UDC: 582.751:577.118

SPECIFIC FEATURES OF THE TRACE ELEMENT COMPOSITION OF THE CULTIVATED FLAX AND SOME OF ITS WILD RELATIVES

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DOI: https://doi.org/10.15673/fst.v15i1.1958

Article history

Received 14.08.2020
Reviewed 22.10.2020
Revised 12.12.2020
Approved 03.02.2021

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Cite as Vancuver style citation

Poliakova I, Sinyaeva N, Lyakh V. Specific features of the trace element composition of the cultivated flax and some of its wild relatives. Food science and technology. 2021;15(1): 73-79. DOI: https://doi.org/10.15673/fst.v15i1.1958

Цитування згідно ДСТУ 8302:2015

Poliakova I., Sinyaeva N., Lyakh V. Specific features of the trace element composition of the cultivated flax and some of its wild relatives // Food science and technology. 2021. Vol. 15, Issue 1. P. 73-79 DOI: https://doi.org/10.15673/fst.v15i1.1958

Abstract. Controlling the content of trace elements in human food is a major problem. Lack of them, as well as their excess, can seriously affect a person’s health. Commonly, people do not receive enough minerals they need. Though these minerals are found in products of both animal and plant origin, many ethnic groups have a significant preference for plant food, which is very often obtained from cereal plants. Not infrequently, though, these plants are poor in mineral elements, or a specific processing technology depletes a product of minerals. This article shows the content of such trace elements important for people as zinc, copper, cobalt, and nickel in the seeds and leaves of cultivated flax (*L. usitatissimum*) and its three wild perennial relatives (*L. austriacum*, *L. hirsutum*, and *L. thracicum*). We focus on flax, because, besides containing valuable trace elements, it is also a source of unsaturated fatty acids which are no less important for the human body. To date, there is but little information on the content of certain trace elements in the seeds of cultivated flax, and practically nothing is known about their content in its wild relatives, which are used mainly as decorative verdure. It has been established that the seeds contain 37.1–64.2 mg/kg of zinc, 5.3–9.3 mg/kg of copper, 2.9–7.3 mg/kg of nickel, and 1.4–3.3 mg/kg of cobalt. In the leaves, these trace elements are present in far smaller amounts (1.1–4.3 mg/kg). The highest in these trace elements is the wild species *L. thracicum*, and the lowest is *L. austriacum*. It has been found that in the plant material of cultivated flax, the ratio of the microelements under study was similar to that in the wild species. Zinc predominates in the flax seeds, but in the leaves, it exceeds other elements only insignificantly. Generally, both cultivated flax and its three wild relatives can be viewed as valuable and worthwhile sources of zinc, cobalt, copper, and nickel.

Key words: Flax, wild *Linum* species, trace elements, seeds, leaves, atomic adsorption spectrometry.

Introduction. Formulation of the problem

Micronutrient deficiency in food is one of today’s urgent problems. That is why the World Health Assembly calls for the prevention of micronutrient malnutrition, for stronger control over the content of trace elements in food [1].

To make the human body more resistant to adverse environmental factors, food should contain enough trace elements. Micronutrient deficiency in people is caused by insufficient consumption of mineral-rich foods. Diseases caused by lack of zinc and iron are especially common in developing countries where the cereal diet is traditional: India, Pakistan, Bangladesh [2].

The Food and Agriculture Organization (FAO) points out that micronutrients and vitamins are necessary for public health [2]. According to some authors, the vitamin boom is in the past, and the time of trace elements is now coming [3-5].

The problem is solved by using natural functional products, flax seeds among them. That is why in many countries, flax seeds are in constant demand, and the volume of their processing is increasing [6].

Analysis of recent research and publications

Recent years have been marked by growing interest in quantifying trace elements in food. It has been found that poor nutrition contributes significantly to the global morbidity increase. The main task now is developing and implementing programmes of fortification food with micronutrients [4,7]. According to Osamu, research of trace elements is an important objective of preventive medicine [8].

Cereals are, first and foremost, a source of carbohydrates. They contain proteins and many trace elements, too, but in minute quantities. Even the highest zinc concentrations (<30 mg/kg) found in brown rice grains are insufficient to meet the needs for this trace element in people who predominantly eat rice [9]. In cereal grains, iron and zinc are concentrated in the hulls removed during preparation of flour. After polishing rice, the concentration of trace elements in grains is significantly reduced [10].

