Chemical composition of seeds of industrial Ukrainian hemp varieties

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Keywords:

Hemp
Seeds
Composition

Article history:

Received 18.03.2024
Received in revised form 17.07.2024
Accepted 30.09.2024

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DOI:
10.24263/2304-974X-2024-13-3-8

Abstract

Introduction. The aim of the work was to study the chemical composition and characteristics of seeds of industrial Ukrainian hemp varieties.

Materials and methods. The research materials are seeds of the industrial hemp varieties Hliana, Hlesiia, Hlukhivs`ki 51, Artemida, and Harmoniia. The content of moisture, protein, oil, fiber, and ash were determined by standard methods. The mineral composition was determined by inductively coupled plasma atomic emission spectrometry (ICP-AES).

Results and discussion. The chemical composition of industrial hemp seeds of the analyzed varieties averaged, %: oil – 37.38, protein – 24.22, fiber – 34.71, ash – 5.15, moisture – 8.31. The highest content of oil (38.90 %) and fiber (37.63 %) was found in the seeds of Artemida, and the highest content of protein (25.68 %) and ash (5.63 %) was detected in Hlukhivs`ki 51. The average oil content in seeds of Ukrainian hemp varieties was by 5.5 % higher than the average oil content in the seeds of the best known world hemp varieties. The average content of macroelements in seeds of Ukrainian hemp varieties was, g/kg of dry weight: calcium, 1.67, phosphorus, 8.08, sodium, 0.06, potassium, 6.82, magnesium, 4.04. The average content of trace elements in the studied seeds was, mg/kg of dry weight: copper, 12.62, zinc, 54.27, iron, 106.28, cobalt, 0.06, manganese, 95.85, meanwhile content of lead was low, 0.08 mg/kg of dry weight and cadmium was not detected. The average content of calcium and copper in the seeds of Ukrainian industrial hemp varieties exceeded the average content of these elements in the seeds of world industrial hemp varieties by 21% and 6%, respectively. The phosphorus content in seeds of studied Ukrainian hemp varieties was almost the same as in the seeds of known world varieties. The average content of sodium, potassium, magnesium, zinc, iron, and manganese in seeds of tested Ukrainain hemp varietiers was lower than the average content in seeds of the known world varieties.

Conclusions. The presented characteristics of seeds of Ukrainian hemp varieties and the comparison with well-known world analogues confirm the high nutritional value of the varieties and its great potential for application.

Introduction

Hemp has been cultivated for thousands of years as a fiber, grain, and medicinal plant. However, strict controls on the cultivation of cannabis for illicit use, the proliferation of other threads and oilseeds, and the emergence of cheap synthetic fiber have led to a decline and even eradication of hemp production. Hemp has been banned in most countries for more than seven decades, and it missed out on the Green Revolution and the adoption of new technologies and varieties (Viskovic et al., 2023).

In the late 60s of the last century, Ukrainian selectionists began working on the creation of cannabis varieties with a minimized content of tetrahydrocannabinol, which is a psychotropic substance. The first varieties (YuSO-14, YuSO-16) that did not cause narcotic excitement were developed at the Institute of Bast Crops of the National Academy of Agrarian Sciences of Ukraine in 1980. In these hemp varieties, the content of tetrahydrocannabinol did not exceed 0.2 %. The year 2011 was a landmark in hemp selection, when scientists at the Institute of Bast Crops of the National Academy of Agrarian Sciences of Ukraine developed the world's first hemp variety, Victoriia, which did not contain tetrahydrocannabinol (Holovii et al., 2024). Such hemp was called non-narcotic hemp, and a little later technical or industrial hemp, depending on the direction of processing. Since then, the hemp industry, previously banned in most European countries due to the rise of drug addiction, has been developing rapidly.

In recent years, the area allocated for hemp cultivation in the EU has increased by 60 % (Figure 1). During the same period, hemp production increased by 84.3 %. France is the largest producer of hemp in the EU with more than 60 % of production, followed by Germany with 17 % and the Netherlands with 5 % (An official website of the European Union: Farming. Crop productions and plant-based products, 2024).

