magnesium content, much lower than reported elsewhere, in muscle tissue depending on the age of fish: 6-month-old trouts contained 87.2 mg kg^{-1}, 12-month-old – 61.3 mg kg^{-1}, 18-month-old – 99.3 mg kg^{-1}, and 24-month-old trouts had 59.5 mg kg^{-1} of magnesium. Brucka-Jastrzębska et al. (2009) studied the effect of culture conditions on the mineral composition of three species of freshwater fish and found 122.1 mg kg^{-1} of Mg in rainbow trout muscle tissue, 166.1 mg kg^{-1} in Siberian sturgeon muscles and 256.1 mg kg^{-1} in common carp. Polak-Juszczak (2007) determined lower Mg content in

Table 1

Mean content of minerals in trout meat from 6 farms (mean ± SD)

Technology	FTS			RAS		
Farm	1	2	3	4	**5**	**6**
Mean ± SD (mg kg^{-1})						
Ca	188.4 ± 20.59^{a}	244.5 ± 17.33^{ab}	391.6 ± 50.28^{bcd}	300.4 ± 31.66^{ad}	310.0 ± 48.30^{ade}	517.4 ± 42.57^{ce}
Mg	309.5 ± 4.30^{a}	336.6 ± 3.22^{b}	306.9 ± 11.56^{ac}	315.8 ± 2.45^{a}	$318.5 \pm 6,.41^{ab}$	338.1 ± 10.69^{cb}
Na	531.8 ± 36.9^{ab}	561.1 ± 26.04^{ab}	489.0 ± 32.14^{a}	464.0 ± 18.08^{a}	670.2 ± 26.98^{bc}	718.2 ± 13.24^{c}
Zn	4.5 ± 0.17^{a}	5.0 ± 0.21^{ab}	5.5 ± 0.30^{bc}	5.3 ± 0.25^{ab}	5.5 ± 0.29^{ac}	6.9 ± 0.61^{c}
P	2488.9 ± 26.80^{a}	2738.1 ± 33.44^{bcd}	2606.8 ± 100.88^{cde}	2686.7 ± 29.33^{bd}	2485.7 ± 29.33^{a}	2823.6 ± 87.08^{be}
K	4261.2 ± 42.43^{a}	4615.4 ± 54.12^{bd}	4343.8 ± 153.62^{cbd}	4419.1 ± 26.91^{ac}	4309.6 ± 61.50^{ac}	4599.7 ± 58.10^{d}
Fe	3.0 ± 0.19^{a}	9.4 ± 2.46^{bd}	3.7 ± 0.25^{abe}	5.3 ± 1.20^{ab}	3.7 ± 0.22^{abc}	5.0 ± 0.4^{cde}
Cu	0.39 ± 0.27^{a}	0.70 ± 0.81^{a}	0.32 ± 0.22^{a}	0.30 ± 0.16^{a}	0.09 ± 0.04^{bc}	0.17 ± 0.34^{b}

Values in rows marked with different letters are significantly different (p <0.05).
FTS – farms: 1, 2,3, RAS – farms: 4, 5, 6;

Nile perch than presented in the current study – 228.6 mg kg^{-1} and African catfish – 282.3 mg kg^{-1}, and higher in pangasius catfish – 353.3 mg kg^{-1} and oilfish – 440.9 mg kg^{-1}.

The tested samples of muscle tissue of rainbow trout contained from 464 to 718.2 mg kg^{-1} of sodium (Table 1). This is much more than found by Celik et al. (2008) in rainbow trout caught in Atatürk Dam Lake in Turkey – 254.9 mg kg^{-1} and similar to the results of Gokoglu et al. (2004) – 544 mg kg^{-1} in raw rainbow trout fillet. Łuczyńska et al. (2011) determined higher contents of sodium in rainbow trout – 370 mg kg^{-1}, than in common carp – 310 mg kg^{-1} and Salmon – 420 mg kg^{-1}.

Zinc contents were determined to range from 4.5 to 6.9 mg kg^{-1} (Table 1) and were lower than those found by Bajc et al. (2005) in muscles of Salmonids from various Slovenian rivers – 9.7 mg kg^{-1}. Apines-Amar et al. (2004) also found a much higher (from 13.0 to 19.1 mg kg^{-1}) Zn content in trout fed with different feed compositions. Brucka-Jastrzębska et al. (2009) determined 8.1 mg kg^{-1} of zinc in muscles of rainbow trout, 7.4 mg kg^{-1} in Siberian sturgeon and 6.1 mg kg^{-1} in common carp. However, Łuczyńska et al. (2011) determined the following zinc content in fish muscles: 4.27 mg kg^{-1} in rainbow trout, 3.35 mg kg^{-1} in salmon and 5.15 mg kg^{-1} in carp.

The samples of muscle tissue contained from 2485.7 to 2823.6 mg kg^{-1} of phosphorus (Table 1). Szlinder-Richert at al. (2011) compared the content of nutrients and contaminants in nine fish species that are popular on the Polish market and found 2775 mg kg^{-1} of P in rainbow trout, which was more than in carp (2090 mg kg^{-1}). Other authors reported much higher values of phosphorus contents in trout: 3378.78 mg kg^{-1} (Gokoglu et al. 2004), 4140-4640 mg kg^{-1} (Apines-Amar et al. 2004).

