review paper
Ratar. Povrt. 2025, 62(2): 54-68
doi: 10.5937/ratpov62-56696
Manuscript submitted: 11 February 2025
Manuscript accepted: 13 March 2025
Published online: 4 April 2025

Reviewing zinc in soils and wheat grain in Serbia - is there a risk of deficiency in human wheat-based diets?

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Summary: Zinc (Zn) soil deficiency negatively affects crop yields and the quality of staple food globally. Soil Zn availability is declining due to soil conditions and is further impacted by factors such as agricultural practices, especially the use of phosphorus fertilizers, which can reduce Zn uptake in wheat. As a result, wheat grain often contains low Zn levels, and its bioavailability is limited, contributing to insufficient Zn intake through wheat-based foods. This review focuses on plant-available Zn status in soils, Zn in wheat grains, and the human population in Serbia, emphasizing the connections between these issues. Data on soils with low available Zn, rather low Zn in wheat grain and general lack of results on Zn concentration in crop plant tissues and application of Zn fertilizers suggest that further research is needed to evaluate nutritional status of wheat plants for Zn. Existing data suggest that Zn deficiency in humans could be a concern in Serbia, especially with dietary shifts toward more plant-based diets. Given the high consumption of wheat in the country, biofortification presents a promising and solution to improve Zn levels in wheat grain in a sustainable way. Agronomic biofortification, through application of soil and foliar Zn fertilizers can enhance Zn concentration in wheat grain and improve human nutrition, thus reducing the risk of deficiency in the population.
Key words: wheat, soil, zinc, deficiency, nutrition, wheat grain, biofortification

Introduction

Zinc (Zn) is an essential micronutrient for plants, animals and humans, playing a crucial role in various physiological processes. It is the only metal present in enzymes across all six enzyme classes in biological systems (Sousa et al., 2009). In higher plants, Zn is required for the activation of numerous enzymes, carbohydrate metabolism, protein and indoleacetic acid synthesis, and for maintaining the integrity of biomembranes (Cakmak et al., 2022). Sensitivity to Zn deficiency varies among crops, with maize and rice being more sensitive than other cereals. Bread wheat is less tolerant to Zn deficiency than rye, barley, and triticale (Cakmak et al., 1997). Zn deficiency in soil and crops has been reported globally, affecting agricultural productivity in various regions.

Zn is a crucial micronutrient for human health, essential for a variety of biological functions, including immune function, DNA and protein synthesis, and cell division (Sharma et al., 2013; Singh & Prasad, 2023). It is crucial for maintaining the structural integrity of cellular membranes and for the proper functioning of over 300 enzymes involved in metabolism, digestion, and nerve function. Zn also contributes to growth and development, particularly during periods of rapid cell division such as pregnancy, infancy, and childhood (Prasad, 2014). A deficiency in Zn can lead to impaired immune responses, stunted growth, delayed wound healing, and increased susceptibility to infections, highlighting the importance of adequate Zn intake for overall health and well-being (King, 2011; Prasad, 2014).

Common wheat (*Triticum aestivum* L.) is one of the most widely grown crops globally. Wheat accounts for approximately 18% of the total daily caloric intake and 19% of global dietary protein consumption (FAO, 2022). In regions such as Central, Southern and Western Asia, as well as North Africa wheat contributes a significantly higher proportion to protein intake, with countries like Tunisia, Algeria and Iran reaching up to 45% (Table 1). In wheat grains, most of the Zn is bound to phytate (Cakmak & Kutman, 2018). This binding significantly lowers the bioavailability of Zn in wheat grains, making it less accessible for absorption and utilization, which can contribute to Zn deficiency, especially in populations with a predominantly cereal-based diet (Gibson et al., 2010).

Table 1. Share of total daily calorie and protein intake (%/capita/day) from wheat and wheat products in the regions and selected countries (FAO, 2022)

Regions/Countries	Calories (Kcal; %)	Protein (g; %)	Regions/Countries	Calories (Kcal; %)	Protein (g; %)
Southern America	13.6	14.1	Northern Africa	34.1	36.7
Australia	15.6	14.7	Tunisia	42.7	45.8
Northern America	15.8	15.2	Algeria	39.8	46.5
Europe	23.2	22.4	Egypt	34.0	36.3
Germany	15.2	15.8	Central Asia	32.1	30.7
Netherlands	15.4	14.3	Kyrgyzstan	29.8	26.5
Czechia	16.4	17.8	Uzbekistan	34.3	33.5
Denmark	17.2	15.8	Tajikistan	42.3	41.9
Portugal	19.0	16.1	Turkmenistan	46.2	41.3
France	20.4	19.3	Southern Asia	33.7	31.9
Sweden	21.5	19.3	India	21.9	24.7
North Macedonia	22.4	23.2	Pakistan	36.8	41.8
Bulgaria	25.5	26.6	Iran	42.9	46.9
Romania	25.6	26.0	Western Asia	31.9	33.7
Bosnia and Herzegovina	30.3	29.9	Eastern Asia	23.6	26.7

In addition to providing dietary energy and protein, wheat is an important source of micronutrients, especially for populations with limited dietary diversity. As a staple crop in many parts of the world, including Serbia, wheat provides essential vitamins and minerals such as iron, Zn, folate, and magnesium, all crucial for maintaining health and preventing nutrient deficiencies. Poole et al. (2021) recently emphasized the need for research that considers the full nutritional contribution of cereals in addressing the "triple burden" of undernutrition, micronutrient deficiencies and overnutrition (including overweight and obesity). This research is particularly important in regions where cereals like wheat form the backbone of the diet but may not provide the full spectrum of nutrients needed for optimal health.

For instance, while wheat is a significant source of calories and protein, its micronutrient content often falls short of meeting the daily nutritional requirements. Zn concentration in wheat grains in wheat-growing regions ranges from 20 mg kg^{-1} to 35 mg kg^{-1} (reviewed by Cakmak & Kutman 2018). Additionally, modern agricultural practices focused on maximizing yield have unintentionally led to the dilution of essential nutrients like Zn in wheat grains. This phenomenon, known as the 'yield dilution effect', means that while wheat yields have increased substantially over the past decades, the concentrations of important micronutrients, including Zn, have decreased, making wheat a less reliable source of key nutrients for various populations (Shewry et al., 2016).

The aim of this study is to evaluate the available data on the status of plant-available Zn in agricultural soils, as well as Zn status in wheat grain and human population in Serbia, while exploring the interconnections among these factors. The study seeks to identify potential factors affecting Zn status in wheat grain, highlight gaps in existing knowledge, and provide recommendations for future research. Additionally, it explores the potential for biofortification of wheat as a sustainable strategy to address possible prevalence of Zn deficiency in the country.