It should be noted that trace elements are very important for the physiological processes during the growth and development of a plant. It has been established that most trace elements activate certain enzymatic systems and can be components of enzyme molecules. Thus, nickel activates a number of enzymes, including nitrate reductase, and has a stabilising effect on the structure of ribosomes. Zinc plays an important role in the formation of the phytohormone auxin. Cobalt affects protein synthesis and is associated with auxin metabolism. Copper regulates the content of phenolic growth inhibitors and makes plants more resistant to lodging, drought, and frost [11]**.**

The main sources of trace elements are red meat, poultry, fish, liver, seafood, and leguminous plants. In our opinion, flax seeds can be an alternative source of these elements. This is especially important for people who do not consume these products (like vegetarians and vegans) or for those with intolerance to the seeds of legumes.

Cultivated flax is widely distributed on all continents. Its seeds are finding ever-widening applications in dietetic and preventative nutrition. Fats are very important for the human body, but unsaturated fatty acids are more preferred. Flax seeds contain up to 50% of flaxseed oil, which is low in saturated and high in unsaturated acids (linoleic, oleic, linolenic). Therefore, flaxseeds are a unique component of people's healthy diet. Besides, their content of such important trace elements as zinc, copper, nickel, and cobalt makes food still more valuable [12].

There is not too much information about the microelement composition of cultivated flax [13]. Some widely cultivated spices, including linseed, which are consumed in Turkey, were analysed for their mineral and trace element content, in particular, for that of cadmium, iron, copper, manganese, and zinc. It was found that the zinc concentration in flax seeds reached 28 mg/kg and was the highest among the plants studied. Besides, linseed contained the highest amount of cadmium (128 mg/kg) [14]. Twenty-three European linseed lines were compared and analysed for their content of fatty acids and minerals. The levels of seven fatty acids and ten minerals (Ca, Mg, Na, K, P, Cu, Fe, Mn, Zn, and B) were determined. It was shown that the lines varied significantly in their contents of both fatty acids and mineral elements [15]. The levels of some essential and non-essential metals were determined in linseed (Linum usitatissimum) samples collected from five different sites in Ethiopia where its cultivation is common. Analysis of variance at a 95% confidence level revealed that the five samples differed significantly in their average levels of these metals (except K and Ni). Thus, the zinc content varied from 29 to 40 mg/kg [16].

As for its wild relatives, there is no such information. Basically, wild species were considered as a valuable material for ornamental use in alpine gardens or in group plantings. It was revealed that the diameter of the flower varied from 38 mm in *L. hirsutum* to 25.7 mm in L. narbonense. The colour spectrum of the flower includes light lilac, blue, and yellow. Also, the foliage of wild species is highly decorative. L.hirsutum is the tallest (75 cm) and has the largest bush (more than 54 cm in diameter), and L. thracicum is the most "compact" (36.0 cm and 38 cm) [17, 18].

Besides, it was shown that some wild flax species differed significantly in the biochemical parameters of seeds. The oil content of seeds in perennial wild species ranged 24.6–33.20%, which is far lower than that of oil-yielding flax. In terms of the protein content, only *L. thracicum* exceeded cultivated flax (26%). Other species contained significantly less protein (18.13–22.44%). It was found that the fatty acid composition of oil from wild species was similar to that of the *Linum* species, where linolenic acid predominated, so they were classified as linum-type, while *L. thracicum* was high in oil with up to 60% of essential linoleic acid. This high content of individual fatty acids allows recommending these plants to be used in preventive medicine [19].

It has been shown that there is no close relationship among the contents of mineral elements in different plant organs. Thus, concentrations of 19 elements were analysed in leaves and seeds from 96 wild plant samples of Arabidopsis thaliana grown in artificial soil, and very few correlations between the elemental composition of these organs were observed [20]. However, the study of trace elements not only in seeds, but also in other plant organs, in particular leaves, is of considerable interest: it reveals that these minerals are important (their quantities as well as ratios) not only for human nutrition, but also for the nutrition of the plant itself. It is known that micronutrients in plant participate in diverse metabolic processes, including cellular defence, gene regulation, hormone perception [21].