The content of potassium in the analyzed samples amounted to 4261.2--4615.4 mg kg^{-1} (Table 1). The content of this element in trout from a Turkish lake determined by Celik et al. (2008) was similar – 4121 mg kg^{-1}, but Gokoglu et al. (2004) reported a much lower content (3060 mg kg^{-1}) in raw rainbow trout fillet.

The samples of rainbow trout muscle tissue contained from 3.0 to 9.4 mg kg^{-1} of iron (Table 1). The lowest Fe content was determined in farm No 1 (3.0 mg kg^{-1}), and the highest (9.4 mg kg^{-1}) was also in the FTS farm number 2. Bajc et al. (2005) determined a lower iron content in Salomonids fish (2.6 mg kg^{-1}). Fallah et al. (2011) found 3.31 mg kg^{-1} of Fe in farmed rainbow trout and 7.01 mg kg^{-1} in wild rainbow trout. Celik et al. (2008) reported 4.15 mg kg^{-1} Fe in muscle tissue of rainbow trout.

Various contents of copper were determined depending on the farms (Table 1). The highest level was determined in fish from farm No 2 (0.70 mg kg^{-1}). Samples of muscle tissue of trout from farms No 5 and No 6 employing the RAS system (respectively, 0.09 and 0.17 mg kg^{-1}) contained much less copper than samples of fish from the other locations. Apines-Amar et al. (2004) found from 1.69 to 2.12 mg kg^{-1} of Cu in trout meat and Bajc et al. (2005) found 0.36 mg kg^{-1} in Salmonid muscle tissue. Similar results were obtained by Szlinder-Richter et al. (2011) in 9 species of fish popular on the Polish market. Bagdonas and Vosyliene (2006) warned that a high content of copper in fish meat can be harmful to humans.

Rainbow trout muscles as a source of minerals

Rainbow trout meat is rich in phosphorous, potassium and copper (Table 1) and 100 g portion may cover much of the daily needs of a human body for these elements (Table 2). According to the Norms of Nutrition for the Polish

Table 2

Meeting the daily recommended allowances for selected minerals by a 100 g portion of rainbow trout

Minerals	RDA* (mg day^{-1})	Meeting the norm (%)	RDA male adult** (mg day^{-1})	Meeting the norm (%)	RDA female adult** (mg day^{-1})	Meeting the norm (%)
Ca	800	4	1000	3.3	1200	2.7
Mg	375	8.5	420	7.6	320	10
Zn	10	5.5	11	5	8	6.9
P	700	37.9	700	37.9	700	37.9
K	2000	22.2	4700	9.4	4700	9.4
Fe	14	3.6	10	5.1	18	2.8
Cu	1	3.3	0.7	4.7	0.7	4.7

* RDA Commission Directive 2008/100/EC of 28 October 2008,
** RDA Norms of Nutrition for Polish Population (2012). National Food and Nutrition Institute in Poland;

Population (2012), a 100 g portion of the trout meat covers almost 40% of the recommended daily allowance for phosphorous, although it supplies only about 10% of the RDA of potassium and magnesium, 5.0÷6.9% of zinc and less of iron, copper and calcium. For comparison, the RDA values after *Commission Directive EU 2008/100/EC* and their coverage by trout meat consumption are presented in Table 2; the demand for all minerals was approximately the same except for potassium.

A supply of minerals in amounts adequate for the age and sex group of consumers is necessary to maintain good health (White, Broadley 2009). Long-term deficiency or excess result in physiological disorders and may also play a role in the aetiology of some metabolic diseases. Research literature notes the influence of an abnormal intake of minerals on the development of cardiovascular diseases, osteoporosis, diabetes and some types of cancers (Carneiro et al. 2013). Mineral deficiencies are especially dangerous to high-risk groups: children, elderly people, persons with a low immunity status and suffering from some diseases, e.g. childhood autism (Herndon et al. 2009).

Inadequate amounts of minerals have been detected in a traditional Polish diet, where an abnormal intake of calcium, magnesium, phosphorous, iron, zinc, copper and selenium has been documented (BARTON 2009, JABLONSKA et al. 2013). However, the same problem is encountered in other countries around he world; it is addmitted that over 60% of the world's 6 billion population are iron-deficient and over 30% are lacking zinc, 30% are short of iodine and 15% need more selenium (WHITE, BROADLEY 2009). It has been proven that 9% of the British and American adults are both calcium- and magnesium-deficient and 14% are lacking in potassium (RUSTON et al. 2004).

Moreover, it is not just the physiological status of an organism or the presence of metabolic disorders and diseases, but also the composition of food that determine the extent of mineral release from food (NALEPA et al. 2012, SKIBNIEWSKA et al. 2010). Different nutritional and non-nutritional factors influence the release, absorption, excretion and metabolism of minerals from a diet. *In vivo* and *in vitro* studies have demonstrated that the bioavailability of minerals also depends on their interaction with anti-nutrients, such as oxalic acid, phytates, dietary fiber, polyphenols as well as drugs (SULIBURSKA et al. 2011). The degree of mineral release from food products also depends on the processing technology (SKIBNIEWSKA et al. 2010).