Wheat production and consumption in Serbia

In Serbia, common wheat is cultivated on approximately 631 thousand ha, with the national average grain yield of around 5 t ha^{-1} (FAO, 2022). Wheat yields in the Vojvodina Province are 10% higher than the national average, contributing 60% to the country's total wheat production (Republic of Serbia, 2023). In this region, wheat high input production systems on large-scale farms often results in significantly higher yields compared to the national average. According to the latest Household Budget Survey, bread and pastry consumption has notably declined over the past decade, currently averaging 62.5 kg/capita/year, with regional variations (Republic of Serbia, 2024). This decline can be attributed to dietary shifts, including a growing preference for diverse and less processed wheat-dependent diets, as well as an increasing trend toward healthier eating patterns that favor less refined wheat products and whole grains over traditional white bread and pastries (Siddiqui et al., 2022; Grafenauer & Curtain, 2020; Hughes & Grafenauer, 2023). However, still in regions such as Šumadija and Western Serbia, Southern and Eastern Serbia consumption remains high, reaching around 75 kg/capita/year, compared to 50 kg/capita/year in the City of Belgrade and the Vojvodina Province. Furthermore, flour consumption, predominantly wheat flour, in households is 19.8 kg/capita/year, following a regional pattern similar to that of bread consumption. Nevertheless, the country's high annual per capita wheat consumption of 200 kg contributes approximately 40% and 35% of daily calorie and protein intake, respectively (Table 2).

Table 2. Share of total daily calorie and protein intake (% per capita per day) from wheat and wheat products in Serbia from 2018 to 2022 (FAO, 2022)

Year	Calories (%)	Protein (%)
2018	38.9	34.9
2019	40.0	35.8
2020	40.4	35.9
2021	40.9	36.3
2022	40.1	35.4

Current status of plant-available Zn in soils across Serbia

The global average concentration of total Zn in non-contaminated soils is around 64 mg kg^{-1} (Kabata-Pendias, 2001). However, the solubility of Zn in soil is very low. The availability of Zn to plants in soil is affected by various soil conditions and biological factors in the rhizosphere. Zn deficiency in agricultural soils and crops is commonly linked to low total Zn concentration, high pH, relatively high organic matter content, the presence of bicarbonates, and low water content (Alloway, 2008). Critical soil Zn deficiency concentrations are usually highly specific to certain soil types and crop species. A widely accepted critical deficiency limit for plant-available (diethylene-triaminepentaacetic acid, DTPA-extractable) Zn in agricultural soils is set at 0.5 mg kg^{-1} (Cakmak et al., 1999), while Srivastava and Gupta (1996) consider 0.65 mg kg^{-1} as the critical lower concentration for wheat. According to Singh et al. (2005), low Zn availability in calcareous soils is one of the most common abiotic stresses in global agriculture, particularly in cereals.

The total Zn concentration in most agricultural soils of Central Serbia typically ranges up to 100 mg kg^{-1}, although in some instances it can exceed 300 mg kg^{-1} (Mrvić et al., 2009). The average concentration in Braničevo District is reported to be 42.8 mg kg^{-1} (Mrvić et al, 2011). In Vojvodina, soil Zn concentrations range from 10.7 mg kg^{-1} to 203 mg kg^{-1} (Ubavić et al., 1993). Additionally, Nešić et al. (2008) reported a mean total soil Zn concentration of 64.4 mg kg^{-1} in the Srem District.

Table 3. Concentration of DTPA-extractable Zn in agricultural soils in Serbia

Locations	Number of samples	Zn concentration (mg kg^{-1})	Reference
Vojvodina and Western Serbia	15	0.02-4.43	Marijanušić et al. (2014)
Mladenovac	5	0.79-0.98	Koković et al. (2022)
Pančevo	2	0.53 and 0.57	Tamindžić et al. (2021)
Veliko Gradište, Mačva and Toplica districts, a section of the E75 highway through Serbia from Belgrade to Preševo, Radočelo mountain	204	0.24-10.60 Mean = 1.10 Median = 0.80	Dinić et al. (2019)
Locations across Serbia	93	Mean = 1.3 Median = 0.89	Nikolić et al. (2016)
Vojvodina Province (District of Banat and Srem)	56	0.4-20.9	Čuvardić et al. (1993)
Velika Morava River valley	27	0.5-13.2	Antić et al. (2006)
Zemun Polje Padinska Skela	1 1	0.88 1.28	Ivanović et al. (2021)

The status of plant-available Zn in Serbian soils has not been systematically evaluated. Additionally, there has been limited attention given to the critical deficiency concentrations of Zn, which are essential for maintaining optimal crop yield and quality. Earlier studies on the plant-available fraction of Zn in soils were predominantly focused on the Vojvodina Province (Table 3). For instance, DTPA extracted Zn in soil samples taken from 56 vegetable production sites ranged from 0.4 mg kg^{-1} to 20.9 mg kg^{-1}, with 37% of the samples showing concentrations below 1 mg kg^{-1} (Čuvardić et al., 1993). Recent large-scale surveys have provided more comprehensive insights into the plant-available Zn status in Serbian soils, using widely accepted critical deficiency concentrations of DTPA-extractable Zn of 0.5 mg kg^{-1}. Nikolic et al. (2016) assessed plant-available Zn levels in major wheat-producing areas across the country, reporting a median value of 0.88 mg kg^{-1}. They also found that

13% of the analyzed samples exhibited low levels of plant-available Zn. Furthermore, incidence of soil Zn deficiency in the region of Vojvodina was 22%, what coincided with the highest soil pH values and concentrations of total $CaCO_3$ and available P. Furthermore, soils with Zn concentrations below this critical limit for plant growth have been recorded in surveys covering the Municipality of Veliko Gradište, the Mačva and Toplica Districts, and the Radočelo mountain area, with median value of 0.80 mg kg^{-1} (Dinić et al, 2019). Two-thirds of the agricultural soil in Serbia is moderately acidic, mainly located in Central Serbia, while calcareous soils are more prevalent in the Vojvodina Province (Manojlovic & Singh, 2012), located in the northern part of the country within the Pannonian Plain. In this region, approximately 55% of agricultural soils have concentrations of $CaCO_3$ higher than 5%. Therefore, based on critical Zn availability standards for calcareous soils (0.5 mg kg^{-1} - 1.0 mg kg^{-1}) (Liu et al., 1982), a significant proportion of soils in Serbia may be considered as potentially deficient in plant-available Zn. Deficient Zn levels in soil may restrict both crop yield and nutritional quality, making it imperative to address this issue to safeguard food security and enhance agricultural sustainability in the region.

Status of Zn in wheat grain and flour in Serbia

Despite the relatively high consumption of bread in Serbia, wheat grain is often overlooked as an important source of essential micronutrients in the human diet. Moreover, studies investigating the relationship between micronutrients in soil and in wheat grain has been scarce until recently, hindering a comprehensive understanding of how soil conditions affect the nutritional content of wheat. Based on the studies presented in Table 4, wheat grain Zn concentrations appear to be lower in Vojvodina Province compared to Central Serbia. For instance, a comprehensive study conducted across multiple sites revealed that the average Zn concentrations in grain from two local bread wheat cultivars in Vojvodina (median value of 20 mg kg^{-1}) was about 26% lower than in other parts of the country (Nikolic et al., 2016). A similar difference between the two regions was recorded by Škrbić and Čupić (2005), who observed Zn concentrations ranging from 20.2 mg kg^{-1} to 24.2 mg kg^{-1} in Vojvodina, and from 24.0 mg kg^{-1} to 29.3 mg kg^{-1} in Central Serbia.

