月旦知識庫

Benefits and risks of consuming *Cannabis sativa* L. in food

Ewa Matyjaszczyk [a,*], Maria Śmiechowska [b]

[a] Bydgoszcz University of Science and Technology, Al. prof. S. Kaliskiego 7, 85-796, Bydgoszcz, Poland
[b] Gdynia Maritime University, ul. Morska 81-87, 81-225, Gdynia, Poland

Abstract

***Cannabis sativa* L. or hemp is a cosmopolitan, multi-purpose plant and area of its cultivation has been growing in recent years. Its public perception is influenced by potential to produce narcotic substances. However, hemp seed can be a valuable source of nutrients for humans and may be of particular interest in more sustainable food consumption patterns, including vegetarian and flexitarian diets. The paper presents benefits and risks of hemp seeds in case of their consumption in food. Low cannabinoids varieties are considered only. The biological activity of cannabinoids and related effects are considered out of scope of the study. Nutritional value of hemp seeds regarding content of amino acids is comparable to the value of egg whites and soya. Oil is a source of two essential fatty acids: linoleic acid and alpha-linolenic acid in a desirable ratio of 3:1. Hemp seeds are also a source of minerals, vitamins and carbohydrates, including fiber. The most characteristic hazardous properties of hemp are ability to accumulate toxic heavy metals and produce anti-nutritional substances. Breeding hemp to reduce the anti-nutritional compounds content may be promising in view of its growing popularity as a food source.**

Keywords: *Cannabis sativa* L., Health properties, Hemp seed, Risk, Sustainable agriculture

1. Introduction

Cannabis sativa L. or hemp has been cultivated since ancient times and has a wide range of uses. During its growth the plant can be used for phytoremediation and as a pest repellent [1,2]. After being harvested it serves among others as food, feed, as well as a raw material for obtaining fiber for clothing, paper, and technical products such as ropes, strings, and construction materials [3,4]. It can also be used for medicinal purposes, by cosmetic industry, and as a source of energy (biofuels) [5,6]. *Cannabis sativa* L. can also be a source of narcotic substances. For that reason its cultivation is regulated in many countries [7,8] and its taxonomy is based on psychoactive properties [9]. The narcotic effect is mainly related to the content of cannabinoids, especially Δ9-tetrahydrocannabinol (Δ9-THC), which has mildly addictive properties, but is also used in medicine [10].

The interest in *Cannabis* is growing. In recent years there has been a significant increase in its cultivation area worldwide. Hemp is produced on all continents. In Asia, the largest producer is China, in Europe, France, in North America, Canada, and in South America, Chile [11].

This paper attempts a narrative review of scientific articles on hemp. The focus here is on one way of use of this multi-purpose plant only - consumption by humans as food - in order to highlight related benefits and risks.

The assumption was made that legally grown, low THC *Cannabis sativa* L. varieties are used to produce food for humans [12]. Hence the risk analysis is focused on factors different that cannabinoids. Abundant literature on risks related to consumption of cannabinoids is, however, available and many reviews focus on them [13,14].

2. Nutrient content

Individual plant parts of *Cannabis sativa* L. differ in their composition in terms of quantity and quality (Table 1).

Received 17 July 2025; accepted 18 November 2025.
Available online 30 July 2026

* Corresponding author.
E-mail addresses: ewa.matyjaszczyk@pbs.edu.pl (E. Matyjaszczyk), m.smiechowska@wznj.umg.edu.pl (M. Śmiechowska).

https://doi.org/10.38212/2224-6614.3578
2224-6614/© 2025 Taiwan Food and Drug Administration. This is an open access article under the CC-BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

月日知識庫

Table 1. Nutrients and phytocannabinoid content in Cannabis sativa *L.*

Plant part	Fat	Protein	Fiber	Ash	Phytocannabinoids
Leaves	20%	24%	19%	11%	THC(0.2%); CBD(2%); CBG(0.2%)
Stem	23%	17%	17%	7%	THC(0.05%); CBD(1.8%)
Seeds	30%	20%	25%	7%	THC(0.003%); CBD(0.02%)

Abbreviations: CBD - cannabidiol; CBG - cannabigerol; THC - delta-9-tetrahydrocannabinol.
Source: Own elaboration of [16].

The data in Table 1 show that *Cannabis sativa* L. seeds contain the most fat and the least phytocannabinoids. For this reason, the part of the plant used for human consumption is almost exclusively seeds [15]. Hemp seed is an achene containing only one seed that does not split when the seeds are mature. The shelled seeds have an oval or spherical shape with green spots, a greenish-gray color, and a pleasant, nutty taste [95].

Since antiquity, hemp seeds have been consumed in China (since 2500 BC) and other regions of Asia (since approx. 500 BC) as evidenced by, among others, artifacts found in tombs [16]. Hemp seeds can be consumed whole, shelled, or processed [17,18].

3. Nutrients in *Cannabis sativa* L. seeds

3.1. Protein content and amino acid composition

The protein content in *Cannabis* seeds varies greatly depending on the variety and form of the seed. Raw seed contains 18.3–23.0% [average 20.4%] of protein, while dehulled one contains 24.6–28.4% [average 26.0%] using the conversion factor of 5.3 [14]. In the study by Franek et al. [19], the protein content in hemp seed was 22.5–26.4% [conversion factor 6.25]. In case of hemp as well as other plant raw materials the conversion factor of 5.3 may be me appropriate as plant proteins are less easily digestible than animal proteins. Hence using conversion factor of 6.25 may lead to overestimation of protein content [20].

The two main proteins in hemp seeds are albumin and edestin. Edestin is the most abundant and constitutes approximately 82% of the hemp protein content. Hemp protein contains most of the essential amino acids needed by the human body. Regarding content of amino acids the nutritional value of hemp seeds can be compared to the value of soy proteins and egg whites. Comparative analysis of hemp protein with soy protein showed that hemp proteins are rich in aspartic acid, glutamic acid, serine, arginine, and leucine. In turn, the content of exogenous amino acids isoleucine, lysine, and phenylalanine was lower in hemp protein than in soy protein [21]. Hemp protein is characterized by high arginine and phenylalanine content. The limiting amino acid in hemp protein is tryptophan [22]. Hemp protein can be considered a good source of sulfur amino acids [23,24]. Rizzo et al. [25] pointed out that the edestin protein contains aromatic amino acids, which are usually poorly represented in a vegetarian diet. Moreover, the albumin fraction contains fewer disulfide bonds, which gives the protein a less compact structure and does not inhibit trypsin, which increases digestibility. The availability and content of protein in hemp seeds also increases after roasting [26].

Xu et al. [27] evaluated hemp protein in comparison to soy, pea, whey, and egg proteins. Hemp protein contained the lowest levels of total and essential amino acids but the highest levels of arginine. Furthermore, hemp protein is characterized by a compact structure, which may explain the protein's low water absorption capacity and solubility.

3.2. Fatty acid profile of Cannabis seeds

Hemp seeds contain an average of 30% fat, but the fat content of the seeds depends on the latitude of cultivation. Research shows that it may remain within quite wide limits, from 24.3% for hemp oil grown in the USA, 26.9% for hemp oil in Pakistan and Canada, to 33.3% for hemp oil from Ukraine [24].