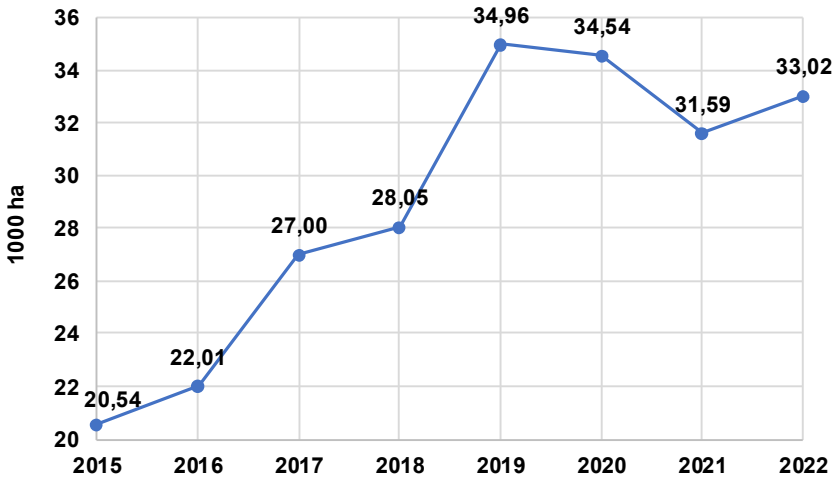

Figure 1. The area of land in the EU devoted to hemp cultivation, according to EUROSTAT

The rapid growth of industrial hemp and its use in the production of various goods is of interest to many scientists and manufacturers. Hemp is used to produce a variety of goods, including textiles (fabrics, yarns, carpets, canvas, and ropes), paper, medicines, food, animal feed and bedding, paints, biofuels, biodegradable plastics, biocomposites, and building

materials. The rapid production of biomass and the ability to grow in a variety of conditions make hemp a good candidate for remediation of contaminated land (Rehman et al., 2021; Viskovic et al., 2023).

Hemp fiber differs from others in its aseptic properties, high absorption capacity, protection from ultraviolet radiation, and lack of allergic effects. According to a study by Schumacher, hemp is a promising alternative to cotton, and growing hemp will reduce agricultural costs by 77.63 % compared to cotton (Schumacher et al., 2020).

Hemp seeds were originally considered a by-product of the industrial fiber industry (Farinon et al., 2020). Hemp seeds began to be used about 3000 years ago, when they were the main source of food for the population of the region that is now China and Nepal (Viskovic et al., 2023). Hemp seeds have a valuable composition, which can be influenced by various factors, including varietal characteristics and the region of cultivation (Arango et al., 2024; Mamadaliev et al., 2023). Hemp seeds contain 25–35 % oil with a balanced composition of fatty acids, 20–25 % proteins that are easily digestible by the human body and contain all essential amino acids, 20–30 % carbohydrates, as well as a significant amount of minerals, deficient coarse dietary fiber, vitamins, antioxidants and other biologically active substances (Capcanari et al., 2024; Oseyko et al., 2021). Given the biochemical composition of hemp seeds, it should be positioned as the most nutrient-rich food product. Hemp seeds can be consumed both as a whole and as processed products – kernels, oil, flour, protein concentrates, and fiber (Oseyko et al., 2021; Sheichenko et al., 2024).

In modern technologies, in order to increase the nutritional and biological value of food products, industrial hemp seeds and its processing products are used, in particular in the production technologies of bakery, dairy, meat, confectionery products, as well as products for children and special nutrition (Oseyko et al., 2021; Xu J. et al., 2022).

It is important to continue the active study of the biochemical composition of seeds of new varieties of industrial hemp to ensure its competitiveness.

The aim of the work was to study the chemical composition of industrial hemp seeds grown in Ukraine, in particular, the varieties Hliana, Hlesiia, Hlukhivs`ki 51, Artemida, and Harmoniia.

Materials and methods

Materials

Ukrainian industrial hemp varieties Glyana, Glesia, Glukhovskaya 51, Artemida, and Garmoniya, from which the seeds for the study were obtained (Figure 2), were grown in the research areas of the Institute of Bast Crops (Glukhov, Sumy region, Ukraine) in compliance with the conditions of spatial isolation.

Methods

Determination of moisture in hemp seeds

The moisture in hemp seeds was determined by drying at 105 °C (± 2 °C) to a constant weight (Kumar et al., 2013).

Figure 2. Seeds of Ukrainian industrial hemp varieties

Determination of total nitrogen and crude protein content

The total nitrogen and crude protein content in the hemp seeds was determined by the Kjeldahl method (Cruz, 2013). A conversion factor equal 6.25 was applied to calculate crude protein content that was based on measured total nitrogen (Mariotti et al., 2008).

Determination of crude oil content

The crude oil content in hemp seeds was determined by extraction in a Soxhlet apparatus (Kumar et al., 2013).