The **purpose** of the work was to compare the content of some trace elements in the seeds and leaves of oil-yielding flax and of some of its wild species. The **objectives** of the study were:

– to determine the content of zinc, copper, nickel, and cobalt in the seeds of oil-yielding flax and three perennial wild species;

– to reveal the content of these trace elements in the leaves of oil-yielding flax and wild species;

– to find the ratio of the microelements in the seeds and leaves of cultivated flax and its wild relatives.

Research materials and methods

The research material was the seeds and leaves of the cultivated oil-yielding flax *L. usitatissimum* (the variety Pivdenna Nich, which is the national standard of Ukraine) and of the wild perennial species *L. austriacum*, *L. hirsutum*, and *L.thracicum*. The species *L. austriacum* and *L. hirsutum* are indigenous to the southern part of the Steppe of Ukraine, where the research was conducted. Seeds and vegetative plants of *L. austriacum* and *L. hirsutum* were collected *in situ*, transferred to the experimental site and studied in detail *ex situ*. The *L. thracicum* sample was obtained from Vavilov Research Institute of Plant Industry (St. Petersburg) and later included in the collection of Zaporizhzhia National University for further study. For our research, green leaves were taken from the middle part of the plant at the end of the growing season, and seeds after full maturation. The studies were carried out during 2018–2019. The plants were grown on the experimental plot of the Department of Genetics and Plant Resources of Zaporizhzhia National University. The soil of the plot is ordinary chernozem.

The trace elements were determined annually in quintuplicate on an atomic absorption spectrophotometer Hitachi 180–80 (2000, Japan) with a flame atomiser and a non-selective interference detector using the Zeeman effect [22]. The data were statistically processed on a computer using Microsoft Office Excel and the modern STATISTICA 10 package.

Results of the research and their discussion

Zinc is known to be a multi-purpose trace element. Its biological role manifests itself in homeostasis, immunity, and chronic diseases. It belongs to the group of elements that are very important for the human body. People’s daily requirement of these trace elements varies from 50 mcg to 18 mg [7,8,12,23,24]. It is important to evaluate the zinc content in products and make up for its deficiency: the unique properties of zinc can make it extremely useful in treating many diseases [25-26]. Since there is no zinc storage system in the body, people depend on its daily intake. Serious zinc deficiency is a problem in developing countries, while marginal zinc deficiency is a problem in developed countries [25].

Table 1 presents data on the content of the four microelements in the seeds of cultivated flax and its three wild species averaged over two years. It has been established that of the four elements studied, zinc accumulates in seeds of all the flax species in the largest amount (37.1 to 64.2 mg/kg), and its content exceeds that of over other elements significantly.

Other trace elements studied are present in flax seeds in a far smaller amount, 1.4 to 9.3 mg/kg (Table 1). It has been found that such an important element as copper in flax seeds ranges from 5.3 to 9.3 mg/kg. Many authors indicate that copper, along with zinc, belongs to the group of essential trace elements. Copper is found in all parts of the musculoskeletal system, and its largest amounts are in the brain and liver [7,8,28].

Nickel falls into the group of “probably essential elements.” Its role in the human body is less studied [7,8,28]. It takes part in the formation of blood cells and the metabolism of fats. It has been revealed that seeds contain 2.9 to 7.3 mg/kg of nickel.

One of the least studied trace elements is cobalt [7,8,28]. Its role in the formation of blood and Vitamin B_{12} has been established. In the composition of flax seeds, the amount of cobalt is relatively small (1.4–3.3 mg/kg).

After comparing the content of various trace elements in the seeds of oil-yielding flax (*L. usitatissimum*) and its wild species, we have come to the conclusion that *L. hirsutum* and *L. thracicum* significantly exceed it in zinc, while the species *L. austriacum* accumulates considerably less zinc in the seeds. The species *L. thracicum* is the highest in all the trace elements studied. *L. austriacum* accumulates smaller amounts of the microelements in the seeds than other species do.

The main food products of the absolute majority of people are cereals, but the content of trace elements in them is low. Of the four elements studied, zinc is the most important for people. Its content in rice seeds is 14 mg/kg, in wheat 34 mg/kg, in barley 36 mg/kg. The copper content in the seeds of these crops is also low: 2.4 mg/kg in rice, 5.1 mg/kg in wheat, 6.6mg/kg in barley. In leguminous seeds, these micronutrients are generally more available than in cereals. The zinc content in beans is 41mg/kg, in soya beans 43-56mg/kg, and that of copper is 13mg/kg and 7.0–15.5mg/kg respectively [29].