Pre-roasting the hemp seeds significantly affects the oil yield and linoleic acid content in the pressing process [26]. Hemp seeds provide oil containing unsaturated fatty acids such as linolenic acid and linolenic acid. It contains omega-6 and omega-3 acids in a ratio of 3:1, which is considered the most correct from a nutritional point of view [28,29]. This desirable ratio of omega-6 and omega-3 acids in *Cannabis sativa* seed oil was confirmed by research conducted in Turkey, where it was additionally shown that the geographical region may influence the composition of the oil [30]. LA and ALA are precursors of polyunsaturated fatty acids [PUFA] n-6 and n-3, biologically active arachidonic acid, docosahexaenoic acid and eicosapentaenoic acid. In a

月日知識庫

study conducted in Lithuania on the fatty acids contained in oils from *Cannabis sativa*, *Linum usitatissimum*, and *Camelina sativa*. Razmaité et al. [6] showed that all oils consisted mainly of two essential acids, namely linoleic and α-linolenic acid. In all seeds, the PUFA/SFA [saturated fatty acids] ratio was much higher than recommended in a healthy diet. The ratio was the highest in case of hemp seeds, while the lowest in linseeds.

Among omega-6 acids, attention is drawn to gamma-linolenic acid 18:3[n-6], which has been shown in studies to have anti-inflammatory effects in many diseases. As shown by Rosso et al. [31], depending on the hemp variety, the content of gamma-linolenic acid remained in the range of 0.54–1.8 g/100 g of total fatty acid content.

3.3. *Carbohydrates, including fiber, in* Cannabis *seeds*

The carbohydrate content of *Cannabis* seeds varies considerably. Callaway [32] reports that the total carbohydrate content in whole hemp seeds of the *Finola* variety was 27.6 g per 100 g of seeds. Mattila et al. [33] determined the carbohydrate content in whole hemp seeds at 34.4 ± 1.5 g/100 g. It was pointed out that the main fraction of carbohydrates is insoluble fiber, i.e., crude fiber. Fiber constitutes 98% of total carbohydrates and the remainder is starch [33]. The high content of insoluble fiber in hemp seeds is reported by Vonapartis et al. [34] at 35.7 g/100 g, with most of the IDF found in the hemp seed husk.

The significant variation in carbohydrate content of hemp reported by the literature is influenced by a number of factors, including the variety, location and growing conditions, as well as the form of the seed, i.e. whether the seed is with or without a husk. It is also worth to keep in mind that carbohydrate content is influenced by other components e.g. the variation in oil content affects carbohydrate composition [33].

3.4. *Vitamins in* Cannabis sativa *seeds*

In addition to the extremely rich composition of fatty acids, hemp seeds contain as well unsaponifiable fractions, which include tocopherols, and phytosterols. The most common isomer of tocopherol, namely γ-tocopherol ensures high oxidative stability of hemp seeds, especially their oil, while the α isomer is considered to be the only bioactive form of tocopherol, i.e., the form showing vitamin E activity in the human body [17], α-tocopherol and δ-tocopherol isomers occur in smaller amounts in hemp seeds. Research conducted by various authors indicate diverse content of tocopherols in hemp seeds. This diversity may be due to various factors such as the influence of seed genotype, year of cultivation, geographical origin, and extraction method [34]. In addition to tocopherols and vitamin E, *Cannabis sativa* oil contains vitamin A and carotenoids [which can be converted to vitamin A in human body]. The content of vitamins E and A in hemp seed oil was determined to be 56.28–92.97 and 7.8 mg/100 g, respectively [35].

3.5. *The content of mineral substances in* Cannabis sativa

Hemp seeds are a good source of minerals [32,35]. The content of microelements and macroelements in hemp seeds can vary within a wide range of 4–7.6%. Studies on the mineral composition of hemp seeds conducted by Montero et al. [35] show that the content of individual elements can remain in a wide range, which may be influenced by the hemp variety and the place of cultivation. Rizzo et al. [25] pointed out that *Cannabis sativa* seeds provide elements such as calcium, iron and zinc, which play an important role in the diet, especially in diets that exclude animal products. The content of minerals in whole and shelled hemp seeds may also vary. Alonso-Esteban et al. [17] showed that whole hemp seeds have higher Ca, Mn, and Cu contents than shelled seeds, while shelled hemp seeds have higher P, K, Mg, and Zn contents than whole seeds. However, the iron content was almost the same in whole and shelled hemp seeds. In the study by Siano et al. [36] all macroelements had a higher content in flour than in seeds. *Fedora* seed flour contained more calcium, potassium, and magnesium than the grain. The content of trace elements: Fe, Mn, Zn, and Cu was also higher in hemp flour. The above-cited authors explain that the varying mineral content in hemp seeds results from factors such as plant variety, soil conditions, and year of cultivation. As showed by Barčauskaitė et al. [37], the content of macro and microelements in hemp seeds is also influenced by sowing density and intensity of fertilization.

4. The use of raw materials from hemp in food production and dietary supplements

In recent years, a rapid development of the market for products obtained from hemp seeds is observed. One of the key factors that sparked the increased interest in *Cannabis sativa* L. was the search for alternative sources of protein. This is influenced by changes in the human nutrition

月日知識庫

model, an increase in consumer interest in plant-based, vegan, and vegetarian diets, or diets with a predominance of plants, as is the case in semi-vegetarian diets, which are associated with limiting the consumption of animal protein. The products obtainable from hemp seeds are presented in Table 2.

Hemp seeds have great potential and can be used in various branches of food and non-food industries [3]. A number of processes used in food technology affect the properties and composition of hemp seeds. Liu et al. [38] demonstrated that hemp seed germination improves the functional properties of protein, increasing the hardness of hemp seed gels. Aloo et al. [39] demonstrated that not only germination but also the fermentation process improves the functional properties of hemp seeds. Germination and fermentation affect the levels of anti-nutritional substances such as tannins, saponins, acid, and trypsin inhibitors [39].

The nutritional value of hemp seeds is positively influenced by roasting, which has already been used in ancient times [25]. In recent years, the seed roasting process has undergone significant innovations, resulting in new attractive products, such as hemp seeds roasted with sea salt. Roasted hemp seeds can also be combined with other food products such as blueberries, barberries, sour cherries, mulberries, cranberries, vanilla, cocoa, and figs to create new snack products [35].

Another product obtained from hemp seeds that arouses great interest is hemp flour. Comparative studies show that hemp flour has a higher nutritional value and higher content of protein, fat, minerals, fiber, essential fatty acids, and essential amino acids than wheat flour [40]. Moreover, hemp flour does not contain gluten, therefore it does not cause related food allergies and is safe for people with celiac disease. Studies have shown that hemp protein isolates do not contain thaumatin-like proteins with allergenic properties, which allows their use as a hypoallergenic food ingredient. Guided by these advantages of hemp flour, it was used, among others, for making pasta. It has been shown that the addition of 30–40% hemp flour to durum wheat flour improves the physicochemical properties, texture parameters, and sensory properties of pasta [41]. Bonacci et al. [42] showed that the rheological and sensory quality, as well as nutritional value of pasta made with hemp flour is influenced not only by the size of the addition, but also by the grinding degree of the flour. Similar conclusions were drawn by Mikulec et al. [43] as regards baking bread.

In addition to bread and pasta, there are various snacks, desserts, bars, muesli and granola with the addition of hemp seeds, drinks, milk, chocolate, sweets and confectionery products, meat substitute, and sprouts [44].

Bukowska [45], Trovato et al. [46] and Kamle et al. [47] indicated that hemp seed products can be classified as healthy foods because they contain many bioactive compounds, such as polyphenols and vitamins. They also stressed as desirable the content of secondary metabolites such as terpenes, phytosterols, tocopherols, and cannabinoids.