Additionally, Zn concentrations in wheat grain below 20 mg kg^{-1}, including minimum values between 10 and 15 mg kg^{-1} in Vojvodina, have been reported by Nikolic et al. (2016), Ludajić et al. (2016), Vidovic et al. (2005) and Ivanović et al. (2021). In the study by Nikolic et al. (2016), 60% of the tested grain samples collected across Serbia had Zn concentration below 24 mg kg^{-1}, and 42% below 20 mg kg^{-1}, while in Vojvodina 70% and 53% of grain samples had Zn concentrations below 24 mg kg^{-1} and 20 mg kg^{-1}, respectively. These rather low levels of grain Zn are below than the average grain Zn concentration of 26.3 mg kg^{-1} reported in a summary of numerous studies which included 2,346 bread wheat cultivars (Velu et al., 2014), and much lower than the average Zn concentrations found in wheat-growing regions worldwide, which generally range from 28 mg kg^{-1} to 30 mg kg^{-1} (Graham et al., 2007; Cakmak and Kutman, 2018). Under varying soil, weather, climate and management conditions, in different wheat cultivars grown in Vojvodina, grain Zn concentrations may be as low as those reported in Zn-deficient soils in Turkey, with levels 10 mg kg^{-1} to 15 mg kg^{-1} (Kalayci et al., 1999; Yilmaz et al., 1997; Zou et al., 2012).

Based on the limited studies conducted in neighboring countries, similar Zn concentrations in wheat grain have been reported to those observed in Serbia. For example, in North Macedonia, Zn concentrations in grain of two wheat cultivars were 19 mg kg^{-1} and 29 mg kg^{-1} (Menkinoska et al., 2014). In Eastern Croatia, the mean grain Zn concentration for two cultivars at two sites was 21.6 mg kg^{-1} (Lončarić et al., 2021).

Grain Zn concentrations are further reduced during the milling process due to the removal of the bran and embryo, parts of the grain that are highly rich in Zn, while the starchy endosperm contains much lower levels of the nutrient (Ozturk et al., 2006; see review by Balk et al., 2018).

Table 4. Concentration of Zn in whole grain of common winter wheat grown in Serbia

Trial sites	Number of samples	Cultivars	Zn concentration (mg kg^{-1} DW)	Reference
Rimski Šančevi, Novi Sad	3	Zvezdana NS Todorka NS Moma	29.7 32.1 25.7	Živančev et al. (2021)
Kikinda	108	NA	6.48-34.0 Mean = 15.4	Vidovic et al. (2005)
District of Banat	10	NA	12.1-48.5 Mean = 21.2	Ludajić et al. (2016)
Kragujevac	5 5 5 5 5 5	Takovčanka Studenica KG-56 Lazarica KG100 Toplica	Mean = 25.42 Mean = 28.56 Mean = 32.88 Mean = 26.94 Mean = 30.34 Mean = 29.20	Milivojević et al. (2018)
Rimski Šančevi, Novi Sad	16	Pesma	16.8-30.6 Mean = 21.80	Kastori et al. (2002)
Belgrade	2 2	Ilina Zvezdana	24.3 and 26.5 23.0 and 27.3	Dolijanović et al. (2022)
Locations across Serbia	157	Simonida NS 40S	11.3-42.8 10.2-42.8 Median = 21.0	Nikolić et al. (2016)
Vojvodina Central Serbia	35 15	NA NA	20.2-24.2 24.0-29.3	Škrbić & Čupić (2005)
Rimski Šančevi, Novi Sad	1 1 1	Crnozrna Rumska Crvenka Stara Banatka	19.3 34.4 13.8	Živančev et al. (2023)
Belgrade	9	Azra	22.2-34.2 Mean = 27.9	Dolijanović et al. (2019)
Zemun Polje	2 2 2 2 2	Talas Ratarica NS 40S Dika Simonida	14.7 and 18.6 15.5 and 18.2 14.0 and 15.0 16.5 and 17.9 13.1 and 15.1	Ivanović et al. (2021)
Padinska Skela	2 2 2 2 2	Talas Ratarica NS 40S Dika Simonida	25.0 and 28.9 31.2 and 31.6 20.6 and 27.3 21.1 and 26.9 21.0 and 27.8	Ivanović et al. (2021)

A low concentration of Zn in the commercially available white flour from mills throughout the Vojvodina Province, with a median value of 8.0 mg kg^{-1}, were reported by Nikolic et al. (2016). Ludajić et al. (2016) found that flour retained only 30% of the Zn present in the analyzed wheat grains from the same region. Furthermore, Živančev et al. (2021) examined the distribution of micronutrients including Zn in milling streams for three common wheat cultivars, finding that in most cases micronutrients intake can be improved by consumption of whole wheat bread or brown instead of white bread. These findings are important because the distribution of Zn within different grain fractions affects its bioavailability in wheat-based foods, influencing the overall nutritional value. Understanding this distribution can help improve processing strategies for enhancing Zn content in wheat and its processed products, benefiting human health.

Factors potentially affecting Zn concentrations in wheat grain

The relatively low Zn levels in wheat, a staple food in Serbia, can be attributed to soil properties, such as low available Zn and high phosphorus (P) availability, also to yield dilution effect. It is well documented that while the application of P fertilizers does not alter the speciation of Zn in soil or its translocation within the plant, it significantly suppresses Zn uptake efficiency by roots and lowers root Zn concentration (see meta-analyses by Zhang et al., 2021). High P levels can reduce Zn uptake by decreasing root growth and limiting root colonization by arbuscular mycorrhizae. For instance, in wheat, P fertilization significantly reduced Zn concentrations in wheat grain and wheat root colonization (Ryan et al., 2008).

In Serbia, mineral fertilizers are applied at 67% of the total agricultural soils (Census of Agriculture, 2013), with annual consumption of P and potassium (K) mineral fertilizers around 73,000 and 28,000 tons, respectively (FAO, 2022). Nikolić et al. (2016) found higher available P levels in soils in Vojvodina compared to soils in other regions of the country. Maize and wheat, the two major crops, are grown on approximately 45% of the total arable land, indicating that significant amounts of P fertilizers are applied to wheat-growing soils. The application of P fertilizers, which is widespread in Serbia, may significantly reduce Zn availability in rhizosphere and concentrations in wheat grains.

It has been previously noted that the historical increase of wheat yields has been associated with a decline in nutrient concentrations in the grain. Indeed, data spanning nine decades show a gradual increase in the average wheat yield at the national level in Serbia, from 1.39 t ha^{-1} to 5-6 t ha^{-1} today (all data available at https://www.stat.gov.rs/). However, historical data on Zn concentrations in wheat grains are lacking, which limits our understanding of trends over time and the potential long-term effects of agricultural practices and soil management on Zn availability in wheat. Nevertheless, a study by Ungai et al. (2022) showed no significant decrease in mineral density in wheat grain in the timeline from 1974 to 2004 in Hungary. In a recent study, Živančev et al. (2023) tested three local cultivars released in Serbia in the 1950s and 1960s. Interestingly, cultivars Crnozrna and Stara Banatka had significantly lower concentrations of Zn in grain (19.3 mg kg^{-1} and 13.8 mg kg^{-1}, respectively) compared to cv. Rumska Crvenka (34.4 mg kg^{-1}). These results indicate to possible differences between the cultivars in their ability to accumulate Zn in grains. Data from available studies that measured grain Zn concentrations in Serbian wheat cultivars are presented in Table 4.

