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The mineral content of fish muscles as an indicator of water quality in Baltic and Scandinavian areas

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ABSTRACT

Fish are an important part of the diet of the people living in Baltic and Scandinavian countries, providing valuable nutrients, including minerals. The levels of metals detected in the muscle suggest that these fish are capable of concentrating and bioaccumulating metals in their bodies from the aquatic environment. The aim of this study was to compare the concentrations of selected micro- and macroelements in the muscles of five fish species: herring (*Clupea harengus* L.), wolffish (*Anarhichas* L.), salmon (*Salmo salar* L.), cod (*Gadidae* L.), mackerel (*Scomber* L.) from the Baltic Sea and Scandinavian regions. The analyses were performed using inductively coupled plasma optical emission spectroscopy (ICP-OES). The results showed significant differences in element content between the fish from both regions. Higher concentrations of calcium, magnesium, phosphorus, potassium and iron were found in the fish from the Baltic Sea region, while higher levels of zinc were observed in some species from Scandinavian waters. The levels of toxic metals were below the permissible standards, indicating no risk to consumer health. Differences in the mineral composition of fish may reflect both diverse environmental conditions and biological factors, such as species affiliation. Due to the observed diversity and increasing anthropogenic pressure on aquatic ecosystems, it is advisable to continue monitoring elements in fish as potential indicators of aquatic environmental quality.

Keywords: water environment quality, Baltic countries, Scandinavian countries, minerals, fish, ICP-OES.

INTRODUCTION

Fish are a source of nutrients, including essential micro- and macroelements that are important for the proper functioning of the human body. Microelements, such as iron, zinc, copper and manganese are found in physiological concentrations in the body and are essential for its proper functioning. Some of these elements are also part of the enzymes that perform key vital functions in humans and animals. Their deficiency or excess can lead to numerous health disorders. Calcium, magnesium and phosphorus act as building materials, forming structural elements of bones and other tissues. Sodium and potassium play an important role in regulating the water and electrolyte balance and acid-base balance in blood and tissues. They also participate in maintaining the resting potential of cell membranes (Kiczorowska et al., 2019). Minerals may contribute to health benefits. Fish consumption has been shown to have a beneficial effect on cardiovascular disease, as confirmed in recent decades. Some studies also suggest that fish may play a protective role in preventing metabolic syndrome. (Torris et al., 2018). Dippong et al. (2024) report in their studies that fish can also cause negative health effects due to their ability to bioaccumulate pollutants. Iron, zinc and copper belong to the group of essential trace elements, but are also classified as heavy metals. Metals can enter the aquatic environment, which is important for the quality of fish raw materials and the safety of their consumption. Effective monitoring and supervision of heavy metal concentrations in the marine environment is highly desirable (Ahmed et al., 2015). Fish are bioindicator organisms used to monitor the quality of aquatic ecosystems because they are readily available in large quantities and have the potential to accumulate metals (Ali et al., 2019). The issue of potentially toxic elements (PTE) in aquatic ecosystems has attracted considerable attention due to their persistent toxicity and bioaccumulation potential. PTE can be released into the marine environment from various geological sources, such as metal-bearing mineral deposits and explosive eruptions, as well as from anthropogenic sources, including industrial, agricultural and aquaculture activities (Ben-Tahar et al., 2025). Once they enter the aquatic environment, metals are redistributed in the water column, settle or accumulate in sediments, and are consumed by fauna and flora. Contaminants can accumulate in fish and ultimately reach humans through the food chain (Hao et al., 2019). Testing the levels of certain heavy metals in selected fresh fish will allow assessing whether their consumption may pose a health risk (Wang et al., 2020). Fish muscles typically contain lower levels of heavy metals and are therefore the main focus of the studies assessing the risks to human health associated with fish consumption (Sharma et al., 2025). This is particularly important in the context of heavy metals, which can be harmful to health if consumed regularly in excess. Informing the public about the levels of heavy metals in fish can help raise consumer awareness about food safety and the impact of the environment on food quality. The ranges of concentrations of selected minerals in all fresh fish muscle samples, based on the overall average, were as follows: calcium 29.48–481 $mg \cdot kg^{-1}$d.m., potassium 686–7591 $mg \cdot kg^{-1}$d.m., phosphorus 906–9385 $mg \cdot kg^{-1}$d.m., magnesium 163–1117 $mg \cdot kg^{-1}$d.m., iron 2.04–22.18 $mg \cdot kg^{-1}$d.m., zinc 6.3–36.76 $mg \cdot kg^{-1}$d.m. The nutritional value of fish meat depends largely on: species, age, sex, living environment, diet, and fishing methods (Kiczorowska et al., 2019). The minerals studied are essential for the proper functioning of the human body. Comparing the levels of these components in different species of fresh fish between selected Baltic and Scandinavian countries can help assess whether fish consumption supplements the nutritional requirements in the human diet, as well as help develop nutritional recommendations for the inhabitants of a given country. The minerals studied are essential for the proper functioning of the human body. Comparing the levels of these components in different species of fresh fish between selected Baltic and Scandinavian countries can help assess whether fish consumption supplements the nutritional requirements in the human diet, as well as help develop nutritional recommendations for the inhabitants of a given country. Much of the research on the nutritional value of food is based on studies of raw materials, but processing methods and temperatures have a significant impact on changes in the nutrients in the finished product (Arvanitoyannis et al., 2012).