Numerous research studies show that hemp seeds have nutraceutical potential. Studies have shown that hemp oil can be helpful in the treatment of skin diseases, cardiovascular diseases, diabetes, rheumatoid arthritis and reduces the risk of cancer [28,45]. Hemp seed oil also contains gamma-linolenic acid, which is beneficial in preventing osteoporosis [48,49]. Therapeutic results in the treatment of central nervous system diseases such

Table 2. Products obtained from Cannabis sativa *seeds.*

Product	Usage	Source
Whole grain	Product intended for consumption after roasting	Cerino et al. [18]; Montero et al. [35]; Babiker et al. [26]
Hemp flour	Product intended for the production of bread, bakery products, pasta	Mikulec et al. [43]
Hemp oil	Cold-pressed oil, intended for direct consumption	Oseyko et al. [24]; Razmaité et al. [6]
Seed cake (residue after oil pressing]	Intended for food production and feed	Tufarelli et al. [99]; Kasula et al. [92]
Dietary fiber	Intended for the production of functional food and dietary supplements	Callaway [32]; Mattila et al. [33]; Montero et al. [35]; Siano et al. [36]; Teterycz et al. [41]; Vonapartis et al. [34]
Hemp Protein	Food enrichment and vegetarian food	Alonso-Esteban et al. [17]; Franek et al. [19]; Absi et al. [23]; Oseyko et al. [24]; Rizzo et al. [25]; Wang et al. [21]; Kotecka-Majchrzak et al. [94]
Hemp seed husk isolates	Source of lignoamides, protein, and polyphenols	Kim et al. [93]

Source: Own study.

月日知識庫

as epilepsy, neurodegenerative diseases, and multiple sclerosis are promising [47,50]. The studies of Pinto and Martel [51] confirm anti-obesity effects of cannabidiol. They also believe that the high content of insoluble dietary fiber in hemp seeds and flour has a functional role influencing food digestibility, prevents obesity, reduces appetite, lowers cholesterol and low-density lipoprotein (LDL) levels. On the other hand Rogers et al. [52] studied use cannabis-infused food products in the treatment of anorexia.

Fig. 1 shows the potential health effects of consuming *Cannabis sativa* L. hemp seeds and their products. It is however worth stressing that not all the effects of *Cannabis sativa* L. shown in Fig. 1, are based on clinical trial results. For clearer distinction the effects based on clinical trials are marked by grey colour.

5. Safety issues related to *Cannabis sativa* L. consumption

Among the factors that may pose risk for humans consuming hemp, heavy metals, pesticides, as well as microorganisms and mycotoxins are frequently mentioned in the literature [53–55]. In addition the seeds contain anti-nutritional compounds.

There are also other threats, such as the presence of THC higher than 0.3%, due to contamination with seeds of different varieties or cannabinoid contamination. Cannabinoid contamination may result from contact with the resin secreted by trichomes during harvest, or cleaning of seeds. Processing hemp must therefore be controlled. Analytical techniques already exist that enable rapid and sensitive methods for detecting cannabinoids [9].

5.1. Presence of anti-nutritional compounds in hemp seeds

While discussing use of *Cannabis sativa* L. in food, it is necessary to stress certain anti-nutritional compounds that may negatively affect its value as a food product. Antinutritional compounds bind to nutrients, causing a decrease in their bioactivity, reduce protein digestibility and mineral utilization [56]. Antinutritional compounds include phytic acid, condensed tannins, saponins, cyanogenic glycosides, and trypsin inhibitors [57]. Phytic acid is a natural compound found in plants. However, the high content of phytates in hemp seeds may limit the bioavailability of P, Fe, Mg, Zn, Mn, and Cu by forming complexes with these elements. They also affect the activity of digestive enzymes. Therefore phytic acid and other phytates have long been considered antinutritional compounds. The phytic acid content in hemp seeds ranges from 4.5 to 7.6 g/100 g of dry, defatted matter [58]. Matila et al. [59] showed that the phytic acid content in hemp seeds is on average 5.3 g/100 g. To reduce the adverse effects of phytic acid contained in *Cannabis sativa*, soaking, germination, fermentation, cooking, extrusion, dehulling, radiation and ultrasound techniques are used [60]. However, recent research indicates that phytic acid may have beneficial effects on the body. Phytic acid has been shown to have anti-inflammatory, antiviral, and antibacterial properties, as well as antidiabetic properties. Phytic acid has free radical scavenging properties, and

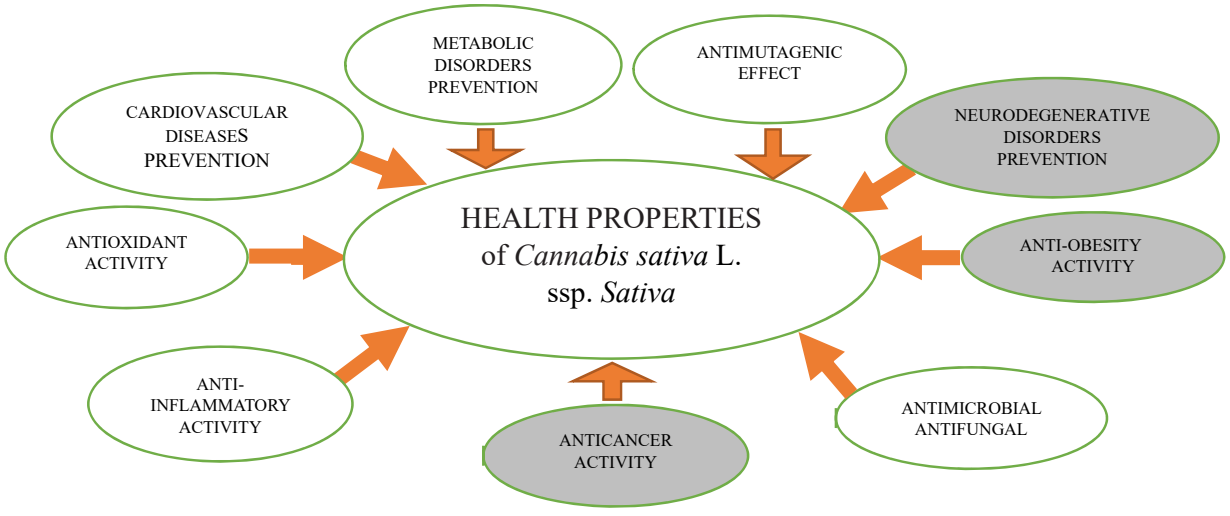

Fig. 1. Health properties of Cannabis sativa *L. Effects based on clinical trials are marked by grey color. Source: Own study based on [28,45–52].*

月日知識庫

research is underway to use it in cancer and neurodegenerative diseases [61].

Condensed tannins, also known as proanthocyanidins, form complexes that are insoluble together with proteins and minerals. Tannins are phenolic compounds that have a positive impact on health by acting as antioxidants, anticancer, cardioprotective, antimicrobial and antidiabetic compounds [62]. Following Cosme et al. [63] the content of condensed tannins in hemp seeds ranged from 88.6 to 13.8 mg/g in terms of catechin equivalents.

Trypsin inhibitors are commonly found in seeds of *Brassicaceae, Solanaceae, Fabaceae* and *Poaceae* plants. They limit the utilization of proteins in food by blocking the proteolytic enzymes trypsin and chymotrypsin. Trypsin inhibitors also adversely affect the digestion of peptides and proteins in the small intestine. Their content in hemp seeds depends on various factors such as variety and genotype, cultivation conditions and is in the range from 10.8 to 27.8 of enzymatic activity units per mg of defatted flour [58].

Cyanogenic glycosides are secondary metabolites produced by plants as pests protective substances. They are classified as toxic to humans because, under unfavorable conditions, they may undergo hydrolysis in the gastrointestinal tract, which ultimately leads to the release of hydrogen cyanide. It is believed that in concentrations below 100 ppm they are not harmful to the human body. However, their content varies significantly depending on the genotype and variety [64].