Strategies to increase Zn in wheat grain

Addressing the observations of Zn deficiency in soils and rather low Zn in wheat grains in Serbia requires a shift in research and agricultural practices, with an emphasis on obtaining not only high grain yields but also rich in essential micronutrients. Biofortification, or the process of increasing the nutrient content of crops through selective breeding or genetic modification, and agronomic biofortification, which is based on optimized fertilizer applications has emerged as a promising strategy to improve the nutritional quality of wheat (Gupta et al., 2021). Biofortification, both genetic and agronomic, offers a promising and sustainable solution for increasing Zn concentrations in wheat grains. Genetic biofortification involves breeding wheat varieties with enhanced Zn uptake, translocation, and grain deposition, leveraging both conventional breeding and advanced biotechnological tools such as marker-assisted selection (Bouis et al., 2010). Programs like CIMMYT and HarvestPlus have successfully developed high-Zn wheat cultivars, demonstrating the feasibility of this approach (Bouis et al. 2010; Gulyas et al., 2024). Complementing genetic strategies, agronomic biofortification through Zn fertilizer application, particularly foliar Zn sprays during grain filling, has proven to be an efficient way to boost Zn concentrations in wheat grains (Sánchez-Palacios et al., 2023).

Such efforts could play a pivotal role in alleviating the micronutrient malnutrition that affects billions of people worldwide, particularly in regions that rely heavily on wheat as a primary food source (Bouis et al., 2020; Bhatt et al., 2020). Biofortification of wheat with Zn offers a promising, sustainable solution to enhance Zn intake in populations that rely heavily on wheat as a primary dietary staple. By breeding wheat varieties with higher Zn content, it is possible to enhance the dietary Zn intake without requiring significant changes to agricultural practices or dietary habits. Such efforts in Serbia, where wheat is integral to the diet, could help address the potential health challenge of Zn deficiency, thereby improving overall health outcomes and reducing the burden of related diseases.

Zn deficiency in humans in Serbia, currently available data

Zn deficiency is estimated to affect around 17% - 20% of the global population (Wessells & Brown, 2012). While populations in regions such as South and Southeast Asia, Sub-Saharan Africa, Central America, and the Andean region of South America are most significantly affected, in recent years, Zn deficiency has also become more evident in developed nations, highlighting the global scope of this issue (Knez et al., 2017; Willoughby & Bowen, 2014; Hess et al., 2023). This situation is particularly concerning given the vital role of Zn in numerous physiological functions, including immune function, growth, and development (Gibson et al., 2008; Prasad, 2012). The International Zinc Nutrition Consultative Group (IZiNCG) suggests 12 mg/day for men and 10 mg/day for women, particularly in regions with high phytate intake (Gibson et al., 2016). In Serbia, Zn deficiency is becoming an increasing concern, influenced by factors such as the rising popularity of plant-based diets, reduced meat consumption, and the lower bioavailability of Zn in plant-based foods (Gupta et al., 2020). Additionally, the decline in Zn levels in food sources due to modern agricultural practices further exacerbates the risk of deficiency. This issue is reflected in reported cases of Zn deficiency within the Serbian population, where serum and whole blood Zn levels are approximately half of those found in other global populations (Jagodić et al., 2021). Zn levels in thyroid and brain tissues were found to be 10 and 20 times lower, respectively, than those reported in existing literature. Authors suggested implementing Zn supplementation or food fortification to address the potential health risks associated with Zn deficiency. Another study revealed that 15% - 25% of seemingly healthy Serbian adults aged 25-65 had inadequate dietary Zn intake. Specifically, over 20% of the 754 participants showed insufficient Zn intake, highlighting concerns about the potential health risks associated with prolonged Zn deficiency (Knez et al., 2017). In Serbia, another challenge is the absence of regular monitoring of Zn intake, which impedes the ability to evaluate its adequacy on a national level. This lack of data makes it difficult to identify at-risk populations and design effective public health interventions to address early-stage Zn deficiency.

Human Zn deficiency, already a significant issue in many parts of the world, has become increasingly evident in developed countries as well (Gibson, 2006; Knez et al., 2023). Inadequate Zn intake is increasingly being documented in resource-rich regions, where overconsumption of food has emerged as a significant public health concern (Mensink et al., 2013). In Serbia, an additional issue is the current trend towards plant-based diets, reduced meat consumption, and the declining Zn content in crops due to modern agricultural practices.

Future research in Serbia

On marginally Zn-deficient soils, a 'hidden' or 'latent' deficiency can reduce crop yields and affect quality without obvious symptoms (Alloway, 2009). Under such conditions, Zn concentrations in cereal grains may remain relatively low (< 20 mg kg^{-1}) without directly impacting yields. Nutrient status in plants can be determined with certainty by measurement of their concentration in plant tissues, commonly in leaves. Yet, grain analyses can indicate Zn status in plants and potential deficiency in crops. For instance, Rafique et al. (2006) proposed a critical grain concentration of 20 mg kg^{-1} - 24 mg kg^{-1} to establish Zn deficiency, whilst Brennan et al. (1993) and Alloway et al. (2008) have set it at 10 mg kg^{-1} and 15 mg kg^{-1}, respectively. Based on studies examining Zn availability in soils and in wheat grain in Serbia (Tables 3 and 4), it appears that limited plant available Zn in the soil may be an overlooked limiting factor for both wheat yields and grain Zn levels. Zn concentrations below critical deficiency thresholds of 15 mg kg^{-1} - 20 mg kg^{-1} in leaf dry weight have been recorded in Serbia in alfalfa, and plants collected from pastures (Marijanušić et al., 2014). However, research on the potential impact of Zn deficiency in crops and the application of Zn-based fertilizers in wheat grown in Serbia remain scarce, which requires further research.

Therefore, additional research is necessary to assess Zn status in plant tissues of key crops and to determine possible impact of soil Zn deficiency on wheat and other crop yields across the country. Investigating the effects of both soil and foliar Zn fertilization on nutritional status of wheat for Zn, grain yields and Zn concentration would enhance understanding of Zn dynamics within the soil-wheat system, particularly regarding wheat's role in Zn dietary intake. In wheat production, the costs of Zn foliar application could be minimized by combining it with the application of pesticides commonly used in wheat production (Ram et al., 2016), while soil Zn application in Zn deficient areas could provide long term benefits by improving both wheat yield and grain Zn concentrations. Therefore, the biofortification of wheat with Zn, through breeding or agronomic practices, represents a promising strategy to increase Zn concentrations in grain, improving its nutritional value.

Enhancing Zn concentration in wheat-based products, such as flour and bread, requires a multi-faceted approach that integrates biofortification, milling modifications, and appropriate processing techniques. The use of biofortified wheat varieties with naturally higher Zn concentrations is a fundamental strategy, ensuring that grains contain elevated Zn levels before processing. Milling techniques that retain more of the nutrient-rich outer layers of the grain, such as stone milling or high-extraction roller milling, can help preserve Zn in flour (Huey et al., 2023). Additionally, processing methods like sourdough fermentation can enhance Zn bioavailability by reducing phytic acid, a major inhibitor of Zn absorption (Gibson et al., 2006; Samtiya et al., 2021). In parallel, agronomic biofortification through Zn fertilizer application, particularly foliar sprays during critical growth stages, can increase grain Zn content and contribute to higher Zn levels in final products. By combining these strategies, it is possible to improve the nutritional quality of wheat-based foods, ultimately supporting efforts to minimize the risk of Zn deficiency in the population.