Determination of crude fiber content

Defatted material, 1 g, was treated with 200 ml of 1.25 % sulfuric acid solution in commercial fiber determination bags (Marichal et al., 2011). The residue after filtration and washing with hot distilled water was treated with 1.25 % sodium hydroxide solution and filtered. The residue was washed in the following sequence: hot distilled water, 1 % nitric acid solution 3 times with hot distilled water. The remaining fiber was dried, weighed, and burned in a muffle furnace. The weight of the ash residue was subtracted and the weight of crude fiber in the sample was obtained (Kumar et al., 2013).

Determination of crude ash content

The ash content was determined after heating and burning in a muffle furnace for 5–6 hours at a temperature of 525±25 °C to a constant weight (Kumar et al., 2013).

Determination of mineral content

Approximately 0.5 g of the pre-ground material was placed in a mineralization vessel and 10 ml of 65 % nitric acid and 1 ml of concentrated hydrochloric acid (Sigma-Aldrich reagents) were added. The sample was microwave digested for 45 minutes (including cooling time) at 185 °C in a commercial pressurized microwave digestion system (Multiwave GO Plus, manufactured by Anton Paar, Austria).

The solution was diluted with ultrapure water to a specified volume. Mineral concentrations were determined by inductively coupled plasma atomic emission spectrometry ICP-AES (Agilent 5110) as presented by Khan et al. (2022). The analysis was performed using an external standard (Agilent, multi-element standard solution). All calibration curves were obtained for 6 different concentrations.

Statistics

All experiments were performed in triplicate and mean±standard deviation was shown.

Results and discussion

Chemical composition of seeds of Ukrainian industrial hemp varieties

The content of moisture, protein, oil, fiber and ash in seeds of industrial Ukrainian hemp varieties are shown in Table 2.

It was shown that: (a) the moisture content in the seeds of industrial hemp varieties was on average 8.31 %, oil – 37.38 %, protein – 24.22 %, fiber – 34.71 %, and ash – 5.15 %; (b) the highest content of oil (38.90 %) and fiber (37.63 %) was found in the seeds of Artemida; protein (25.68 %) and ash (5.63 %) in Hlukhivs`ki 51 varieties; (c) the lowest content of oil (35.11 %) was in the seeds of Hliana, protein (22.92 %) in Harmoniia, fiber (31.49 %) in Hlukhivs`ki 51, and ash (4.55 %) in Artemida varieties. Thus, the seeds of industrial Ukrainian hemp varieties can be positioned as modern raw materials for efficient complex processing.

Table 2

Chemical composition of seeds of Ukrainian industrial hemp varieties

Variety	Moisture, %	Content, % dry weight			
		oil	protein	fiber	ash
Hliana	8.93±0.13	35.11±1.89	25.58±0.32	36.11±1.12	5.55±0.21
Hlesiia	8.55±0.18	37.16±1.25	23.57±0.41	33.73±1.25	4.71±0.42
Hlukhivs`ki 51	7.86±0.11	37.59±1.37	25.68±0.26	31.49±1.08	5.63±0.38
Artemida	7.98±0.21	38.90±1.54	23.34±0.52	37.63±1.41	4.55±0.29
Harmoniia	8.24±0.22	38.15±1.48	22.92±0.17	34.58±1.33	5.32±0.40
Average value	8.31	37.38	24.22	34.71	5.15
Minimum value	7.86	35.11	22.92	31.49	4.55
Maximum value	8.93	38.90	25.68	37.63	5.63

Chemical composition of the seeds of Ukrainian industrial hemp varieties was compared with the published data on world varieties. The seeds of industrial hemp varieties Alyssa, CanMa, Anka, Jutta, Yvonne, Delores, CFX-1, CFX-2, CRS-1, and Finola, grown in Canada, contained 26.9–30.6 % oil; 23.8–28.0 % protein, 32.7–38.8 % fiber, and 5.1–5.8 % ash. The richest in oil, protein, and ash content was Finola, and the richest in fiber content was Anka (Vonapartis et al., 2015).

Seeds of industrial hemp varieties CFX-2, X-59, CRS-1, Grandi, Picolo, CFX-1, Katani, Canda, Delores, and Joey grown in the USA (North Dakota) contained 32.75–35.88 % oil; 24.30–28.13 % protein; 32.47–37.53 % carbohydrates, and 4.86–6.08 % ash. Variey CFX-1 had the highest oil and ash content, CFX-2 in protein, and Delores in carbohydrates (Lan et al., 2019).