Saponins include glycoside compounds containing non-sugar steroid or triterpenoid aglycone. They have an irritating effect on the stomach and may have toxic properties that cause hemolysis of red blood cells. Due to the toxic effects, FAO/WHO proposed limits for the saponin content in quinoa (*Chenopodium quinoa* Willd.) to 0.12%. Quinoa contains the most saponins among other seeds and grains, such as linseed or soybean [65]. The amount of saponins in hemp seed flour can vary greatly owing to numerous factors [64,66]. Tasie et al. [67] determined the content of saponins in three non-defatted and defatted varieties of industrial hemp seeds. The saponin content for non-defatted seeds was in the range of 0.16–0.18 g/100 g, and in defatted seeds 0.18–0.20 g/100 g.

In the future, it may appear possible to reduce or eliminate the content of certain anti-nutrients mentioned above through breeding methods. Such a direction in hemp breeding may be promising in view of its growing popularity as a food source.

5.2. Microorganisms and mycotoxins

Cannabis sativa L. is associated with various epiphytic as well as endophytic microbial communities. This includes organisms that may potentially pose a threat to human health. Some of the bacteria species inhabiting *Cannabis* are opportunistic human pathogens [e.g. *Escherichia coli, Salmonella* sp., *Listeria* sp.]. Among fungi identified in *Cannabis* are species with both the ability to cause human infections as well as produce mycotoxins. Fungi such as *Aspergillus* sp., *Fusarium* sp., and *Penicillium* sp. that were found in *Cannabis*, are potentially infectious to humans (in particular for groups with compromised immune system) and at the same time a potential source of mycotoxins [53,68].

Microorganisms may be eliminated or neutralised during the process of food preparation, however some of them may survive and pose risks, in particular for vulnerable groups of consumers. On the other hand, mycotoxins generally survive food processing as they are chemically stable. Production of mycotoxins can occur either before harvest or during storage of harvested seeds, in particular while drying and storing in humid environments. The long-term effects of mycotoxins occurring in food may include the induction of cancers and immune deficiency [69].

Several *Fusarium* species were isolated from hemp seeds, some of which were found in the seeds and some on the seed surface [70]. Mycotoxins produced by *Fusarium* species include deoxynivalenol, zearalenone, fumonisin B and T-2. Mycotoxins were also detected in hemp flour, with more toxins in flour stored in plastic packaging than in a paper bag. Sacco et al. [71] found that hemp flour contained four times more mycotoxins than wheat flour.

5.3. Pesticides

There are harmful organisms that may affect hemp production [72] and pesticides may be used to control them. It is generally considered that detection of pesticides below maximum residue levels [MRL] confirms their use in the food chain, while detection residues above MRL may mean incorrect application and risk to consumers [73]. Pesticides residues are mentioned as potentially hazardous compounds detected in *Cannabis sativa* L. [54]. Arena et al. [74] showed presence of pesticides above MRL in four out of ten analyzed samples of hemp seed oil. The remaining samples [six out of ten] showed no detectable levels of pesticide residues.

月日知識庫

It is worth stressing that pesticide residues are present in numerous plants [75,76] and the ability to accumulate pesticide residues although worth noting may not be a characteristic specific to hemp. On the other hand, hemp is known in agronomy as a plant with potential to inhibit growth of certain weeds and produce pests repelling substances, as well as potential source of biopesticides. In horticulture hemp is known to be introduced to the gardens in order to inhibit the growth of soil nematodes and repel pests from the neighbouring plants of different species enabling elimination or reduced use of pesticides [2,77]. It is therefore possible that compounds produced by hemp may have potential to be commercialized for use in plant protection as biopesticides [78]. The protective substances produced by hemp against pests may influence its value as food source and were discussed above as anti-nutritional compounds.

5.4. Heavy metals

Cannabis have deep root system and through it is able to absorb and accumulate various elements from the soil. This includes toxic heavy metals, as well as other elements of potential toxicity for humans. According to the available literature, cannabis can absorb among others lead, cadmium, mercury, arsenic, antimony, tin, selenium, strontium, bismuth, titanium, nickel, chromium, as well as cobalt [1,79]. The absorption level depends on a number of factors including concentration in the soil, type of soil, fertilization level, and the *Cannabis* variety. The concentration of heavy metals and other toxic element in the plant organs and tissues differs. Some studies show quite high content of heavy metals in the plant parts that could be potentially consumed by humans [80]. According to Flajšman *et al* [79], Golia *et al* [81] and Ćaćić et al. [82] heavy metals bioaccumulate mainly in the underground part, while the stem, leaves and seeds contain lower concentration of pollutants. Zafeiraki et al. [83] and Gauvin et al. [84] report that higher concentrations of Cd are found in leaves than in seeds. Considering the literature, it is not unlikely that the *Cannabis* plant parts consumed by humans as food may contain elevated levels of toxic elements. It seems that two heavy metals - lead and cadmium - may be of particular concern. The reason is their high toxicity for humans as well as the fact that both are accumulated by edible parts of *Cannabis*.

However the data on heavy metals in hemp available in the literature often come from the studies focused on phytoremediation potential of *Cannabis* and/or accumulation of elements in the plant parts. Consequently, many samples come from plants grown on wastelands, near abandoned mines or other areas known to be contaminated and not intended for food production, rather than from land in agricultural use. The use of such data in the context of food safety may lead to an overestimation of health risk scenarios.

The data on the content of toxic elements coming from *Cannabis* grown in laboratory conditions on a substrate very high in heavy metals, or on agricultural soil purposefully enriched with toxic elements shall be not considered for risk assessment as unrealistic. The concentration levels of lead and cadmium coming from the samples collected in the areas known to be polluted, but still used as agricultural land, may give an indication regarding the worst-case scenario. Such approach was used in other works on risk assessment of heavy metals in plants consumed by human and possessing the ability to accumulate toxic elements [85,86].

What are the maximum levels of cadmium and lead as food contaminants? According to WHO guidelines on quality of herbal medicines and products [87], the limits are 0.3 mg/kg dry weight for cadmium and 10 mg/kg dry weight for lead. The European Union Commission Regulation 2023/915 sets the maximum levels of metals in food for different groups of products. *Cannabis* seeds are not mentioned, however, it seems that regarding the pattern of use of hemp seeds the levels set for cereals (0.1 mg/kg wet weight for cadmium and 0.2 mg/kg wet weight for lead) may be relevant [88].

A number of studies performed on *Cannabis* as agricultural crop, where results come from fields in agricultural use, report heavy metals concentration below detection level or no risk for the population exposed to *Cannabis* [83,89–91].

Table 3 presents study results focused on the food chain where cadmium and/or lead were detected in *Cannabis*. In case of studies focused on agricultural production the area of production was known. For studies on herbs the exact area of production was usually not known, however the samples were bought on local markets as intended for human consumption. While analysing Table 3, differences in content of heavy metals can be observed. The highest content of cadmium was noted in the samples of leaves from Ethiopia, while the highest content of lead in plants bought in India. While considering seeds only the highest cadmium concentration was noted in samples from Romania, while the highest lead concentration was detected in Greece. The studies reporting samples with

月日知識庫

Table 3. Content of cadmium and lead in edible parts of Cannabis sativa *L. in studies focused on food chain.*[a]

Content mg/kg dry weight[a]	Plant Part	Area	Source	Remarks
Cd 0.012–0.431[b] Pb 0.095–1.752	Leaves	Greece	Zafeiraki [83]	The study showed that leaves accumulate more trace elements than seeds of the same sample, regardless of the field location and cannabis variety.
Cd 0.007–0.113 Pb 0.019–0.462	Seeds			
Cd 0.0135 ± 0.0007 Pb 0.4018 ± 0.0173	Mature fruits, collected from wild plants	China	Fu et al. [91]	
Cd 0.56 ± 0.13[b] Pb 6.32 ± 0.50	Uspecified plant parts intended for human consumption as herbs	Purchased from the local markets of Iran	Moghaddam et al. [98]	
Cd 3–10[b] Pb 8–10	Leaves	Ethiopia	Zerihun et al. [100]	
Cd 0.01–2.10[b] Pb 13.00–54.47[b]	Unspecified plant parts intended for human consumption as herbs	Bought at local market of Lucknow, India	Kumar et al. [96]	
Cd 0.005–0.023 Pb Below detection level	Seeds	North-western Turkey	Korkmaz et al. [90]	
Cd 1.3–4.0[b]	Seeds	Romania	Mihoc et al. [97]	

[a] Study results reporting concentration of Cd and Pb below detection level in all analyzed samples are not presented.
[b] One or more samples containing Cd or Pb above WHO limits (World Health Organization, 2007] were found in this study.
Source: Own study.

content of cadmium or lead exceeding the limits set by WHO were marked in the Table 3 with letter 'b'.