One additional strategy is to encourage the consumption of whole wheat bread instead of white bread, as whole grains retain more of their micronutrient content, including Zn (Brouns, 2021). Additionally, optimizing flour milling and processing methods, such as retaining the bran and germ, can help preserve the Zn content, making wheat-based products more nutritious (Živančev et al., 2021). Further research and implementation of these processing techniques, combined with increased awareness about the benefits of whole grains, can contribute to better dietary Zn intake. However, it is important to exercise caution by carefully considering the antinutrient content that may be present in whole grains, as these compounds can interfere with Zn absorption. Nonetheless, these challenges can be mitigated through the use of appropriate processing methods that reduce antinutrient levels and enhance Zn bioavailability (reviewed by Samtiya et al., 2021). Finally, it is essential to implement rigorous methods to accurately evaluate the impact of these interventions, ensuring that any potential improvements in Zn bioavailability and overall nutritional intake are thoroughly measured, validated, and understood.

Appropriate processing methods, along with education on the potential benefits of consuming whole grain-based products processed in specific ways, could enhance Zn bioavailability and bioaccessibility. Additionally, regular monitoring of dietary Zn intake is crucial to ensure deficiencies are identified and addressed in a timely manner. Early detection of Zn deficiency in its initial stages would allow for timely interventions, preventing the progression to more severe health consequences. Ultimately, addressing Zn deficiency in both soils, wheat grains, and diets is essential for improving public health, agricultural sustainability, and food security, particularly in regions like Serbia, where wheat is a key staple in the diet.

Conclusions

In agricultural soils in Serbia available Zn concentrations are often suboptimal, with low bioavailability exacerbated by factors such as high phosphorus levels, which reduce Zn uptake by plants. As a result, wheat grains, a staple food in Serbia, often contain Zn levels below the global average, impacting the nutritional quality of wheat-based products and increasing the risk of Zn deficiency among the population.

Although comprehensive and up-to-date data on the Zn concentrations in human populations remains limited, available findings suggest that the potential for Zn deficiency exists, particularly considering factors such as wheat processing practices and dietary patterns. In light of this, there is a need for continuous monitoring of available Zn levels in soils, nutritional status of wheat plants for Zn, and wheat grain to better understand their relationship and to ensure that any deficiencies in agricultural production are detected and managed effectively. Finally, regular follow-ups are essential to monitor Zn intake and status, ensuring that potential deficiencies are identified and addressed promptly to prevent adverse health outcomes. Addressing these gaps through continued investigation, alongside the application of known strategies such as biofortification and improved agricultural practices, could play a crucial role in alleviating Zn deficiency and improving overall health outcomes for the population.

Author contributions: conceptualization JS and MK; visualization JM and MR; writing – original draft JS, MK and JM; writing – review and editing JS and MK.

Competing interests' statement: No competing interests were disclosed.

Funding statement: This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Grant No: 451-03-137/2025-03/200116; 451-03-136/2025-03/200015; 451-03-136/2025-03/200011.

References

Alloway, B.J. (2008). *Zinc in Soils and Crop Nutrition*. International Zinc Association and Brussels. International Fertilizer Industry Association.

Alloway, B.J. (2009). Soil factors associated with zinc deficiency in crops and humans. *Environmental Geochemistry and Health, 1*, 537–548. https://doi.org/10.1007/s10653-009-9255-4

Antić, A., Cvetković, O., Jovančićevic, B., Blagojević, S., & Nikolić-Mandić, S. (2006). Eco-chemical characterization of fluvisol of Velika Morava river valley (Serbia) based on the physico-chemical parameters and distribution of heavy metals. *Fresenius Environmental Bulletin*, *15* (11), 1439-1441.

Balk, J., Connorton, J.M., Wan, Y., Lovegrove, A., Moore, K.L., Uauy, C., Sharp, P.A., & Shewry P.R. (2019). Improving wheat as a source of iron and zinc for global nutrition. *Nutrion Bulletin*, *44* (1), 53-59. https://doi.org/10.1111/nbu.12361

Bhatt, R., Hossain, A., & Sharma, P. (2020). Zinc biofortification as an innovative technology to alleviate the zinc deficiency in human health. a review. *Open Agriculture, 5,* 176–187. https://doi.org/10.1515/opag-2020-0018

Bouis, H., Birol, E., Boy, E., Gannon, B.M., Haas, J.D., Low, J., ... & Welch, R.M. (2020). *Food biofortification. Reaping the benefits of science to overcome hidden hunger*. In October webinar on The Need for Agricultural Innovation to Sustainably Feed the World by 2050 (69). Council for Agricultural Science and Technology (CAST).

Bouis, H. E., & Welch, R. M. (2010). Biofortification — a sustainable agricultural strategy for reducing micronutrient malnutrition in the global south. *Crop Science*, *50*, S-20. https://doi.org/10.2135/cropsci2009.09.0531

Brennan, R.F., Armour, J.D., Reuter, D.J. (1993). Diagnosis of zinc deficiency. In Robson, A.D. (ed) *Zinc in Soils and Plants*, Kluwer Academic Publishers, Dordrecht, p. 206.

Brouns, F. (2021). Phytic acid and whole grains for health controversy. *Nutrients, 14* (1), 25. https://doi.org/10.3390/nu14010025

Cakmak, I., & Kutman, U.B. (2018). Agronomic biofortification of cereals with zinc. A review. *European Journal of Soil Science*, *69* (1), 172–180. https://doi.org/10.1111/ejss.12437

Cakmak, I., Brown, P., Colmenero-Flores, H.M., Husted, S., Kutman, B.Y., Nikolic, M., Zed Rengel, Z., Schmidt, S.B. & Zhao, F.J. (2022). Micronutrients. In. *Marschner's Mineral Nutrition of Plants*, Fourth Edition, Z. Rengel, I. Cakmak, P. White Eds, Academic Press, Elsevier, London, UK, pp. 283-385.

Cakmak, I., Ekiz, H., Yilmaz, A., Torun, B., Köleli, N., Gültekin, I., Alkan, A., & Eker, S. (1997). Differential response of rye, triticale, bread and durum wheats to zinc deficiency in calcareous soils. *Plant and Soil, 188*, 1-10. https://doi.org/10.1023/A.1004247911381

Cakmak, I., Kalayci, M., Ekizc, H., Braund, H.J., Kilince, Y., & Yilmaz, A. (1999). Zinc deficiency as a practical problem in plant and human nutrition in Turkey. a NATO-science for stability project. *Field Crops Research. 60* (1-2), 175–188. https://doi.org/10.1016/S0378-4290(98)00139-7

Čuvardić, M., Ubavić, M., & Bogdanović, D. (1993). Content of macro and microelements in vegetable plots. *Zemljište i biljka*, *42*, 93-103.