The aim of the study was to compare the zinc, iron, calcium, potassium, phosphorus and magnesium content in the meat of five common species of fresh fish (herring, mackerel cod, salmon, wolffish) from selected Baltic and Scandinavian countries.

MATERIAL AND METHODS

The research material consisted of muscle tissue samples from five species of fresh fish: herring, mackerel, cod, salmon, wolffish and from selected Baltic countries FAO 27.3.d (Denmark, Estonia, Finland, Lithuania, Latvia, Germany, Poland, Russia, Sweden) and Scandinavian countries FAO 27 (Norway, Sweden, Finland, Iceland, Denmark). All fresh fish were purchased from a specialist shop. According to the seller's specifications, the fish came from the Baltic and Scandinavian regions. The fish were delivered to the laboratory of the Regional Centre for Research on the Environment, Agriculture and Innovative Technologies EKO-AGRO-TECH in an insulated bag with ice and were analyzed or stored in a freezer at -20 °C until analysis. The content of selected micro- and macroelements was determined after the following sample preparation process. The weight of the sample was 0.4 g for dry matter and 0.1 g for the ashes. To each sample, 4 ml of 65% nitric acid (HNO_3), 0.5 ml of 37% hydrochloric acid (HCl) and 2 ml of demineralized water were added. The digestion process was carried out in a microwave device manufactured by AntonPaar, under the following conditions: maximum power 1500 W, temperature ramp up to 230 °C within 20 minutes, maintaining a temperature of 230 °C for 15 minutes, followed by cooling for 27 minutes. After completion of the digestion, the solution was filtered and then diluted with distilled water to a volume of 50 ml. The content of selected macronutrients (Ca, Mg, K, P) and microelements (Fe and Zn) were determined using inductively coupled plasma optical spectroscopy (ICP-OES) equipped with an argon saturation system and a CCD detector. An ICP-OES analyzer (Spectroblue, AMETEK Inc., Germany) enabled precise determination of elements in the samples. A certified standard was used for the analysis VHGSM68-1-500 Element Multi Standard 1 containing 48 control elements in a 5% HNO_3 solution. The collected material was subjected to statistical analysis using STATISTICA version 13.0 software from StatSoft Polska. All confounding factors were controlled to minimize the risk of error. An analysis of variance t-Student was used to evaluate the differences between species at a confidence level of $p \leq 0.05$.

RESULTS AND DISCUSSION

The content of micro- and macroelements in fish tissues varies significantly, which may be determined by a number of environmental and biological factors, food preferences and migratory behavior. Even within a single body of water, differences in feeding habits or bioaccumulation capacities can result in varying elemental profiles between species, as well as between individuals of the same species (Anan et al., 2005). Fish are a real treasure trove of valuable nutrients (Woźniak et al., 2018). Zinc (Zn) is a microelement essential for the proper functioning of the human body, performing a number of key biological functions. It participates in the regulation of the immune response, wound healing processes, protein and nucleic acid synthesis, as well as in the metabolism of sex hormones and thyroid hormones. In addition, it plays an important role in taste perception and fetal development during the prenatal period. Zinc deficiency can lead to numerous physiological disorders. Fish and fish products are one of the sources of zinc in the human diet. According to the standards established by the Food and Agriculture Organization (FAO), the maximum permissible zinc content in fish and fish products is 30 mg·kg^{-1} of fresh weight (Food and Agriculture Organization [FAO], 2025). Exceeding this value may indicate environmental pollution or improper farming and processing practices. The highest significant concentration of zinc (Zn) in the muscles of the tested fish was recorded in the wolffish 26.76 mg·kg^{-1} and herring 24.36 mg·kg^{-1} from Scandinavian countries compared to Baltic countries in the case of the toothbrush 21.00 mg·kg^{-1}, and herring 18.64 mg·kg^{-1} (Figure 1). Nissbet et al. (2009) and Mutlu (2024) reported similar zinc concentrations in their studies. One of the essential trace elements that play a key role in the proper functioning of the human body is iron (Fe), classified as a heavy metal. Fe is a component of hemoglobin, ensuring the transport and retention of oxygen in cells, and participates in the synthesis of hormones and neurotransmitters. Iron intake must be strictly controlled, as both deficiency and excess can lead to serious health problems. According to European legislation, there are no maximum levels of Fe in fish and fish products. However, the American Academy of Sciences stipulates that the total amount of Fe in canned fish must not exceed 30 mg·kg^{-1} (U.S. EPA, 2011).