Based on data presented in Table 3 it may be concluded that for hemp seeds consumed in food the content of heavy metals, in particular cadmium and lead may be potentially of concern. Therefore, it seems that additional studies focused on heavy metals in *Cannabis sativa* consumed in food may be useful. Furthermore, in order to assess the health risks associated with contaminants in *Cannabis sativa*, data on the consumption of cannabis in food are needed. To date, such data are lacking in the literature. For this reason, preparing quantitative risk-benefit model with contaminants in *Cannabis sativa* requires further research.

6. Conclusions

The rapid growth observed in recent years in the market for products derived from hemp seeds can be linked to their interesting properties, as well as to the growing consumer interest in vegetarian and flexitarian diets. Hemp seeds present high nutritional value. They contain proteins with amino acid profile comparable to egg whites and soya. Hemp oil is a source of two essential fatty acids: linoleic acid and alpha-linolenic acid in desirable ratio of 3:1. Hemp seeds contain also carbohydrates, including fiber, minerals and vitamins.

Consumption of *Cannabis* seed may have positive health effects that include anticancer and antimutagenic effects, obesity prevention, antioxidant and anti-inflammatory effects as well as prevention of cardiovascular diseases.

Pesticides as well as mycotoxins are mentioned in the literature among the factors that may pose risk for humans consuming hemp. Those contaminants may however occur in numerous plants. A hazardous characteristic of hemp is its ability to absorb toxic heavy metals from the soil. Consequently, hemp seeds may contain elevated levels of heavy metals, in particular cadmium and lead. In addition, the seeds contain anti-nutritional compounds produced by the plant that include inhibitors of trypsin, condensed tannins, phytic acid, saponins, and cyanogenic glycosides.

The risks associated with consuming hemp in food can be reduced in various ways. Cultivation of hemp intended for human consumption only in the fields where the level of heavy metals is known to be safe seems quite an effective tool to address the risk regarding heavy metals. There is also significant potential in breeding. As regards hemp intended for human and possibly also for animal consumption breeding could be focused on development low-accumulation varieties as well as of varieties that enhance nutritional benefits while producing fewer anti-nutritional compounds.

月日知識庫

The increase in production and, consequently, the availability of hemp-based food products on the market may be associated with a number of problems, including issues related to the supply chain, economic feasibility and the harmonisation of regulations around the world. There appear to be no technical obstacles to increase agricultural production. As regards its soil and climate requirements, hemp can be cultivated and indeed be a useful addition to crop rotation in many countries around the world. It therefore seems that a more harmonised regulatory environment may be crucial for the popularisation of this plant.

Conflict of interest

We have no conflict of interest.

References

[1] Milan J, Michalska A, Jurowski K. The comprehensive review about elements accumulation in industrial hemp (Cannabis sativa L.). Food Chem Toxicol 2024;184:114344. https://doi.org/10.1016/j.fct.2023.114344.

[2] Ona G, Balant M, Bouso JC, Gras A, Vallès J, Vitales D, et al. The use of Cannabis sativa L. for pest control: from the ethnobotanical knowledge to a systematic review of experimental studies. Cannabis Cannabinoid Res 2022;7(4):365–87. https://doi.org/10.1089/can.2021.0095.

[3] Raihan A, Bijoy TR. A review of the industrial use and global sustainability of Cannabis sativa. Glob Sustain Res 2023;2:1–29. https://doi.org/10.56556/gssr.v2i4.597.

[4] Ahmed ATMF, Islam MZ, Mahmud MS, Sarker ME, Islam MR. Hemp as a potential raw material toward a sustainable world: a review. Heliyon 2022;8(1):e08753. https://doi.org/10.1016/j.heliyon.2022.e08753.

[5] Xie Z, Mi Y, Kong L, Gao M, Chen S, Chen W, et al. Cannabis sativa: origin and history, glandular trichome development, and cannabinoid biosynthesis. Horticulture Research 2023;10. https://doi.org/10.1093/hr/uhad150. uhad150.

[6] Razmaité V, Pileckas V, Bliznikas S, Šiukščius A. Fatty acid composition of Cannabis sativa, Linum usitatissimum and Camelina sativa seeds harvested in Lithuania for food use. Foods 2021;10:1902. https://doi.org/10.3390/foods10081902.

[7] Crowley R, Cline K, Hilden D, Beachy M. Regulatory framework for cannabis: a position paper from the American College of Physicians. Ann Intern Med 2024;177. https://doi.org/10.7326/M24-0638.

[8] Sevigny EL, Greathouse J, Medhin DN. Health, safety, and socioeconomic impacts of cannabis liberalization laws: an evidence and gap map. Campbell Systematic Reviews 2023;19:e1362. https://doi.org/10.1002/cl2.1362.

[9] Small E. Evolution and classification of Cannabis sativa (mari¬juana, hemp) in relation to human utilization. Bot Rev 2015;81(3):189–294. https://doi.org/10.1007/s12229-015-9157-3.

[10] Hoch E, Volkow ND, Friemel CM, Lorenzetti V, Freeman TP, Hall W. Cannabis, cannabinoids and health: a review of evidence on risks and medical benefits. Eur Arch Psychiatr Clin Neurosci 2025;275:281–92. https://doi.org/10.1007/s00406-024-01880-2.

[11] Süzerer V, Tilkat E, Onay A, Fidan M. Industrial hemp seed: production, chemical content and potential uses for human nutrition. Türk Bilimsel Derlemeler Dergisi 2023;16(1):29–53. https://derleme.gen.tr/index.php/derleme/article/view/455.

[12] European Commission. EU Plant Variety Database, Plant variety catalogues, databases & information systems, common catalogue of varieties of agricultural plant species – consolidated version 27.01.2023 [Internet]. Brussels: European Commission; [cited 2025 Jul 17). Available from: https://food.ec.europa.eu/plants/plant-reproductive-material/plant-variety-catalogues-databases-information-systems_en.

[13] Massey ZB, Hammond D, Froeliger B. A systematic review of cannabis health warning research. Prev Med Rep 2024;37:102573. https://doi.org/10.1016/j.pmedr.2023.102573.

[14] Solmi M, De Toffol M, Kim JY, Choi MJ, Stubbs B, Thompson T, et al. Balancing risks and benefits of cannabis use: umbrella review of meta-analyses of randomised controlled trials and observational studies. BMJ 2023;382:e072348. https://doi.org/10.1136/bmj-2022-072348.

[15] Burton RA, Andres M, Cole M, Cowley JM, Augustin MA. Industrial hemp seed: from the field to value-added food ingredients. J Cannabis Res 2022;4:45. https://doi.org/10.1186/s42238-022-00156-7.

[16] Martinez V, De-Hond AI, Borelli F, Capasso R, del Castillo MD, Abalo R. Cannabidiol and other non-psychoactive cannabinoids for prevention and treatment of gastrointestinal disorders: useful nutraceuticals? Int J Mol Sci 2020;21:3067. https://doi.org/10.3390/ijms21093067.