Dinić, Z., Maksimović, J., Stanojković-Sebić, A., & Pivić, R. (2019). Prediction Models for Bioavailability of Mn, Cu, Zn, Ni and Pb in Soils of Republic of Serbia. *Agronomy, 9* (12), 856. https://doi.org/10.3390/agronomy9120856

Dolijanović, Ž., Roljević Nikolić, S, Kovačević, D., Djurdjić, S., Miodragović, R., Jovanović Todorović, M., & Popović Djordjević, J. (2019). Mineral profile of the winter wheat grain. effects of soil tillage systems and nitrogen fertilization. *Applied Ecology and Environmental Research, 17* (5), 11757-11771. http://dx.doi.org/10.15666/aeer/1705_1175711771

Dolijanović, Ž., Nikolić, S. R., Dragičević, V., Mutić, J., Šeremešić, S., Jovović, Z., & Popović Djordjević, J. (2022). Mineral composition of soil and the wheat grain in intensive and conservation cropping systems. *Agronomy*, *12* (6), 1321. https://doi.org/10.3390/agronomy12061321

FAO (2022). FAOSTAT. Rome: FAO. https://www.fao.org/faostat

Gibson, R.S., Hess, S.Y., Hotz, C., & Brown, K.H. (2008). Indicators of zinc status at the population level. a review of the evidence. *British Journal of Nutrition, 99* (S3), S14–S23. https://doi.org/10.1017/s0007114508006818

Gibson, R.S. (2006). Zinc: the missing link in combating micronutrient malnutrition in developing countries. *Proceedings of the Nutrition Society, 65* (1), 51-60. https://doi.org/10.1079/PNS2005474

Gibson, R.S., King, J.C., & Lowe, N.M. (2016). A review of dietary zinc recommendations. *Food and Nutrition Bulletin*, *37*(4), 443–460. https://doi.org/10.1177/0379572116652252

Gibson, R.S., Bailey, K.B., Gibbs, M., & Ferguson, E.L. (2010). A review of phytate, iron, zinc, and calcium concentrations in plant-based complementary foods used in low-income countries and implications for bioavailability. *Food and Nutrition Bulletin, 31*, (2_suppl2). S134–S146. https://doi.org/10.1177/15648265100312s206

Grafenauer, S., & Curtain, F. (2020). Historical and Global Perspectives on Grains and Whole Grains within Dietary Guidelines. *Cereal Foods World*, *65* (3). https://doi.org/10.1094/CFW-65-3-0029

Graham, R.D., Welch, R.M., Saunders, D.A., Ortiz-Monasterio, I., Bouis, H.E., Bonierbale, M., de Haan, S., Burgos, G., Thiele, G., Liria, R., et al. (2007). Nutritious subsistence food systems. *Advances in Agronomy, 92,* 1–74. https://doi.org/10.1016/S0065-2113(04)92001-9

Gulyas, B.Z., Mogeni, B., Jackson, P., Walton, J., & Caton, S.J. (2024). Biofortification as a food-based strategy to improve nutrition in high-income countries. a scoping review. *Critical Reviews in Food Science and Nutrition*, 1-22. https://doi.org/10.1080/10408398.2024.2402998

Gupta, S., Brazier, A. K. M., & Lowe, N.M. (2020). Zinc deficiency in low-and middle-income countries. prevalence and approaches for mitigation. *Journal of Human Nutrition and Dietetics, 33* (5), 624-643. https://doi.org/10.1111/jhn.12791

Gupta, P.K., Balyan, H.S., Sharma, S., & Kumar, R. (2021). Biofortification and bioavailability of Zn, Fe and Se in wheat: present status and future prospects. *Theoretical and Applied Genetics, 134,* 1-35. https://doi.org/10.1007/s00122-020-03709-7

Hess, S.Y., Wessells, K.R., Haile, D., Rogers, L.M., Tan, X., Barros, J.G., Bourassa, M.W., Gorstein, J., Brown, K.H. (2023). Comparison of published estimates of the national prevalence of iron, vitamin a, and zinc deficiency and sources of inconsistencies. *Advances in Nutrition, 14* (6), 1466-1478. https://doi.org/10.1016/j.advnut.2023.08.011

Huey, S.L., Konieczynski, E.M., Mehta, N.H., Krisher, J.T., Bhargava, A., Friesen, V.M., & Mehta, S. (2023). A systematic review of the impacts of post-harvest handling on provitamin A, iron and zinc retention in seven biofortified crops. *Nature Food, 4* (11), 978-985. https://doi.org/10.1038/s43016-023-00874-y

Hughes, J., & Grafenauer, S.J. (2023). The slow rise of sourdough. a nutrition audit of the bread category highlights whole grain. *International Journal of Food Sciences and Nutrition, 74* (3), 303-312. https://doi.org/10.1080/09637486.2023.2213858

Ivanović, D., Dodig, D., Đurić, N., Kandić, V., Tamindžić, G., Nikolić, N., & Savić, J. (2021). Zinc biofortification of bread winter wheat grain by single zinc foliar application. *Cereal Research Communications, 49,* 673–679. https://doi.org/10.1007/s42976-021-00144-2

Jagodić, J., Rovčanin, B., Borković-Mitić, S., Vujotić, L., Avdin, V., Manojlović, D., & Stojsavljević, A. (2021). Possible zinc deficiency in the Serbian population. examination of body fluids, whole blood and solid tissues. *Environmental Science and Pollution Research, 28,* 47439-47446. https://doi.org/10.1007/s11356-021-14013-2

Kabata-Pendias, A. (2001). Trace elements in soils and plants (3rd ed.). Boca Raton. CRC Press.

Kalayci, M., Torun, B., Eker, S., Aydin, M., Ozturk, L., & Cakmak, I. (1999). Grain yield, zinc efficiency and zinc concentration of wheat cultivars grown in a zinc-deficient calcareous soil in field and greenhouse. *Field Crops Research, 63* (1), 87–98. https://doi.org/10.1016/S0378-4290(99)00028-3

Kastori, R., Molnar, I., Sekulic, P., & Arsenijevic-Maksimovic, I. (2002). Contents of essential and predominantly toxic elements in wheat grown on Chermozem. *Proceedings of EKO Conference of Safe Food*, Novi Sad, Serbia, pp. 251-256.

King, J.C. (2011). Zinc. an essential but elusive nutrient. *The American Journal of Clinical Nutrition, 94* (2), 679S-684S. https://doi.org/10.3945/ajcn.110.005744

Knez, M., Nikolic, M., Zekovic, M., Stangoulis, J.C., Gurinovic, M., & Glibetic, M. (2017). The influence of food consumption and socio-economic factors on the relationship between zinc and iron intake and status in a healthy population. *Public Health Nutrition, 20* (14), 2486-2498. https://doi.org/10.1017/s1368980017001240

Knez, M., & Stangoulis, J.C. (2023). Dietary Zn deficiency, the current situation and potential solutions. *Nutrition Research Reviews, 36* (2), 199-215. https://doi.org/10.1017/s0954422421000342

Koković, N., Jaćimović, G., Sikirić, B., Čirić, V., Ugrenović, V. Zhapparova, E., & Saljnikov, E. (2022). Changes in Eutric Cambisol due to long-term mineral fertilisation. A case study in Serbia. *Italian Journal of Agronomy, 17,* 2029.

Liu, Z., Zhu, Q.Q., Tang, L.H., Xu, J.X., & Yin, C.L. (1982). Geographical distribution of trace elements deficient soils in China. *Acta Pedologica Sinica, 19,* 209–223.