Seeds of industrial hemps cultivars grown in Greece - Santhica 27 (France), Fedora 32 (France), Felina 32 (France), Futura 75 (France), Tygra (Poland), Bialobrzeskie (Poland), and Finola (Finland) - contained 8.5–29.2 % oil, 12.2–25.4 % protein, 4.4–5.3 % ash, and 40.8–74.5 % carbohydrates. The highest content of oil and protein was in Finola, and the highest carbohydrate content was in Santhica 27 (Irakli et al., 2019).

Seeds of industrial hemp grown in the USA (Kansas) of the varieties Fedora 17, Helena, Joey, Hlukhivs`ki 51, Katani, Felina 32, Futura 75, Tygra, Hlesiia, CRS-1, Canda, YuSO 31, and CFX-1 contained 28.03–33.23 % oil, 26.48–32.03 % protein, 28.78–36.55 % fiber, and 5.43–6.32 % ash. Among the analyzed varieties the highest content was found: oil in Katani, protein in CRS-1, fiber in Canda, and ash in Fedora 17 (Xu Y. et al., 2021).

Seeds of hemp grown in Spain of the varieties Bialobrzeskie, Carmagnola, Fedora 17, Felina 32, KC Dora, Kompolti, Santhica 27, Tiborszallasi contained 29.1–32.66 % oil, 18.3–23.0 % protein, 32.5–40.4 % fiber, and 8.7–10.4 % ash. Bialobrzeskie has the highest oil and protein content among the analyzed varieties, Kompolti has the highest fiber content, and Santhica 27 has the highest ash content (Alonso-Esteban et al., 2022).

Seeds of Henola and Bialobrzeskie hemp varieties grown in Poland contained an average of 32.52 % oil, 23.47 % protein, 28.15 % fiber, and 4.66 % total ash. Henola seeds contained more oil, 32.75±1.7 %, Bialobrzeskie seeds contained more protein, 23.54±0.59 %; fiber, 28.88±0.18 %, and ash, 4.66±0.47 % (Teleszko et al., 2022).

Seeds of hemp varieties Felina 32, Santhica 27, and Rodnik, grown in Uzbekistan, contained 29.10–31.70 % oil, 23.44–26.95 % protein, and 4.95–6.10 % ash. Among the analyzed varieties, seeds of Santhica 27 had the highest oil and ash content, while Rodnik had the highest protein content (Mamadaliev et al, 2023).

Industrial hemp seeds of Antal, Bacalmas, Fibrol, KC Dora, KC Virtus, KC Zuzana, Kompolti, Monoica, Tiborszallasi, Tisza (Hungary), Carmagnola (Italy), Chameleon (Netherlands), Dioica 88, Epsilon 88, Fedora 17, Felina 32, Ferimon FR 8194, Futura 75, Santhica 23 (France), Helena, Marina, Novosadska, Novosadska+, Simba (Serbia), Kina (China), Lovrin 110, Srcuienijubilee (Romania), Silesia, and Wojko (Poland) varieties, grown in different countries, contained 21.12–35.67 % oil, 21.63–28.92 % protein, 25.49–43 % carbohydrates, and 4.4–7.49 % ash. Industrial hemp seeds of the Fibrol variety had the highest content of oil, Tisza –of protein, Epsilon 88 – of carbohydrates, and KC Virtus – of ash (Arango et al., 2024).

The chemical composition of the best samples of industrial hemp seeds of world selection are given in Table 3.

Table 3

Chemical composition of seeds of world industrial hemp varieties

Variety	Cultivation region	Content , % DW				Reference
		Oil	Protein	Fiber	Ash	
Finola	Greece	29.20	25.40	n.d*	4.80	Irakli et al., 2019
Finola	Canada	30.60	28.00	33.20	5.80	Vonapartis et al., 2015
Anka		28.80	23.80	38.80	5.70	
CFX-1	USA (North Dakota)	35.88	25.97	n.d	6.08	Lan et al., 2019
CFX-2		35.52	28.13	n.d	5.34	
Katani	USA (Kansas)	33.23	30.07	28.85	6.00	Xu Y. et al., 2021
CRS-1		31.53	32.03	28.78	5.95	
Canda		28.92	26.81	36.55	6.03	
Fedora 17		30.24	26.48	35.02	6.32	
Rodnik	Uzbekistan	29.10	26.95	n.d	5.82	Mamadaliev et al, 2023
Santhica 27		31.70	23.44	n.d	6.10	
Santhica 27	Spain	29.90	18.30	37.44	10.40	Alonso-Esteban et al., 2022
Kompolti		31.70	18.80	40.40	9.40	
Bialobrzeskie		32.66	23.00	32.50	10.28	
Bialobrzeskie	Poland	32.28	23.54	28.88	4.66	Teleszko et al, 2022
Henola		32.75	23.39	27.42	4.40	
Tisza	Hungary	33.91	28.92	n.d	4.55	Arango et al., 2024
Fibrol		35.67	25.46	n.d	5.54	
KCVirtus		33.04	23.33	n.d	7.49	
Average value		31.93	25.36	33.44	6.35	
Minimum value		28.80	18.30	27.42	4.40	
Maximum value		35.88	32.03	40.40	10.40	