Farming technology and content of minerals

It has been demonstrated that a farming technology significantly influences the content of calcium, sodium, zinc, iron and copper, while it does not affect much the content of magnesium, phosphorus and potassium in rainbow trout muscle tissue (Table 3). The results have been confirmed by a correlation analysis and calculated values of the Spearman's indices (Table 4). The farming technology showed a clear statistical relationship with the copper (-0.34, $p < 0.05$), zinc (0.30, $p < 0.05$) and calcium (0.28, $p < 0.05$) content. The contents of iron and sodium were weakly correlated (although significantly) and the contents of magnesium, potassium and phosphorous were insignificantly correlated.

Higher average contents of calcium, sodium, potassium and much higher concentrations of iron were determined in the muscle tissue of rainbow trout netted in spring than in autumn (Table 3). The content of phosphorous was higher and that of copper was even much higher in autumn than in spring. The season of fish netting significantly influenced the content of sodium, phosphorus, zinc, iron and copper (Table 3) and the Spearman's indices of correlation between the netting season and the content of the elements were significant only for sodium, phosphorus, iron and copper (Table 4). The contents of these elements were clearly correlated with the netting season while the contents of calcium, magnesium, zinc and potassium were insignificantly correlated. For all minerals, except magnesium, the contents in trout meat depended on the fish's origin and the dependence was clearly statistically significant (Table 4).

Many authors have stressed the influence of breeding conditions on the content of nutrients in fish tissues, thus on the quality of fish fillets (WEDE-

Table 3

Mean content of minerals (mg kg^{-1}) in rainbow trout, depending on breeding technology and season (mean ± SD)

Specification	Ca	Mg	Na	Zn	P	K	Fe	Cu
	mean ± SD (mg kg^{-1})							
Technology*								
RAS	$384.5 \pm 25{,}64^a$	324.7 ± 4.44^a	590.3 ± 17.01^a	5.9 ± 0.28^a	2710.2 ± 37.99^a	4472.3 ± 29.16^a	4.9 ± 0.60^a	0.22 ± 0.25^a
FTS	267.2 ± 20.27^b	316.9 ± 4.23^a	527.7 ± 19.23^b	5.0 ± 0.14^b	2597.4 ± 35.29^a	4393.9 ± 54.20^a	5.2 ± 0.81^b	0.46 ± 0.51^b
Season*								
Spring	347.5 ± 25.02^a	320.2 ± 2.54^a	634.8 ± 12.31^a	5.4 ± 0.13^a	2583.1 ± 20.41^a	4456.9 ± 27.17^a	32.0 ± 0.08^a	0.14 ± 0.07^a
Autumn	318.0 ± 22.22^a	321.2 ± 4.40^a	523.9 ± 17.33^b	5.5 ± 0.23^b	2690.4 ± 17.32^b	4423.4 ± 43.04^a	6.0 ± 0.72^b	0.42 ± 0.46^b

* Values in columns within the same groups (Year, Season, Technology) marked with different letters are significantly different ($p < 0.05$).
RAS – recirculation aquaculture systems, FTS –technology with flow-through systems;

Table 4

Spearman correlation coefficients of mineral contents, breeding technology and trout culture conditions

Element	Technology	Season	Farm
Ca	0.28*	0.15	0.46*
Mg	- 0.02	0,04	0.13
Na	0.17*	0.29*	0.31*
Zn	0.30*	0.04	0.48*
P	0.15	-0.29*	0.28*
K	0.01	0.07	0.19*
Fe	0.18*	- 0.37*	0.31*
Cu	- 0.34*	- 0.41*	- 0.46*

* statistically significant correlations ($p < 0.05$)

KIND 2009, FALLAH et al. 2011, ÖZOGUL et al. 2008, ALI et al. 2013). BRUCKA-JASTRZĘBSKA et al. (2010) also confirmed that the location of a fish farm and farming conditions significantly influenced the content of macro- and microelements in fish.

Production technology is another factor determining the quality of fish meat. The increasingly popular RAS technology positively influences fish meat quality, takes into account the water management and environmental conditions and protects water resources. The advantages of RAS systems in trout farming have been emphasized by SINDILARIU et al. (2009) and ROQUE D'ORBCASTEL et al. (2009).

CONCLUSIONS

The farming technologies tested affected the contents of calcium, sodium, zinc, iron and copper but had no influence on the contents of magnesium, phosphorous and potassium in rainbow trout muscle tissue. Fish from farms employing the RAS system contained higher mean concentrations of most of the elements compared to trout from the FTS farms. The season of sample collection (date of netting) also influenced the contents of sodium, zinc, phosphorus, iron and copper. The fish farm itself (location of the farm) determined the content of most of the minerals, except magnesium. Rainbow trout is a good source of phosphorous and potassium in human diet, covering a considerable share of daily demands for the elements.

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