Lončarić, Z., Ivezić, V., Kerovec, D., & Rebekić, A. (2021). Foliar Zinc-Selenium and Nitrogen Fertilization Affects Content of Zn, Fe, Se, P, and Cd in Wheat Grain. Plants, 10(8), 1549. https://doi.org/10.3390/plants10081549

Ludajić, G., Pezo, L., Filipović, J., Filipović, V., & Kosanić, N. (2016). Determination of essential and toxic elements in products of milling wheat. *Hemijska industrija, 70* (6) 707–715. https://doi.org/10.2298/HEMIND151119008L

Manojlovic, M., & Singh, B.R. (2012). Trace elements in soils and food chains of the Balkan region. *Acta Agriculturae Scandinavica, Section B – Soil & Plant Science 62* (8), 673–695. https://doi.org/10.1080/09064710.2012.690445

Marijanušić, K., Manojlović, M., Bogdanović, D., Lombnes, P., & Stojković-Jevtić, S. (2014). Sadržaj bakra i cinka u zemljištu i krmnim biljkama na različitim lokalitetima u Srbiji (Copper and zinc concentration in soil and plants used for feed on different locations in Serbia). *Letopis naučnih radova Poljoprivrednog fakulteta, 38* (1), 80-86. https://doi.org/10.5937/lnrpfns1401080M

Menkinoska, M., Gorgoski, I., Pavlova, V., Manasievska-Simic, S., Stamatovska, V., & Blazevska, T. (2013). Effects of milling on the Zn and Fe content of soft wheat flour from Macedonia. *Food Science, Engineering and*

Technologies, 18-19 October, Plovdiv, Scientific works, *XL*, 756-760.

Mensink, G.B.M., Fletcher, R., Gurinovic, M., Huybrechts, I., Lafay, L., Serra-Majem, L., Szponar, L., Tetens, I., Verkaik-Kloosterman, J., Baka, A., & Stephen, A.M. (2013). Mapping low intake of micronutrients across Europe. *British Journal of Plant Nutrition, 110* (4), 755–773. https://doi.org/10.1017/s000711451200565x

Milivojević, J., Bošković-Rakočević, Lj., Đekić, V, Luković, K., & Simić, Z. (2018). Cultivar-specific accumulation of iron, manganese, zinc and copper. *Journal of Central European Agriculture, 19* (2), 423-436. https://doi.org/10.5513/JCEA01/19.2.2051

Mrvić, V., Zdravković, M., Sikirić, V., Čakmak, D., & Kostić-Kravljanac, Lj. (2009). Štetni i opasni elementi u zemljištu (Harmful and dangerous elements in the soil). In: Mrvić V., Antonović G. (eds.), Plodnost i sadržaj opasnih i štetnih materija u zemljištima centralne Srbije (Fertility and contents of harmful and dangerous matters in the soils of central Serbia). Belgrade: Institute of Soil Science, pp. 75-145.

Mrvić, V., Kostić-Kravljanac, Lj., Čakmak, D., Sikirić, B., Brebanović, B., Perović, V., & Nikoloski, M. (2011). Pedogeochemical mapping and background limit of trace elements in soils of Branicevo Province (Serbia). *Journal of Geochemical Exploration, 109,* (1–3), 18-25. https://doi.org/10.1016/j.gexplo.2010.09.005.

Nešić, Lj., Belić, M., Manojlović,M., Pucarević, M., Sekulić, P., & Vasin, J. (2008). Fertility status and hazardous and harmful residues in the soils of Srem. *Book of Abstracts of Eurosoil 2008*, 4 August, Vienna, Austria, p. 286.

Nikolic, M., Nikolic, N., Kostic, Lj., Pavlovic, J., Bosnic, P., Stevic, N., Savic, J., & Hristov, N. (2016). The assessment of soil availability and wheat grain status of zinc and iron in Serbia. Implication for human nutrition. *Science of the Total Environment, 553,* 141-148. https://doi.org/10.1016/j.scitotenv.2016.02.102

Ozturk, L., Yazici, M.A., Yucel, C., Torun, A., Cekic, C., Bagci, A., Ozkan, H., Braun, H.-J., Sayers, Z., & Cakmak, I. (2006). Concentration and localization of zinc during seed development and germination in wheat. *Physiologia Plantarum, 128* (1), 144e152. https://doi.org/10.1111/j.1399-3054.2006.00737.x

Poole, N., Donovan, J., & Erenstein, O. (2021). Viewpoint. Agri-nutrition research. Revisiting the contribution of maize and wheat to human nutrition and health. *Food Policy, 100,* 101976. https://doi.org/10.1016/j.foodpol.2020.101976.

Prasad, A.S. (2014). Zinc: an antioxidant and anti-inflammatory agent. role of zinc in degenerative disorders of aging. *Journal of Trace Elements in Medicine and Biology, 28* (4), 364-371. https://doi.org/10.1016/j.jtemb.2014.07.019

Prasad, A.S. (2012). Discovery of human zinc deficiency. 50 years later. *Journal of Trace Elements in Medicine and Biology, 26* (2-3). 66–69. https://doi.org/10.1016/j.jtemb.2012.04.004

Rafique, E., Rashid, A., Ryan, J., & Bhatti, A.U. (2006). Zn deficiency in rainfed wheat in Pakistan. magnitude, spatial variability, management and plant analysis diagnostic norms. *Communications in Soil Science and Plant Analysis, 37,* 181–197. https://doi.org/10.1080/00103620500403176

Ram, H., Rashid, A., Zhang, W., Duarte, A.P., Phattarakul, N., et al. (2016). Biofortification of wheat, rice and common bean by applying foliar zinc fertilizer along with pesticides in seven countries. *Plant and Soil, 403,* 389–401. https://doi.org/10.1007/s11104-016-2815-3

Republic of Serbia (2013). Census of Agriculture 2012. Agriculture in the Republic of Serbia. Statistical Office of the Republic of Serbia.

Republic of Serbia (2023). Statistical Yearbook. Statistical Office of the Republic of Serbia.

Republic of Serbia (2024). Household budget survey, income and living conditions. Statistical Office of the Republic of Serbia.

Ryan, M.H., McInerney, J.K., Record, I.R., & Angus J.F. (2008). Zinc bioavailability in wheat grain in relation to phosphorus fertilizer, crop sequence and mycorrhizal fungi. *Journal of the Science of Food and Agriculture 88,* 1208–1216. https://doi.org/10.1002/jsfa.3200

Sánchez-Palacios, J.T., Henry, D., Penrose, B., & Bell, R. (2023). Formulation of zinc foliar sprays for wheat grain biofortification. a review of current applications and future perspectives. *Frontiers in Plant Science 14,* 1247600. https://doi.org/10.3389/fpls.2023.1247600

Samtiya, M., Aluko, R. E., Puniya, A. K., & Dhewa, T. (2021). Enhancing micronutrients bioavailability through fermentation of plant-based foods. A concise review. *Fermentation, 7* (2), 63. https://doi.org/10.3390/fermentation7020063

Sharma, A., Patni, B., Shankhdhar, D., & Shankhdhar, S.C. (2013). Zinc – an indispensable micronutrient. *Physiology and Molecular Biology of Plants, 19* (1), 11-20. https://doi.org/10.1007/s12298-012-0139-1

Shewry, P.R., Pellny, T.K., & Lovegrove, A. (2016). Is modern wheat bad for health? *Nature Plants, 2,* 1–3. https://doi.org/10.1111/nbu.12461

