Türk Bilimsel Derlemeler Dergisi
E-ISSN:2146-0132 16(1):29-53, 2023
Derleme Makalesi

INDUSTRIAL HEMP SEED: PRODUCTION, CHEMICAL CONTENT AND POTENTIAL USES FOR HUMAN NUTRITION

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(Received 2th February 2023; accepted 3th April 2023)

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ABSTRACT. *Cannabis sativa* L., also referred to as industrial hemp, is used to make a variety of goods. *C. sativa* L. strains with delta-9-tetrahydrocannabinol (Δ^9-THC or THC) values less than 0.3% are considered industrial hemp. Industrial hemp has become widely accepted as an agricultural commodity over the past 20 years. Due to their great nutritional value, hemp seeds are already utilized as food additivesin many different foods. The growth of the food industry is also supported by using seeds as nutraceuticals.An overview of cannabis cultivation around the world, the nutritional value of hemp seeds (proteins, lipids, vitamins, carbs, and minerals), the bioactive phytocannabinoids, phenolics, and flavonoids of hemp seeds, and their potential applications as food will all be covered in this review. The primary goal of this review is to discuss how industrial hemp seeds might be used in the food industry.

Keywords: *Cannabis sativa* L., Food ingredients, Hemp seed, Hemp seed protein

ENDÜSTRİYEL KENEVİR TOHUMU: ÜRETİM, KİMYASAL İÇERİK VE İNSAN GIDA ÜRÜNÜ OLARAK POTANSİYEL KULLANIMI

ÖZET. Endüstriyel kenevir, *Cannabis sativa* L., çok sayıda endüstriyel ürünler yapmak için kullanılır. Delta-9-tetrahidrokanabinol (THC) seviyeleri %0,3'den daha az olan *C. sativa* L. çeşitleri, endüstriyel kenevir olarak adlandırılır. Son yirmi yılda, endüstriyel kenevir, çoğu ülkede tarımsal bir meta olarak yasal statü kazanmıştır. Zengin besin içeriği nedeniyle, kenevir tohumları halihazırda çok sayıda gıda ve gıda katkı maddesi yapımında kullanılmaktadır. Tohumların nutrasötik olarak kullanılması da, gıda endüstrisinin büyümesini teşvik etmektedir. Bu derleme, küresel kenevir üretimi, kenevir tohumunun besin değeri (proteinler, lipidler, vitaminler, karbonhidratlar ve mineraller), kenevir tohumlarının fitokannabinoidlerin biyoaktif bileşikleri, fenolik ve flavonoidleri ve tohumların gıda ürünü olarak potansiyel kullanımlarına genel bir bakışı kapsayacaktır. Bu derlemenin temel amacı, endüstriyel kenevir tohumlarının gıda endüstrisindeki potansiyel kullanımını tartışmaktır.

Anahtar Kelimeler: *Cannabis sativa* L., Gıda katkı maddeleri, Kenevir tohumu, Kenevir tohumu proteini

INTRODUCTION

Industrial hemp is a dioecious, annual plant pollinated by the wind and a member of the Rosales order of the Cannabaceae family [1]. *Cannabis* has a diploid genome with 20 chromosomes, one sex pair, and 18 autosomal. Male plants have unusual X and Y chromosomes (XY), whereas female and monoecious plants have two X chromosomes (XX) [2]. In the past, hemp was used as a crop for the production of textiles and ropes [3]. *C. sativa* L. is one of the first plant species that can be grown known to man, according to research that has already been published, and it is believed to have its origins in numerous eastern and Asian societies [4]. There have allegedly been hemp-based artifacts found in graves dating back to 8000 BC, including cloth made of hemp fiber [5]. Additionally, it was grown in China 4,500 years ago to produce fiber, seeds, and oil. The cultivation of *C. sativa* L. has decreased in the twenty-first century due to the use of some narcotic strains that are highly psychoactive and contain abundant amounts of psychoactive THC and its derivatives, as well as the production of synthetic fibers at the same time as technological advancements.