[17] Alonso-Esteban JI, Pinela J, Ćirić A, Calhelha RC, Soković M, Ferreira ICFR, et al. Chemical composition and biological activities of whole and dehulled hemp (Cannabis sativa L.) seeds. Food Chem 2022;374:131754. https://doi.org/10.1016/j.foodchem.2021.131754.

[18] Cerino P, Buoneraba C, Cannazza G, D'Aria J, Ottoni E, Fulgione A, et al. A review of hemp as food and nutritional supplement. Cannabis Cannabinoid Res 2021;6(1). https://doi.org/10.1089/can.2020.0001.

[19] Franek D, Kasprowicz-Potocka M, Zaworska-Zakrzewska A. The chemical composition, nutritional value, and potential use of Cannabis sativa L. seeds in animal nutrition. Anim Sci Genet 2022;18(1):33–44. https://doi.org/10.5604/01.3001.0015.7906.

[20] Park S, Church D, Schutzler S, Azhar G, Il-Young, Ferrando A, et al. Metabolic evaluation of the dietary guidelines' ounce equivalents of protein food sources in young adults: a randomized controlled trial. J Nutr 2021;151(5):1190–6. https://doi.org/10.1093/jn/nxaa401.

[21] Wang X-S, Tang C-H, Yang X-Q, Gao W-R. Characterization, amino acid composition and in vitro digestibility of hemp (Cannabis sativa L.) proteins. Food Chem 2008;107:11–8. https://doi.org/10.1016/j.foodchem.2007.06.064.

[22] Chen H, Xu B, Wang Y, Li W, He D, Zhang Y, et al. Emerging natural hemp seed proteins and their functions for nutraceutical applications. Food Sci Hum Wellness 2023;12:929–41. https://doi.org/10.1016/j.fshw.2022.10.016.

[23] Absi Y, Revilla I, Vivar-Quintana AM. Commercial hemp (Cannabis sativa subsp. sativa) proteins and flours: nutritional and techno-functional properties. Appl Sci 2023;13:10130. https://doi.org/10.3390/app131810130.

[24] Oseyko M, Sova N, Lutsenko M, Kalyna V. Chemical aspects of the composition of industrial hemp seed products. Ukr Food J 2019;8(3):544–59. https://nuft.edu.ua/doi/doc/ufj/2019/3/11.pdf.

[25] Rizzo G, Storz MA, Calapai G. The role of hemp (Cannabis sativa L.) as a functional food in vegetarian nutrition. Foods 2023;12:3505. https://doi.org/10.3390/foods12183505.

[26] Babiker EE, Uslu N, Al Juhaimi F, Ahmed IAM, Ghafoor K, Özcan MM, et al. Effect of roasting on antioxidative properties, polyphenol profile and fatty acids composition of hemp (Cannabis sativa L.) seeds. LWT 2021;139:110537. https://doi.org/10.1016/j.lwt.2020.110537.

[27] Xu Y, Sismour E, Britland JW, Sellers A, Abraha-Eyob Z, Yousuf A, et al. Physicochemical, structural, and functional properties of hemp protein vs. several commercially available plant and animal proteins: a comparative study.

月日知識庫

ACS Food Sci Technol 2022;2(10):1672–80. https://doi.org/10.1021/acsfoodscitech.2c00250.
[28] Bishehkolaei M, Pathak Y. Influence of omega n-6/n-3 ratio on cardiovascular disease and nutritional interventions. Hum Nutr Metab 2024;37:200275. https://doi.org/10.1016/j.hnm.2024.200275.
[29] Hossain L, Whitney K, Simsek S. Hemp seed as an emerging source of nutritious functional ingredients. Crit Rev Food Sci Nutr 2025. https://doi.org/10.1080/10408398.2025.2534839.
[30] Aytaç E. An ideal fatty acid composition for human health: hemp (Cannabis sativa L.) seed. Chem Rep 2021;3(1):188–94. https://doi.org/10.25082/CR.2021.01.003.
[31] Rosso E, Armone R, Costale A, Meineri G, Chiofalo B. Hemp seed (Cannabis sativa L.) varieties: lipids profile and antioxidant capacity for monogastric nutrition. Animals (Basel) 2024;14(18):2699. https://doi.org/10.3390/ani14182699.
[32] Callaway JC. Hempseed as a nutritional resource: an overview. Euphytica 2004;140:65–72. https://doi.org/10.1007/s10681-004-4811-6.
[33] Mattila P, Mäkinen S, Eurola M, Jalava T, Pihlava JM, Hellström J, et al. Nutritional value of commercial protein-rich plant products. Plant Foods Hum Nutr 2018;73:108–15. https://doi.org/10.1007/s11130-018-0660-7.
[34] Vonapartis E, Aubin M-P, Seguin P, Mustafa AF, Charron J-B. Seed composition of ten industrial hemp cultivars approved for production in Canada. J Food Compos Anal 2015;39:8–12. https://doi.org/10.1016/j.jfca.2014.11.004.
[35] Montero L, Ballesteros-Vivas D, Gonzalez-Barrios AF, Sánchez-Camargo AdP. Hemp seeds: nutritional value, associated bioactivities and the potential food applications in the Colombian context. Front Nutr 2023;9:1039180. https://doi.org/10.3389/fnut.2022.1039180.
[36] Siano F, Moccia S, Picariello G, Russo GL, Sorrentino G, Di Stasio M, et al. Comparative study of chemical, biochemical characteristic and ATR-FTIR analysis of seeds, oil and flour of the edible fedora cultivar hemp (Cannabis sativa L.). Molecules 2019;24:83. https://doi.org/10.3390/molecules24010083.
[37] Barčauskaitė K, Žydelis R, Ruzgas R, Bakšinskaitė A, Tilvikienė V. The seeds of industrial hemp (Cannabis sativa L.): a source of minerals and biologically active compounds. J Nat Fibers 2022;19(16):13025–39. https://doi.org/10.1080/15440478.2022.2084486.
[38] Liu M, Childs M, Loos M, Taylor A, Smart LB, Abbaspourrad A. The effects of germination on the composition and functional properties of hemp seed protein isolate. Food Hydrocoll 2023;134:108085. https://doi.org/10.1016/j.foodhyd.2022.108085.