*n.d, not determined.

Thus, the highest content of oil (35.88 %) was found in seeds of industrial hemp CFX-1 (Lan et al., 2019), protein (32.03 %) in CRS-1 (Xu Y. et al., 2021), fiber (40.40 %) in Kompolti, and ash (10.40 %) in Santhica 27 (Alonso-Esteban et al., 2022).

Comparison of the chemical composition of the seeds of industrial Ukrainian hemp varieties with the best ones of industrial world hemp varieties revealed that (a) the oil content in seeds of industrial Ukrainian hemp varieties Hlesiia (37.16 %), Hlukhivs`ki 51 (37.59 %), Harmoniia (38.15 %), and Artemida (38.90 %) exceeds oil content in the world varieties Finola, Anka, CFX-1, CFX-2, Katani, CRS-1, Canda, Fedora 17, Rodnik, Santhica 27, Kompolti, Bialobrzeskie, Henola, Tisza, Fibrol, and KCVirtus, listed in Table 3; (b) oil content in seeds of industrial hemp variety Artemida (the highest among the analyzed Ukrainian varieties) is 3 % higher than the oil content in seeds of industrial hemp variety CFX-1 (the highest among the analyzed world varieties); (c) the average oil content in the seeds of industrial Ukrainian hemp varieties is by 5.5 % higher than the average oil content in the seeds of industrial world hemp varieties; (d) the content of protein, fiber, and ash in Ukrainian and world hemp varieties was the same.

Mineral composition of seeds of Ukrainian industrial hemp varieties

The content of macroelements – calcium (Ca), phosphorus (P), sodium (Na), potassium (K), and magnesium (Mg) - in seeds of Ukrainian industrial hemp varieties are given in Table 4.

Table 4

Content of macroelements in seeds of Ukrainian industrial hemp varieties

Variety	Content, g/kg dry weight				
	Ca	P	Na	K	Mg
Hliana	1.72±0.09	8.81±0.21	0.06±0.002	7.77±0.31	4.09±0.15
Hlesiia	1.61±0.06	7.53±0.30	0.06±0.002	6.44±0.24	3.90±0.22
Hlukhivs`ki 51	1.94±0.10	9.07±0.25	0.05±0.003	6.23±0.22	4.33±0.20
Artemida	1,49±0,08	6.72±0.12	0.05±0.003	6.32±0.27	3.77±0.12
Harmoniia	1.58±0.05	8.25±0.29	0.07±0.002	7.36±0.31	4.12±0.17
Average value	1.67	8.08	0.06	6.82	4.04
Minimum value	1.49	6.72	0.05	6.23	3.77
Maximum value	1.94	9.07	0.07	7.77	4.33

The highest content of calcium (1.94 g/kg DW), phosphorus (9.07 g/kg DW), and magnesium (4.33 g/kg DW) was determined in seeds of Hlukhivs`ki 51 variety; sodium (0.07 g/kg DW) in Harmoniia variety, and potassium (7.77 g/kg DW) in Hliana variety. The lowest content of calcium (1.49 g/kg DW), phosphorus (6.72 g/kg DW, and magnesium (3.77 g/kg DW) was found in seeds of Artemida variety; sodium (0.05 g/kg DW) in Hlukhivs`ki 51 and Artemida varieties, and potassium (6.23 g/kg DW) in Hlukhivs`ki 51 variety. According to Awuchi et al. (2020), 100 g of industrial hemp seeds fully meet the recommended daily requirement for adults for phosphorus and 96 % for magnesium.

The content of trace elements – copper (Cu), zinc (Zn), iron (Fe), cobalt (Co), manganese (Mn), cadmium (Cd), and lead (Pb) - in seeds of Ukrainian industrial hemp varieties is shown in Table 5.