Compared to industrial hemp types, C. *sativa* varieties produced for medical purposes range from 2 to over 20% THC. 26 hemp varieties with low THC content have been registered and are permitted to be grown in the nations of the European Union [6]. In contrast to the US, 0.2% THC on a dry basis is now the maximum legal level for industrial hemp cultivars used to produce fiber and seeds in most European countries [7]. Today, all strains of *Cannabis*, whether wild or cultivated, are now separated into two categories: marijuana, used as medicine, and industrial forms, used for industrial purposes. The food and fiber sectors rely heavily on industrial hemp, whereas medical cannabis is often used for therapeutic and recreational purposes. The majority of nations have approved industrial hemp production during the past 20 years, which has prompted extensive study into the advantages of hemp-based goods. Due to its use in several industrial sectors to create goods with multiple uses, industrial hemp is a special kind of plant. Paper, pulp, cigarette paper, waxed paper, packaging, and paper for electrical insulation, textiles, construction materials, composite materials, fuel, medical treatments, cosmetics, synthetic plastics, fiberglass, and other items can all be made from industrial hemp [8]. Recent years have witnessed a substantial increase in research on various foods and beverages, dietary supplements, and non-animal protein sources manufactured from hemp seeds [9]. Hemp seeds are very nutritious, containing about 35% oil, 25% protein, and significant amounts of antioxidants. However, the nutrient content of seeds varies with strain and growing conditions [10]. Hemp is a versatile crop with significant nutritional value. Hemp seeds are a great source of oil, protein, and fiber and can be consumed raw, boiled, or turned into oil [11]. The hemp stem is used to shelter and feed chickens and provides fiber, minerals [boron (B), zinc (Zn), iron (Fe), copper (Cu), manganese (Mn)], carbohydrates, vitamins, and vital amino acids.

Hemp seed oil can be used to make plastic, paint, varnish, lamp oil, ethanol-based biofuel, skin moisturizer, and other products in addition to edible oil [12]. Hemp has therapeutic value as well because it is explicitly farmed for its cannabidiol (CBD) oil, which is utilized to treat many different illnesses, including epilepsy, cancer, and diabetes. As a result, we discussed hemp seed ingredients in this review, which are rich in lipids, minerals, vitamins, protein, dietary fibers, and carbohydrates, making them good sources of these nutrients for enhancing foods. "Hemp seed + food, hemp seed + oil, hemp seed

+ protein, hemp seed + cannabidiol, hemp seed + nutrasotics, and hemp seed + minerals" keyword pairs were used in a literature search in PubMed, Google Scholar, Web of Science, and refereed articles; books were preferred as sources up until May 15, 2023, to find published articles on the development of edible foods, nutraceuticals, and other nutrients from hemp seeds. The data reviewed using current literature has been restated in a way that does not disturb the semantic integrity of the sentences. All the sources from which the data were taken are fully cited, while the original sentences of the authors were written without mentioning the source.

Overview of World Hempseed Production

Hemp was grown on 473,273 ha of land worldwide in the 1960s; however, it has been estimated that this area has shrunk significantly over the past 50–60 years, reaching 48,860 ha in 2021 [13, 14]. The rapid decline in the production areas continued until 1995; after this year, it became stable at 50–60 thousand hectares. The hemp cultivation area and hemp seed production data presented in Fig. 1 were obtained for 2021 in the FAO and Agreste databases [13, 14].