Table 1 – The content of trace elements in the seeds of different flax species, mg/kg (n=5)

Element	Species			
	L. usitatissimum	***L. austriacum***	***L. hirsutum***	***L. thracicum***
Zn	49.2 ± 0.36	37.1 ± 0.32*	56.3 ± 0.33*	64.2 ± 0.46*
Cu	7.6 ± 0.14#	5.3 ± 0.09*,#	8.3 ± 0.12#	9.3 ± 0.17*,#
Ni	4.4 ± 0.12#	2.9 ± 0.11*,#	5.7 ± 0.13*,#	7.3 ± 0.12*,#
Co	1.5 ± 0.08#	1.4 ± 0.09#	2.6 ± 0.09*,#	3.3 ± 0.15*,#

* differences from *L. usitatissimum* are significant at P<0.01

differences from Zn are significant at P<0.01

In general, the concentration of many trace elements in the seeds of cereals and legumes is considered insufficient for people's proper nutrition. In cereal seeds, the concentration of trace elements, low as it is, becomes still lower due to the processing technology. And in fresh vegetables, the concentration of trace elements is even lower [11].

The research conducted have shown that flax seeds can become an important component of nutrition, make up for the lack of essential trace elements, and form the basis of preventive and dietetic nutrition. In flax seeds, besides a quite high content of important trace elements, there is more than 42% of oil containing unsaturated acids such as linolenic, linoleic, oleic.

A similar tendency in the content of trace elements can be observed in the leaves of the flax species under study (Table 2). The species *L. thracicum* accumulates more of the microelements considered than other species do, while *L.austriacum* has the least of them. Like it is in the seeds, the trace element the leaves of all flax species accumulate the most is zinc, although they do not exceed other elements in its content as significantly as seeds do.

Table 2 – The content of trace elements in the leaves of different flax species, mg/kg (n=5)

Element	Species			
	L. usitatissimum	*L. austriacum*	*L. hirsutum*	*L. thracicum*
Zn	3.4±0.09	2.4±0.08*	4.2±0.12*	4.3±0.11*
Cu	2.4±0.06#	1.9±0.03*#	2.5±0.11#	3.4±0.04#*
Ni	2.3±0.05#	1.3±0.04*#	2.4±0.11#	3.3±0.05#*
Co	1.3±0.07#	1.2±0.07#	1.4±0.06#	1.1±0.05#

* differences from *L. usitatissimum* are significant at P<0.01

differences from Zn are significant at P<0.01

These results indicate the difference in the content of trace elements in flax seeds and leaves. Both the content of individual elements and the total trace elements content in seeds is several times higher. The smallest difference noted by us is in the cobalt content. The content of copper and nickel in the seeds is 2–3 times higher. The greatest difference is in the zinc content: it exceeds the amount of zinc in leaves by 13–15 times.

Fig. 1 shows the ratio of the content of different microelements in the plant material of two flax species. A similar tendency is clearly seen in the two species studied. Thus, zinc is predominant in the seeds both of the cultivated flax *L.usitatissimum* and of the wild species *L. thracicum.*

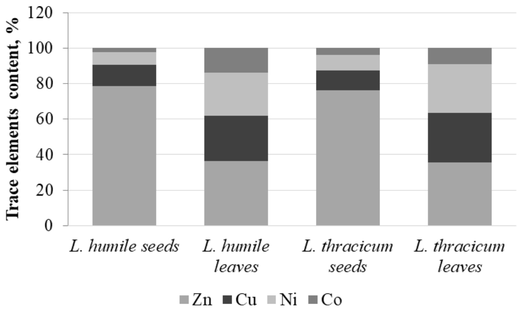

Fig. 1 Ratio of trace elements in the seeds and leaves of different flax species

Our results prove that accumulation of zinc in seeds is important for flax plants. Flax is an early sowing culture. Its seeds begin germinating at 1–4°C. Probably, a plant requires zinc at the germination stage, for example, to protect itself against phytoinfection. Zinc is an essential element for the life of plants: it is involved in many biochemical and physiological processes. It is the only metal in the six classes of enzymes (oxidoreductases, transferases, hydrolases, lyases, isomerases, ligases) [30].