Table 5

Content of trace elements in seeds of Ukrainian industrial hemp varieties

Variety	Content, mg/kg dry weight						
	Cu	Zn	Fe	Co	Mn	Cd	Pb
Hliana	8.42 ±0.27	43.58 ±1.33	111.92 ±1.54	0.02 ±0.002	101.35 ±1.85	n.d*	0.12 ±0.002
Hlesiia	10.76 ±0.38	52.87 ±0.61	120.51 ±1.12	0.10 ±0.003	97.29 ±1.24	n.d	n.d
Hlukhivs`ki 51	13.75 ±0.41	61.21 ±0.84	104.03 ±0.98	0.06 ±0.004	89.74 ±1.15	n.d	0.07 ±0.002
Artemida	13.01 ±0.55	55.81 ±0.72	93.12 ±1.05	0.06 ±0.002	89.68 ±0.92	n.d	0.09 ±0.003
Harmoniia	17.15 ±0.60	57.88 ±0.35	101.83 ±1.21	0.08 ±0.007	101.19 ±1.19	n.d	0.11 ±0.004
Average	12.62	54.27	106.28	0.06	95.85	0	0.08
Minimum	8.42	43.58	93.12	0.02	89.68	0	0
Maximum	17.15	61.21	120.51	0.10	101.35	0	0.12

*not detected.

The highest content of trace elements in hemp seeds was found: copper (17.15 mg/kg) in Harmoniia; zinc (61.21 mg/kg) in Hlukhivs`ki 51; iron (120.51 mg/kg), cobalt (0.10 mg/kg) in Hlesiia; manganese, (101.35 mg/kg) and lead (0.12 mg/kg) in Hliana varieties. The lowest content of copper (8.42 mg/kg), zinc (43.58 mg/kg), and cobalt (0.02 mg/kg) was in the seeds of the Hliana variety, iron (93.12 mg/kg) and manganese (89.68 mg/kg) in Artemida, lead (absent) in Hlesiia. 100 g of industrial hemp seeds fully meet the recommended daily requirement (Awuchi et al., 2020) for copper; 59 % for iron, and 49 % for zinc.

Minerals are essential for the human body to maintain biochemical processes. They play a functional and structural role and are electrolytes. Phosphorus is a component of bones, cells and is important for bioenergy transformations, maintains the pH of the body. Magnesium is necessary for bones and ATP conversion, participates in muscle contraction and control of acid-base and water-salt balance (Awuchi et al., 2020; Quintaes et al., 2015). Seeds of Ukrainian industrial hemp varieties should be considered as a valuable source of minerals, especially in terms of phosphorus, magnesium, manganese, copper, zinc, and iron.

The population of many developed countries faces the problem of food contamination with toxic metals. Consumption of products with a high content of toxic metals has serious consequences for human health, as it can lead to disruption of some cellular processes due to the displacement of essential metals from the relevant biological structures. Toxic metals such as lead, cadmium, mercury, and arsenic are very common in the environment (Nedzvetsky et al., 2022). Lead damages and causes dysfunction of the kidneys, liver, reproductive, nervous, urinary, and immune systems. Cadmium toxicity is mainly manifested in organs such as the liver, kidneys, brain, lungs, and bones. Cobalt affects lung function, vision and hearing impairment. Copper, nickel, zinc and iron, on the other hand, are vital trace elements in the human body (Okereafor et al., 2020). Copper is a necessary component of various redox reactions, participates in the synthesis of collagen and elastin, the formation of hemoglobin and red blood cells. Zinc is essential for the functioning of many enzymes,

for normal sense of taste and participates in protein synthesis. Iron is necessary for the synthesis and functioning of many enzymes and proteins, in particular hemoglobin, to prevent anemia, and is involved in cellular metabolism and oxygen transport. Manganese is a cofactor of enzymes, participates in bone formation and reproductive function (Awuchi et al., 2020; Quintaes et al., 2015). However, excessive consumption of these microelements is harmful to the human body. Prolonged exposure to copper often leads to severe irritation of the mucous membranes and central nervous system, damage to capillaries, liver, and kidneys. Systemic dysfunctions that lead to impaired growth and gastrointestinal irritation are associated with an excess of zinc. The development of Parkinson's disease, changes in cardiovascular function may be associated with an excess of manganese in the body (Okereafor et al., 2020).