[39] Aloo SO, Park S, Oh D-H. Hemp seed: nutritional quality and potential functionality in food systems. Food Chem 2023;428:136722. https://doi.org/10.1016/j.foodchem.2023.136722.
[40] Rusu IE, Marc (Vlaic RA, Mureşan CC, Mureşan AE, Filip MR, Onica BM, et al. Advanced characterization of hemp flour (Cannabis sativa L.) from Dacia Secuieni and Zenit varieties, compared to wheat flour. Plants 2021;10:1237. https://doi.org/10.3390/plants10061237.
[41] Teterycz D, Sobota A, Przygodzka D, Łysakowska P. Hemp seed (Cannabis sativa L.) enriched pasta: physicochemical properties and quality evaluation. PLoS One 2021;16(3):e0248790. https://doi.org/10.1371/journal.pone.0248790.
[42] Bonacci S, Di Stefano V, Sciacca F, Buzzanca C, Virzi N, Argento S, et al. Hemp flour particle size affects the quality and nutritional profile of the enriched functional pasta. Foods 2023;12(4):774. https://doi.org/10.3390/foods12040774.
[43] Mikulec A, Kowalski S, Sabat R, Skoczylas Ł, Tobaszewska M, Wywrocka-Gurgul A. Hemp flour as a valuable component for enriching physicochemical and antioxidant properties of wheat bread. LWT 2019;102:164–72. https://doi.org/10.1016/j.lwt.2018.12.028.
[44] Aloo SO, Mwiti G, Ngugi NW, Oh DH. Uncovering the secrets of industrial hemp in food and nutrition: the trends, challenges, and new-age perspectives. Crit Rev Food Sci Nutr 2022;28:1–20. https://doi.org/10.1080/10408398.2022.2149468.
[45] Bukowska B. Current and potential use of biologically active compounds derived from Cannabis sativa L. in the treatment of selected diseases. Int J Mol Sci 2024;25:12738. https://doi.org/10.3390/ijms252312738.
[46] Trovato E, Arena K, La Tella R, Rigano F, Laganà Vinci R, Dugo P, et al. Hemp seed-based food products as functional foods: a comprehensive characterization of secondary metabolites using liquid and gas chromatography methods. J Food Compos Anal 2023;117:105151. https://doi.org/10.1016/j.jfca.2023.105151.
[47] Kamle M, Mahato DK, Sharma B, Gupta A, Shah AK, Mahmud MMC, et al. Nutraceutical potential, phytochemistry of hemp seed (Cannabis sativa L.) and its application in food and feed: a review. Food Chem Adv 2024;4:100671. https://doi.org/10.1016/j.focha.2024.100671.
[48] VanDolah HJ, Bauer BA, Mauck KF. Clinicians' guide to cannabidiol and hemp oils. Mayo Clin Proc 2019;94(9):1840–51. https://doi.org/10.1016/j.mayocp.2019.01.003.
[49] O'Sullivan SE, Jensen SS, Nikolajsen GN, Bruun HZ, Bhuller R, Hoeng J. The therapeutic potential of purified cannabidiol. J Cannabis Res 2023;5:21. https://doi.org/10.1186/s42238-023-00186-9.
[50] Crescente G, Piccolella S, Esposito A, Scognamiglio M, Fiorentino A, Pacifico S. Chemical composition and nutraceutical properties of hempseed: an ancient food with actual functional value. Phytochem Rev 2018;17:733–49. https://doi.org/10.1007/s11101-018-9556-2.
[51] Pinto JS, Martel F. Effects of cannabidiol on appetite and body weight: a systematic review. Clin Drug Invest 2022;42(11). https://doi.org/10.1007/s40261-022-01205-y.
[52] Rogers CI, Pacanowski CR. The relationship between cannabis and anorexia nervosa: a scoping review. J Eat Disord 2023;11(1):186. https://doi.org/10.1186/s40337-023-00887-9.
[53] Montoya Z, Conroy M, Vanden Heuvel BD, Pauli CS, Park SH. Cannabis contaminants limit pharmacological use of cannabidiol. Front Pharmacol 2020;11:571832. https://doi.org/10.3389/fphar.2020.571832.
[54] McPartland JM, McKernan KJ. Contaminants of concern in cannabis: microbes, heavy metals and pesticides. In: Chandra S, Lata H, ElSohly M, editors. Cannabis sativa L. - Botany and biotechnology. Cham: Springer; 2017. p. 457–74. https://doi.org/10.1007/978-3-319-54564-6_22.
[55] Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006 (Text with EEA relevance) OJ L 119, 5.5. 2023. p. 103–57. http://data.europa.eu/eli/reg/2023/915/oj.
[56] Samtiya M, Aluko RE, Dhewa T. Plant food anti-nutritional factors and their reduction strategies: an overview. Food Prod Process and Nutr 2020;2:6. https://doi.org/10.1186/s43014-020-0020-5.
[57] Kumar Y, Basu S, Goswami D, Devi M, Shivhare US, Vishwakarma RK. Anti-nutritional compounds in pulses: implications and alleviation methods. Legume Sci 2022;4:e111. https://doi.org/10.1002/leg3.111.
[58] Galasso I, Russo R, Mapelli S, Ponzoni E, Brambilla IM, Battelli G, et al. Variability in seed traits in a collection of Cannabis sativa L. genotypes. Front Plant Sci 2016;7:688. https://doi.org/10.3389/fpls.2016.00688.
[59] Mattila PH, Pihlava JM, Hellström J, Nurmi M, Eurola M, Mäkinen S, et al. Contents of phytochemicals and anti-nutritional factors in commercial protein-rich plant products. Food Qual Saf 2018;2:213–9. https://doi.org/10.1093/fqsafe/fyy021.
[60] Feizollahi E, Mirmahdi RS, Zoghi A, Zijlstra RT, Roopesh MS, Vasanthan T. Review of the beneficial and anti-nutritional qualities of phytic acid, and procedures for