Siddiqui, S.A., Mahmud, M.C., Abdi, G., Wanich, U., Farooqi, M.Q.U., Settapramote, N., ... & Wani, S. A. (2022). New alternatives from sustainable sources to wheat in bakery foods. Science, technology, and challenges. *Journal of Food Biochemistry, 46* (9), e14185. https://doi.org/10.1111/jfbc.14185

Singh, B., Natesan, S. K. A., Singh, B. K., & Usha, K. (2005). Improving zinc efficiency of cereals under zinc deficiency. *Current Science, 88* (1), 36–44. https://www.jstor.org/stable/24110091

Singh, P., & Prasad, S. (2023). A review on iron, zinc and calcium biological significance and factors affecting their absorption and bioavailability. *Journal of Food Composition and Analysis, 123,* 105529. https://doi.org/10.1016/j.jfca.2023.105529

Škrbić, B., & Čupić, S. (2005). Toxic and essential elements in soft wheat grain cultivated in Serbia. *European Food Research and Technology, 221,* 361–366. https://doi.org/10.1007/s00217-005-1179-3

Sousa, S.F., Lopes, A.B., Fernandes, P.A. & Ramos, M.J. (2009). The zinc proteome. a tale of stability and functionality. *Dalton Transactions*, 7946–7956. https://doi.org/10.1039/B904404C

Srivastava, P.C., & Gupta, U.C. (1996). *Trace Elements in Crop Production*. Science Publishers, Lebanon, New Hampshire.

Tamindžić, G., Ignjatov, M., Milošević, D., Nikolić, Z, Kostić Kravljanac, Lj., Jovičić, D., Dolijanović, Ž., & Savić, J. (2021). Seed priming with zinc improves field performance of maize hybrids grown on calcareous chernozem. *Italian Journal of Agronomy, 16,* 1795. https://doi.org/10.4081/ija.2021.1795

Ubavić, M., & Bogdanović D. (1993). Teški metali u zemljištima Vojvodine (Heavy metals in the soils of Vojvodina). In R. Kastori (ed.) *Teški metali i pesticidi u zemljištu (Heavy metals and pesticides in the soil)*. Novi Sad: Faculty of Agriculture, Institute of Field and Vegetable Crops, pp. 217–222.

Ungai, D., Sipos, P., & Győri, Z. (2022). Evolution of the mineral content of winter wheat in Hungary based on 30 years of measurement results. *Journal of Food Investigation, 68,* 4013-4019. https://doi.org./10.52091/EVIK-2022/3-3-ENG

Velu, G., Ortiz-Monasterio, I., Cakmak, I., Hao, Y., & Singh, R.P. (2014). Biofortification strategies to increase grain zinc and iron concentrations in wheat. *Journal of Cereal Science, 59* (3), 365e372. https://doi.org/10.1016/j.jcs.2013.09.001

Vidovic, M., Sadibasic, A., Cupic, S., & Lausevic, M. (2005). Cd and Zn in atmospheric deposit, soil, wheat, and milk. *Environmental Research, 97* (1), 26-31. https://doi.org/10.1016/j.envres.2004.05.008

Wessells, K.R., & Brown, K.H. (2012). Estimating the global prevalence of zinc deficiency. results based on zinc availability in national food supplies and the prevalence of stunting. *PLoS One 7,* e50568. https://doi.org/10.1371/journal.pone.0050565

Willoughby, J.L., & Bowen, C.N. (2014). Zinc deficiency and toxicity in pediatric practice. *Current Opinion in Pediatrics, 26* (5), 579-84.

Yilmaz, A., Ekiz, H., Torun, B., Gültekin, I., Karanlik, S., Bagci, S.A., & Cakmak, I. (1997). Effect of different zinc application methods on grain yield and zinc concentration in wheat grown on zinc-deficient calcareous soils in Central Anatolia. *Journal of Plant Nutrition, 20* (4-5), 461–471. https://doi.org/10.1080/01904169709365267

Zhang, W., Zhang, W., Wang, X., Liu, D., Zou, C., & Chen, X. (2021). Quantitative evaluation of the grain zinc in cereal crops caused by phosphorus fertilization. A meta-analysis. *Agronomy for Sustainable Development, 41,* 6. https://doi.org/10.1007/s13593-020-00661-0

Živančev, D., Ninkov, J., Jocković, B., Momčilović, V., Torbica, A., Mirosavljević, M., Belović, M., Aćin, V., & Ilin S. (2021). Distribution of iron, zinc and manganese in milling streams of common Serbian wheat cultivars. Preliminary survey. *International Journal of Food Science and Technology, 56*, 3099–3110. https://doi.org/10.1111/ijfs.14953

Živančev, D.R., Buljovčić, M.S., Ninkov, J.M., Antić, I.B., Mikić, S.Z., Jaćimović, S.Ž., & Jocković, B.Đ. (2023). Micronutrient composition of milling streams of traditional wheat cultivars from Serbia. *Food and Feed Research, 50* (1), 12-23. https://doi.org/10.5937/ffr0-42946

Zou, C.Q., Zhang, Y.Q., Rashid, A., Savasli, E., Arisoy, R.Z., Ortiz-Monasterio, I., et al (2012). Biofortification of wheat with zinc through zinc fertilization in seven countries. *Plant and Soil 361,* 119-130. https://doi.org/10.1007/s11104-012-1369-2

Pregled cinka u zemljištu i zrnu pšenice u Srbiji – postoji li rizik od nedostatka cinka u ishrani baziranoj na pšenici?

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Sažetak: Nedostatak cinka u zemljištu negativno utiče na prinos i kvalitet osnovnih prehrambenih namirnica širom sveta. Dostupnost cinka biljkama u zemljištu opada pod uticajem različitih faktora, najpre osobina zemljišta, a može biti dodatno smanjena faktorima poput agrotehničkih mera, naročito primenom fosfornih đubriva, što može da dovede do toga da usevi kao što je pšenica slabije usvajaju cink. Zbog toga je koncentracija cinka u zrnu pšenice često niska, a njegovu biološku raspoloživost u organizmu dodatno ograničavaju različiti faktori, što doprinosi nedovoljnom unosu cinka ishranom. U fokusu ovog preglednog rada su koncentracija dostupnog Zn u poljoprivrednom zemljištu, nivo

cinka u zrnu pšenice i njegov značaj za zdravlje ljudi u Srbiji, sa posebnim osvrtom na vezu između ovih aspekata. Podaci o zemljištima sa niskim sadržajem dostupnog Zn, relativno niskim nivoima Zn u zrnu pšenice, kao i opšti nedostatak rezultata o koncentraciji Zn u tkivima gajenih biljaka i o primeni cinkovih đubriva, ukazuju na potrebu za daljim istraživanjima kako bi se procenio nutritivni status pšenice u pogledu Zn. Budući da je potrošnja pšenice u Srbiji velika, postojeći podaci sugerišu da deficit cinka kod ljudi može biti značajan problem, naročito zbog trenda prelaska na ishranu sa više biljnih namirnica. Agronomska biofortifikacija, proces tokom kog se đubriva unose u zemljište ili se primenjuju folijarno, predstavlja efikasno rešenje za povećanje nivoa cinka u zrnu pšenice i može doprineti boljoj ishrani ljudi, smanjujući rizik od njegovog nedostatka u populaciji.
Ključne reči: pšenica, zemljište, cink, nedostatak cinka, ishrana, zrno pšenice, biofortifikacija