In the leaves of both species, the ratio of trace elements is more balanced. In our opinion, during the growing season, all these elements are important for the plant. The leaf is the main plant organ responsible for a plant's mineral nutrition, water balance, transpiration, and photosynthesis. This is probably why none of the elements studied predominates in flax leaves. Zinc does not exceed copper and nickel so greatly. As for the percentage of the trace elements, it has been noted that the seeds of *L. usitatissimum* contain less cobalt than *L. thracicum* does, but in its leaves, on the contrary, there is more of it than in the wild species.

In general, summarising the information we have obtained, both cultivated flax and its three wild relatives can be considered valuable sources of zinc, cobalt, copper, and nickel, which deserves attention.

Conclusion

It has been demonstrated that the seeds of all four species of flax contain a lot of zinc, 37.1 to 64.2 mg/kg. Such an amount exceeds this parameter not only in cereals, but also in many leguminous plants. It is characteristic that some wild species such as *L. hirsutum* and *L. thracicum* have an advantage in this regard over cultivated flax by 7.1 and 15.0 mg/kg respectively. The three other mineral elements (copper, nickel, and cobalt) are contained in the seeds of the species under study in far smaller quantities than zinc.

In the leaves, the content of mineral elements is much lower than in the seeds. Moreover, in the leaves, there is no big difference between the contents of zinc and other elements as it is in the seeds. Leaves contain zinc in a range of 2.4–4.3 mg/kg, while the content of other trace elements varies from 1.1 to 3.4 mg/kg.

It has been shown that these microelements were present in a similar ratio in the plant material from both the cultivated flax and the wild flax species. Zinc is predominant in the seeds (about 80%), but in the leaves, it does not exceed other elements so greatly (30–40%).

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ОСОБЛИВОСТІ МІКРОЕЛЕМЕНТНОГО СКЛАДУ РОСЛИН КУЛЬТУРНОГО ЛЬОНУ ТА РЯДУ ЙОГО ДИКИХ РОДИЧІВ

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Анотація. Проблема контролю вмісту мікроелементів у продуктах харчування людини є дуже гострою. Як їхня нестача, так і надлишок призводять до серйозних порушень здоров'я. Частіше за все людина не отримує необхідні їй мінерали, які можна знайти як в продуктах тваринного, так і рослинного походження. Тим не менш, багато етнічних груп віддають значну перевагу рослинній їжі. Її джерелом дуже часто є злакові рослини, які або бідні на мінеральні елементи, або мінеральне виснаження продукту обумовлене специфічною технологією переробки. В цій статті показано вміст таких важливих для людини мікроелементів, як цинк, мідь, кобальт та нікель, в насінні та листках культурного льону *L. usitatissimum* і його трьох диких багаторічних родичів *L. austriacum, L. hirsutum* і *L. thracicum.* Увага до льону як джерела цінних мікроелементів пов'язано з тим, що, крім самих мікроелементів, льон є джерелом цінних ненасичених жирних кислот, не менш важливих для людського організму, ніж самі мікроелементи. На сьогоднішній день мається лише небагато інформації про вміст певних мікроелементів в насінні культурного льону, і практично нічого не відомо в цьому зв'язку про його диких родичів, які використовувались в основному тільки для декоративного озеленення. Встановлено, що в насінні цинк міститься в діапазоні від 37,1 до 64,2мг/кг, мідь – 5,3-9,3мг/кг, нікель – 2,9 до 7,3мг/кг, а кобальт – 1,4-3,3мг/кг. В листках ці мікроелементи наявні у суттєво меншій кількості від 1,1 до 4,3мг/кг. Найбільшим вмістом досліджуваних мікроелементів вирізняється вид *L. thracicum,* а найменшим – вид *L. austriacum.* Виявлено, що співвідношення мікроелементів, які вивчались, у рослинному матеріалі культурного виду льону та його дикорослих видів є схожим. Цинк переважає в насінні льону, але він не має суттєвої переваги над іншими елементами в листках. В цілому, як культурний льон, так і три його дикі родичі можна вважати цінними джерелами цинку, міді, кобальту та нікелю, які заслуговують на увагу людини.

Ключові слова: льон олійний, дикі види льону, мікроелементи, насіння, листя, атомно-адсорбційна спектрометрія.

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