The mineral compositions of seeds of Ukrainian industrial hemp varieties and world varieties were compared. Seeds of industrial hemp varieties CFX-2, X-59, CRS-1, Grandi, Picolo, CFX-1, Katani, Canda, Delores and Joey grown in the USA (North Dakota) contained, mg/100 g DW: calcium, 94.12–120.60; phosphorus, 910.38–1014.30; magnesium, 430–482.14; sodium, 22.09–26.49; potassium, 727.03–866.17; iron, 10.88–13.40; manganese, 12–14.59; copper, 0.78–0.92; zinc, 9.87–11.01, and selenium, 0.28–0.30. The highest content of calcium, sodium, potassium, manganese and selenium was determined in Delores, of phosphorus and magnesium in Grandi, of iron and zinc in Joey, and of copper in X-59 varieties (Lan et al., 2019).

Seeds of Felina 32 variety grown in the Northern Europe and Baltic region contained 0.69–0.9 % potassium; 0.41–0.51 % phosphorus; 0.42–0.46 % magnesium; 0.10–0, 19 % calcium; iron, 181–334 mg/kg DW; manganese, 58–81 mg/kg DW; zinc, 55–68 mg/kg DW; copper, 13–20 mg/kg DW; boron, 7–16 mg/kg DW; aluminum, 6–12.6 mg/kg DW, and sodium, 0.9–16.1 mg/kg DW (Barcauskaitė et al, 2022).

Seeds of industrial hemp varieties Antal, Bacalmas, Fibrol, KC Dora, KC Virtus, KC Zuzana, Kompolti, Monoica, Tiborszallasi, Tisza (Hungary), Carmagnola (Italy), Chameleon (Netherlands), Dioica 88, Epsilon 88, Fedora 17, Felina 32, Ferimon FR 8194, Futura 75, Santhica 23 (France), Helena, Marina, Novosadska, Novosadska+, Simba (Serbia), Kina (China), Lovrin 110, Srcuienijubilee (Romania), Silesia, Wojko (Poland), grown in different countries contained, mg/100 g DW: calcium 70.99–177.21; magnesium, 274.66–499.90; potassium, 509.96–1182.65; iron, 5.06–32.37; manganese, 2.84–12.48; copper, 0.57–1.47, and zinc, 2.21–7.93 (Arango et al., 2024).

The mineral compositions of the seeds of world industrial hemp varieties are given in Tables 6 and 7.

Thus, the highest content of calcium (1.9 g/kg DW) was found in the seeds of industrial hemp variety Felina 32 (Barcauskaitė et al., 2022), phosphorus (10.14 g/kg DW) in Grandi, sodium (0.26 g/kg DW) in Delores (Lan et al., 2019), potassium (11.83 g/kg DW) in Fibrol, magnesium (5.00 g/kg DW) in KC Dora (Arango et al., 2024).

The average content in the seeds of world industrial hemp varieties were, mg/kg DW: copper, 11.86; zinc, 77.75; iron, 159.36; and manganese, 110.6. The highest contents of copper (20 mg/kg DW) and iron (334 mg/kg DW) were found in the seeds of the Felina 32 (Barcauskaitė et al., 2022); zinc (110.1 mg/kg DW) in Joey; manganese (145.9 mg/kg DW) in Delores (Lan et al., 2019) varieties.

Table 6

Content of macroelements in the seeds of world industrial hemp varieties

Variety	Cultivation region	Content, g/kg DW					Reference
		Ca	P	Na	K	Mg	
Delores	USA (North Dakota)	1.21	9.64	0.26	8.66	4.54	Lan et al., 2019
Grandi		1.08	10.14	0.25	8.37	4.82	
Felina 32	Northern Europe, the Baltic states	1.90	5.10	0.17	9.00	4.60	Barcauskaitė et al., 2022
KCDora	Hungary	1.19	n.d	n.d	7.44	5.00	Arango et al., 2024
Fibrol		1.14	n.d	n.d	11.83	3.75	
Helena	Serbia	1.77	n.d	n.d	7.40	4.26	
Average value		1.38	8.29	0.23	8.78	4.49	
Minimum value		1.08	5.10	0.17	7.40	3.75	
Maximum value		1.90	10.14	0.26	11.83	5.00	

n.d., not determined.