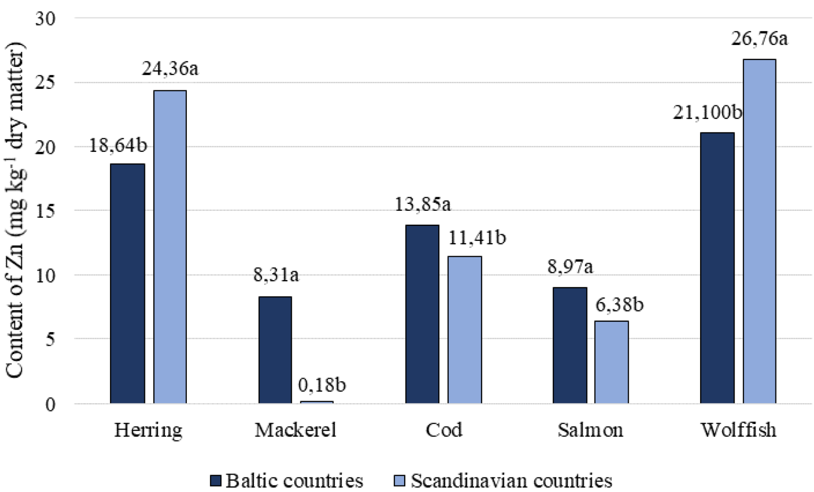

Figure 1. Average content Zn in the muscles of selected fish species from the Baltic Sea and Scandinavian regions

The iron (Fe) content in fish from the Baltic Sea countries ranges from 7.78 mg·kg^{-1} in the wolffish to 22.18 mg·kg^{-1} in mackerel. In the case of the fish originating from Scandinavian countries, the lowest iron concentration was recorded in salmon, amounting to 2.04 mg·kg^{-1} (Figure 2). Turkmen et al. (2009) and Tuzen (2009), reported iron concentrations of up to 45 mg·kg^{-1} in various fish species. From a nutritional point of view, fish are an exceptionally rich source of phosphorus, providing it in much greater quantities than land animal meat (Januszko and Kałuża, 2019). For this reason, they are a valuable part of a diet that supports the proper functioning of the body. Phosphorus (P) is an element that plays key roles in living organisms. It is an essential component of many biologically active compounds and is responsible for the storage and transfer of chemical energy in cells (Januszko and Kałuża, 2019). Phosphorus participates in numerous metabolic and physiological processes, occurs in nucleic acids, proteins, lipids and bone tissue, where it plays an important role in bone mineralization and maintaining their structural integrity (Macia, 2005). The highest significant concentration of phosphorus was recorded in the fish from the Baltic countries in wolffish 8633.67 mg·kg^{-1}, and in Scandinavian countries in cod 8737.34 mg·kg^{-1}. (Figure 3). Fish is a good source of potassium (K), containing more than meat (Januszko and Kałuża, 2019). Potassium plays a key role in regulating blood pressure, and an adequate supply of potassium is associated with a reduced risk of developing cardiovascular and kidney diseases. Potassium deficiency can lead to carbohydrate metabolism disorders (He and MacGregor, 2008**)**. The highest significant concentration of