月日知識庫

removing it from food products. Food Res Int 2021;143: 110284. https://doi.org/10.1016/j.foodres.2021.110284.
[61] Abdulwaliyu I, Arekemase SO, Adudu JA, Batari ML, Egbule MN, Okoduwa SIR. Investigation of the medicinal significance of phytic acid as an indispensable anti-nutrient in diseases. Clin Nutr Exp 2019;28:42–61. https://doi.org/10.1016/j.yclnex.2019.10.002.
[62] Mattila PH, Pihlava JM, Hellström J, Nurmi M, Eurola M, Mäkinen S, et al. Contents of phytochemicals and anti-nutritional factors in commercial protein-rich plant products. Food Qual Saf 2018;2:213–9. https://doi.org/10.1093/fqsafe/fyy021.
[63] Cosme F, Aires A, Pinto T, Oliveira I, Vilela A, Gonçalves B. A comprehensive review of bioactive tannins in foods and beverages: functional properties, health benefits, and sensory qualities. Molecules 2025;30:800. https://doi.org/10.3390/molecules30040800.
[64] Russo R, Reggiani R. Evaluation of protein concentration, amino acid profile and antinutritional compounds in hempseed meal from dioecious and monoecious varieties. Am J Plant Sci 2015;6(6):14–22. https://doi.org/10.4236/ajps.2015.61003.
[65] FAO/WHO Food Standards Programme. Proposed draft standard for quinoa. Available from: https://www.fao.org/fao-who-codexalimentarius/sh-proxy/fr/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FCircular%252520Letters%252FCL%2525202017-01%252Fcl17_01e.pdf; 2018.
[66] Food and Agriculture Organization, World Health Organization. Proposed draft standard for quinoa [Internet) [cited 2025 Jul 17). Available from: http://www.fao.org/fao-who-codexalimentarius/shproxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FCircular%252520Letters%252FCL%2525202018-25%252Fcl18_25e.pdf; 2018.
[67] Tasie O, Boateng J, Cebert E. Screening for anti-nutrients, antioxidants, minerals, and cannabinoid content in hemp (Cannabis sativa L.) seed cultivars. EC Nutrition 2024;19(1): 1–15.
[68] Seltenrich N. Cannabis contaminants: regulating solvents, microbes, and metals in legal weed. Environ Health Perspect 2019;127(8):82001. https://doi.org/10.1289/EHP5785.
[69] Food and Agriculture Organization. Fact sheets: mycotoxins [Internet). Geneva: World Health Organization; [cited 2025 Jul 16). Available from: https://www.who.int/news-room/fact-sheets/detail/mycotoxins.
[70] Yulfo-Soto GE, Smith H, Szarka D, Dixon E, Vaillancourt LJ, Gauthier N. First report of Fusarium graminearum causing flower blight on hemp (Cannabis sativa) in Kentucky. Plant Dis 2021. https://doi.org/10.1094/PDIS-06-21-1292-PDN.
[71] Sacco C, Donatoa R, Zanella B, Pinia G, Pettinia L, Marino MF, et al. Mycotoxins and flours: effect of type of crop, organic production, packaging type on the recovery of fungal genus and mycotoxins. Int J Food Microbiol 2020; 334:108808. https://doi.org/10.1016/j.ijfoodmicro.2020.108808.
[72] Punja ZK, Collyer D, Scott C, Lung S, Holmes J, Sutton D. Pathogens and molds affecting production and quality of Cannabis sativa L. Front Plant Sci 2019;10:1120. https://doi.org/10.3389/fpls.2019.01120.
[73] Matyjaszczyk E. Is the volume of pesticides consumed in agriculture a good indicator of environmental concerns? Environ Sci Pollut Res Int 2024;31:31657–63. https://doi.org/10.1007/s11356-024-33365-z.
[74] Arena A, Ferracane A, Zoccali M, Obkircher M, Sprecher H, Tranchida P, et al. Direct extraction with acetonitrile of hemp seed oil for the analysis of pesticides by using comprehensive two-dimensional gas chromatography-triple quadrupole mass spectrometry. J Chromatogr A 2023; 1710:464432. https://doi.org/10.1016/j.chroma.2023.464432.
[75] Rutkowska E, Kaczyński P, Iwaniuk P, Łozowicka B, Hrynko I, Jankowska M, et al. An extensive pesticide residue study in minor Polish vegetables based on critical consumer diets. Food Control 2025;176:111383. https://doi.org/10.1016/j.foodcont.2025.111383.
[76] Jardim A, Caldas E. Pesticide residues in food of plant origin commercialized in Brazil from 2010 to 2020 – an update from the two national monitoring programs. Food Control 2024; 165. https://doi.org/10.1016/j.foodcont.2024.110674.
[77] Hadi F, Kõlõc O, Ullah S, Gul A, Shah GM, Noreen S, et al. Indigenous utilization of medicinal plants in Kalasha tribes, District Chitral, Hindukush Range, Pakistan. Ethnobot Res Appl 2024;27:1–19.
[78] Matyjaszczyk E. Legislative situation of botanicals used in plant protection in the European Union. J Plant Dis Prot 2023. https://doi.org/10.1007/s41348-023-00724-w.
[79] Flajšman M, Košmelj K, Grčman H, Kocjan Ačko D, Marko Zupan M. Industrial hemp (Cannabis sativa L.)—A valuable alternative crop for growing in agricultural soils contaminated with heavy metals. Environ Sci Pollut Res Int 2023;30:115414–29. https://doi.org/10.1007/s11356-023-30474-z.
[80] Wielgusz K, Praczyk M, Irzykowska L, Świerk D. Fertilization and soil pH affect seed and biomass yield, plant morphology, and cadmium uptake in hemp (Cannabis sativa L.). Ind Crop Prod 2022;175:114245. https://doi.org/10.1016/j.indcrop.2021.114245.
[81] Golia E, Bethanis J, Ntinopoulos N, Kaffe G, Komnou A, Vasilou C. Investigating the potential of heavy metal accumulation from hemp. The use of industrial hemp (Cannabis sativa L.) for phytoremediation of heavily and moderately polluted soils. Sustain Chem Pharm 2023;31: 100961. https://doi.org/10.1016/j.scp.2022.100961.
[82] Ćaćić M, Perčin A, Zgorelec Z, Kisić I. Evaluation of heavy metals accumulation potential of hemp (Cannabis sativa L.). J Cent Eur Agric 2019;20(2):700–11. https://doi.org/10.5513/JCEA01/20.2.2201.
[83] Zafeiraki E, Kasiotis KM, Nisianakis P, Machera K. Macro and trace elements in hemp (Cannabis sativa L.) cultivated in Greece: risk assessment of toxic elements. Front Chem 2021;9:654308. https://doi.org/10.3389/fchem.2021.654308.
[84] Gauvin DV, Zimmermann ZJ, Yoder J, Tapp R. Marijuana toxicity: heavy metal exposure through state-sponsored access to "la Fee Verte". Pharmaceut Reg Affairs 2018;7: 1000202. https://doi.org/10.4172/2167-7689.1000202.
[85] Matyjaszczyk E, Schumann R. Risk assessment of white willow (Salix alba) in food. EFSA J 2018;16(S1):e16081. https://doi.org/10.2903/j.efsa.2018.e16081.
[86] Matyjaszczyk E, Schumann R. Cadmium contamination in food supplements containing white willow (Salix alba) bark. J Consum Prot Food Saf 2019;14(2):179–82. https://doi.org/10.1007/s00003-018-1199-0.
[87] WHO guidelines for assessing quality of herbal medicines with reference to contaminants and residues. World Health Organization; 2007. ISBN 9789241594448.
[88] Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006 (Text with EEA relevance) http://data.europa.eu/eli/reg/2023/915/oj.
[89] Struk O, Grytsyk A, Mikitin M, Obodianskyi M, Stasiv T, Svirska S. Research of biologically active substances of hemp seeds, hemp seed oil and hemp pomace. ScienceRise: Pharm Sci 2022;5(39):46–54. https://doi.org/10.15587/2519-4852.2022.241249.
[90] Korkmaz K, Kara SM, Ozkutlu F, Gul V. Monitoring of heavy metals and selected micronutrients in hempseeds from north-western Turkey. Afr J Agric Res 2010;5(6): 463–7.
[91] Fu L, Shi SY, Chen XQ. Accurate quantification of toxic elements in medicine food homologous plants using ICP-MS/MS. Food Chem 2018;245:692–7. https://doi.org/10.1016/j.foodchem.2017.10.136.
[92] Kasula R, Solis F, Shaffer B, Connett F, Barrett C, Cocker R, et al. Characterization of the nutritional and safety properties of hemp seed cake as animal feed ingredient. Int J

月日知識庫

Livest Prod 2021;12(2):53–63. https://doi.org/10.5897/IJLP2020.0750.

[93] Kim JH, Huh YC, Hur M, Park WT, Moon YH, Kim TI, et al. Inhibitory activity of lignanamides isolated from hemp seed hulls (Cannabis sativa L.) against soluble epoxide hydrolase. Heliyon 2023;9:e19772. https://doi.org/10.1016/j.heliyon.2023.e19772.

[94] Kotecka-Majchrzak K, Sumara A, Fornal E, Montowska M. Oilseed proteins – properties and application as a food ingredient. Trends Food Sci Technol 2020;106:160–70. https://doi.org/10.1016/j.tifs.2020.10.004.

[95] Krüger M, van Eeden T, Beswa D. Cannabis sativa cannabinoids as functional ingredients in snack foods—historical and developmental aspects. Plants 2022;11:3330. https://doi.org/10.3390/plants11233330.

[96] Kumar N, Kulsoom M, Shukla V, Kumar D, Kumar S, Tiwari J, et al. Profiling of heavy metal and pesticide residues in medicinal plants. Environ Sci Pollut Res Int 2018;25:29505–10. https://doi.org/10.1007/s11356-018-2993-z.

[97] Mihoc M, Pop G, Alexa E, Radulov I. Nutritive quality of Romanian hemp varieties (Cannabis sativa L) with special focus on oil and metal contents of seeds. Chem Cent J 2012;6:122. https://doi.org/10.1186/1752-153X-6-122.

[98] Moghaddam M, Mehdizadeh L, Sharifi Z. Macro and microelement content and health risk assessment of heavy metals in various herbs in Iran. Environ Sci Pollut Res Int 2020;27:12320–31. https://doi.org/10.1007/s11356-020-07789-2.

[99] Tufarelli V, Losacco C, Tedone L, Passantino L, Tarricone S, Laudadio V, et al. Hemp seed (*Cannabis sativa* L.) cake as sustainable dietary additive in slow-growing broilers: effects on performance, meat quality, oxidative stability and gut health. Vet Q 2023;43(1):1–12. https://doi.org/10.1080/01652176.2023.2260448.

[100] Zerihun A, Chandravanshi BS, Debebe A, Mehari B. Levels of selected metals in leaves of Cannabis sativa L., cultivated in Ethiopia. SpringerPlus 2015;4:359. https://doi.org/10.1186/s40064-015-1145-x.