Table 7

Content of trace elements in the seeds of world industrial hemp varieties

Variety	Cultivation region	Content, mg/kg dry weight				Reference
		Cu	Zn	Fe	Mn	
Delores	USA (North Dakota)	8.5	103.2	133.9	145.9	Lan et al., 2019
Joey		8.9	110.1	134.0	135.0	
X-59		9.2	98.7	108.8	120.0	
Felina 32	Northern Europe and the Baltic states	20.0	68.0	334.0	81.0	Barcauskaitė et al., 2022
Antal	Hungary, mg/100 g	11.3	45.6	323.7	105.1	Arango et al., 2024
Tiborszallasi		10.8	53.8	116.3	124.8	
Helena	Serbia	14.7	63.3	84.6	95.5	
Novosadska		11.5	79.3	119.6	77.5	
Average value		11.86	77.75	159.36	110.6	
Minimum value		8.5	45.6	84.6	77.5	
Maximum value		20.0	110.1	334.0	145.9	

As a result of comparing the mineral composition of the studied seeds of Ukrainian industrial hemp varieties with the best samples of industrial hemp seeds of world varieties, it was found that: (a) the average content of calcium and copper in the seeds of Ukrainian industrial hemp varieties exceeded the average content of these elements in the seeds of world industrial hemp varieties by 21% and 6%, respectively. The phosphorus content in the tested Ukrainian varieties was close in value to known world varieties. The average content of such elements as sodium, potassium, magnesium, zinc, iron and manganese in the studied seeds of Ukrainian industrial hemp varieties was lower than in world varieties by 22, 10, 23.5, 33, and 13%, respectively.

Conclusions

1. The chemical composition of seeds of industrial Ukrainain hemp varietiers Hliana, Hlesiia, Hlukhivs`ki 51, Artemida, and Harmoniia was determined. The average content of moisture content was 8.31 %. The content of oil, protein, fiber, and ash were, g/100 g of dry weight: 37.38; 24.22; 34.71, and 5.15, respectively. The highest content of oil (38.90 g/100 g DW) and fiber (37.63 g/100 g DW) was determined in the seeds of Artemida variety, and the highest content of protein (25.68 g/100 g DW) and ash (5.63 g/100 g DW) was found in Hlukhivs`ki 51. The average oil content in the seeds of industrial Ukrainian hemp varieties was by 5.5% higher than the average oil content in the seeds of the known world hemp varieties.
2. The average content of macroelements in the seeds of the analyzed Ukrainian hemp varieties was, g/kg of dry weight: calcium, 1.67; phosphorus, 8.08; sodium, 0.06; potassium, 6.82, and magnesium, 4.04. The average content of trace elements in the studied seeds was, mg/kg of dry weight: copper, 12.62; zinc, 54.27; iron, 106.28; cobalt, 0.06; manganese, 95.85; lead, 0.08; cadmium was not detected. The highest content of calcium (1.94 g/kg), phosphorus (9.07 g/kg), magnesium (4.33 g/kg) and zinc (61.21 mg/kg) was in the seeds of Hlukhivs`ki 51; sodium (0.07 g/kg) and copper (17.15 mg/kg) in Harmoniia; potassium (7.77 g/kg), manganese (101.35 mg/kg) and lead (0.12 mg/kg) in Hliana; iron (120.51 mg/kg) and cobalt (0.10 mg/kg) in Hlesiia.
3. 100 g of industrial hemp seeds fully meet the recommended daily requirement of the adult human body for phosphorus, copper, and manganese, 96 % for magnesium, 59 % for iron, and 49 % for zinc. The average calcium content in the seeds of Ukrainian hemp varieties was by 21 % higher than the average calcium content in the seeds of the studied known varieties. The phosphorus content in the seeds of the analyzed Ukrainian hemp varieties was almost the same as in the seeds of known world hemp varieties. The average content of sodium, potassium, magnesium, zinc, iron, and manganese in the seeds of Ukrainian hemp varieties was lower than their average content in the known world hemp varieties.
4. Comparison of the chemical compositions of seeds of industrial Ukrainian hemp varieties with known world analogues confirmed the high value of the varieties and its great potential for application.

Acknowledgments

The authors are grateful to the staff of the Institute of Bast Crops of the National Academy of Agrarian Sciences of Ukraine for providing seed samples of industrial hemp varieties of Ukrainian selection for the study.

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Cite:

UFJ Style

Oseyko M., Sova N., Yefimov V., Petrachenko D. (2024), Chemical composition of seeds of industrial Ukrainian hemp varieties, *Ukrainian Food Journal*, 13(3), pp. 542–556, https://doi.org/10.24263/2304-974X-2024-13-3-8

APA Style

Oseyko, M., Sova, N., Yefimov, V., & Petrachenko, D. (2024). Chemical composition of seeds of industrial Ukrainian hemp varieties. *Ukrainian Food Journal*, *13*(3), 542–556. https://doi.org/10.24263/2304-974X-2024-13-3-8