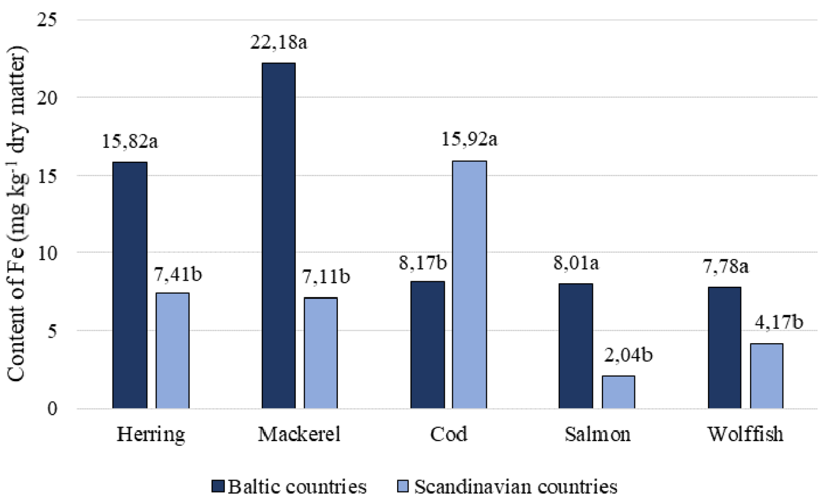

Figure 2. Average content Fe in the muscles of selected fish species from the Baltic Sea and Scandinavian regions

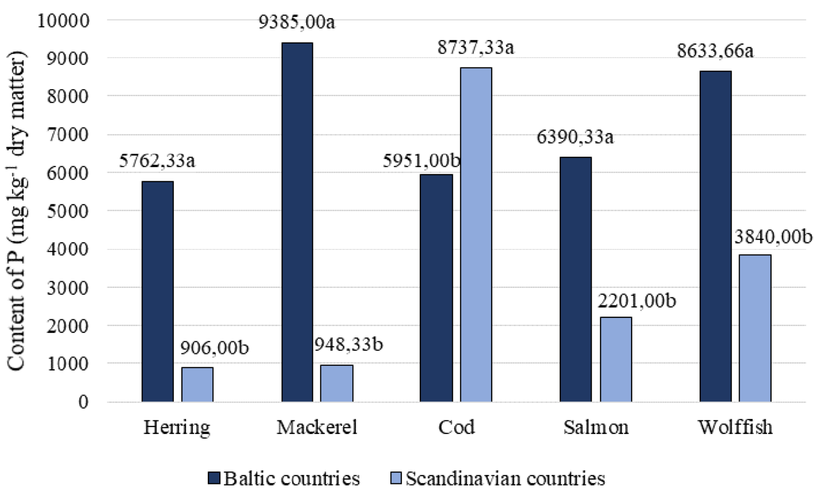

Figure 3. Average content P in the muscles of selected fish species from the Baltic Sea and Scandinavian regions

potassium (K) in the muscles of the tested fish was recorded in mackerel (6505.33 mg·kg⁻¹) and wolffish (6457.00 mg·kg⁻¹) from the Baltic countries, while cod (7590.66 mg·kg⁻¹) had the highest concentration among the Scandinavian countries (Figure 4). When analyzing the magnesium (Mg) macroelement, which is a valuable source in fish, it was found that its concentration in the tested samples ranged from 589.66 mg·kg⁻¹ in salmon to 1071.00 mg·kg⁻¹ in herring from the Baltic Sea area (Figure 5). The magnesium content in the fish from Scandinavian waters was lowest in herring (163.00 mg·kg⁻¹) and highest in cod (1117.66 mg·kg⁻¹) (Figure 5). Magnesium performs a number of important physiological functions in the human body. It has a beneficial effect on the cardiovascular system, lowers blood pressure and counteracts heart rhythm disorders (Woźniak et al., 2018). It also participates in the metabolic conversion of fats, proteins and carbohydrates, and regulates calcium and vitamin D levels. Magnesium also plays an important role in stabilizing DNA structure. Magnesium deficiency can lead to a number of clinical symptoms, such as chronic fatigue, excessive irritability, low mood and poor concentration (Kiczorowska et al., 2019). The analyzed fish showed varying amounts of Ca, ranging from 0.297 mg·kg⁻¹ in the salmon from Scandinavian waters to 481.3 mg·kg⁻¹ in the herring from the Baltic Sea (Figure 6). The observed differences in nutrient concentrations in the analyzed fish species result not only from species variability in the accumulation of minerals in tissues, but also from the availability of these nutrients in the

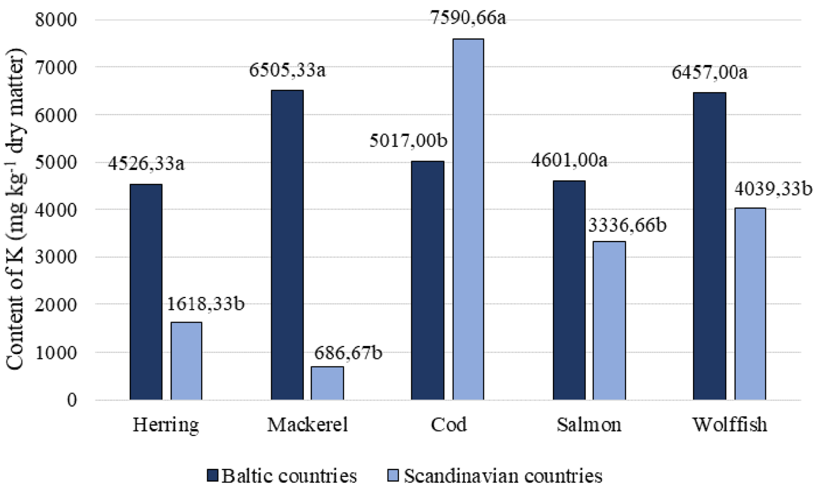

Figure 4. Average content K in the muscles of selected fish species from the Baltic Sea and Scandinavian regions

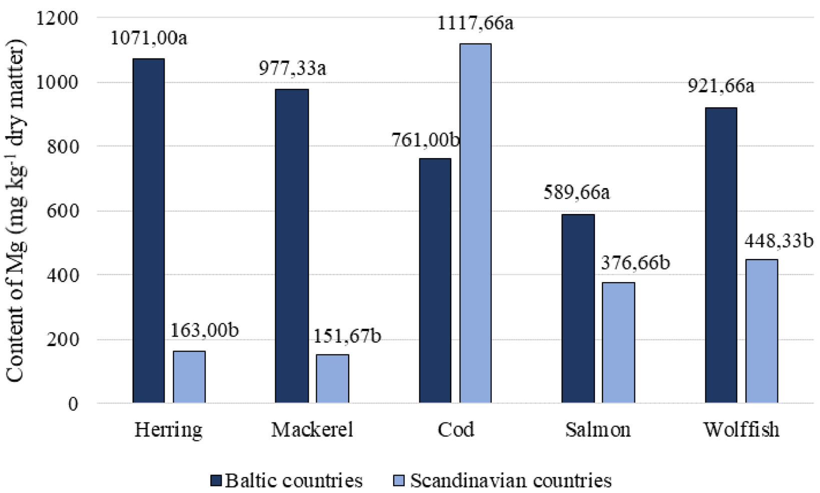

Figure 5. Average content Mg in the muscles of selected fish species from the Baltic Sea and Scandinavian regions

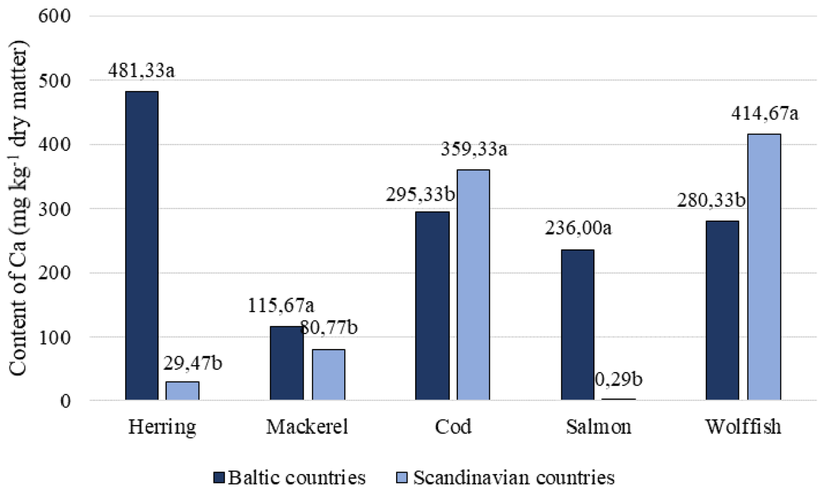

Figure 6. Average content Ca in the muscles of selected fish species from the Baltic Sea and Scandinavian regions

aquatic environment or feed, as well as from the ability of fish to absorb and convert them into essential nutrients (Fawole et al., 2007).

CONCLUSIONS

The fish from the Baltic Sea and Scandinavian regions are a valuable source of minerals essential for the proper functioning of the human body, with the content of individual elements varying depending on the region of catch and species. Higher concentrations of calcium, magnesium, phosphorus, potassium and iron have been found in the muscles of the fish from the Baltic Sea, which may reflect both the specific local environmental conditions and biological differences between fish populations. The increased zinc content in selected fish species from Scandinavian waters indicates diverse bioaccumulation processes, which may result from local geochemical or anthropogenic factors. The levels of toxic metals in all analyzed samples were below the permissible standards, which confirms the safety of fish consumption from the studied areas. The variation in mineral content in fish muscles can be used as an indicator of water environment quality, but for a more complete assessment of marine ecosystems, it is advisable to monitor the metal content in aquatic organisms.

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