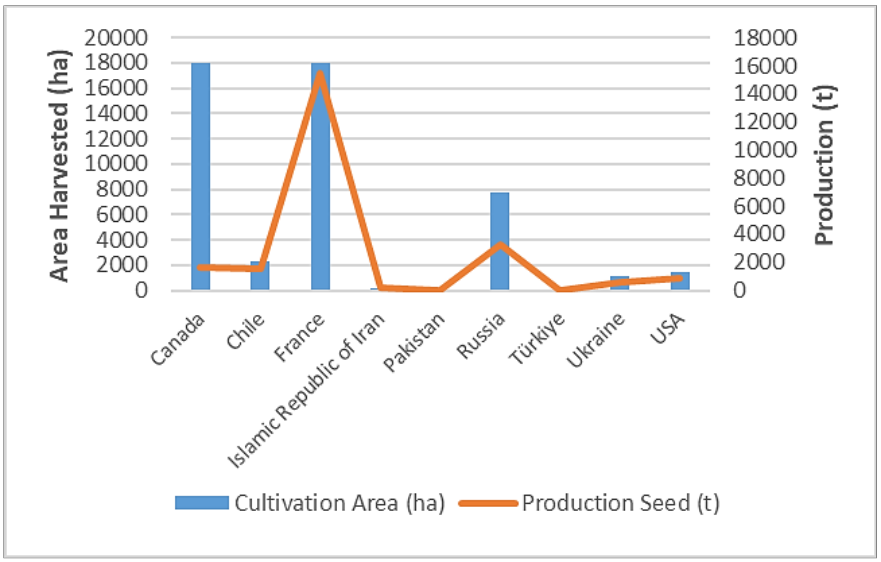

Fig. 1. *Global area harvested and hemp seed production in 2021 based on countries [13, 14]*

There have been large increases in acreage and hemp seed production in recent years, but statistical databases on the subject are not accessible to everyone in most countries. Major hemp-producing countries are France, China, Russia, Chile, Romania, Ukraine, Hungary, and the Netherlands, while other countries are Austria, Italy, the Czech Republic, Iran, Poland, Spain, Pakistan, Turkey, South Korea, and Japan [13, 14]. Canada has the most production in North America, while Chile has the biggest in South America.

Incentives introduced in European Union countries in the early 1990s encouraged interest in hemp cultivation. In Europe, France has the highest production rate. Austria (4%), The Netherlands (10%), and France (more than 70% of EU production) round out the top three producers in Europe [13, 14, 15]. The top four countries in seed production—France, China, Chile, and Russia—account for around 90% of global seed production.

Hemp Cultivars

Each nation has created successful hemp seed varieties employed in a range of industrial sectors, including the food industry, based on their ecological and geographic characteristics, or a study on this topic is in progress. A partial list of some "approved cultivars" in different countries is presented in Table 1. As referred to in the "approved cultivars" definition of the Industrial Hemp Regulations (IHR), a THC test is required for an industrial hemp variety to be included in the "Approved Cultivar List" [16]. For instance, the Colorado Department of Agriculture (CDA) stated that members of the Colorado Seed Growers Association could cultivate six industrial hemp cultivars (CRS-1, B11, Medicine Mother, Rajan, VC Star, and Henola) for "CDA Approved Certified Seed Production." [16, 17; Table 1].

Hemp Seeds

Each flower of hemp produces a seed, as well as flattened, one-seeded fruits (known as achenes), which are referred to as "seeds" [23]. The seed coat (testa) is usually mottled and has a camouflaging layer, protecting mammals and other herbivores from fallen seeds [24; Fig. 2]. The hemp seeds are small, walnut-like parts of the fruits about 4-6 weeks after the female flowers are pollinated [25]. These seeds contain a significant source of minerals, proteins, and dietary fat [6]. The seeds of the cultivars and wild forms were found to be different in terms of morphological and physiological characteristics (Fig. 2). A similar situation is also common among subspecies or cultivars. Cultivated hemp seeds are larger than wild ones and appear to lack a permanent cover layer originating from the perianth and extension in the plant attachment region [24]. Unlike cultivated seeds, the fruit wall, or shell, of wild hemp seeds is thicker. The advantages of this situation are listed as follows: 1) protects seeds from mechanical wear; 2) makes it harder for herbivores to consume the embryos by opening the seeds; and 3) seeds do not germinate quickly and remain dormant for several years, as it prevents water from easily penetrating into the seed.

Table 1. *A partial list of largely authorized industrial hemp cultıvars that yield pedigreed seeds. By dry weight of the plant's flowering parts and leaves, the majority of these cultivars have been certified to have less than 0.3%. THC under EU Regulation 1307/2013 (0.3% as of 2023) [18], Italian republic law No. 685/1975 [19]; USA Farm Bill [21]; and Canadian Cannabis Law Reform [22].*

Origin	Registered Variety Name
Canada	Altair, Alyssa, Ambassador, Angie Anka, Bountiful, CBF1, CFX-1, CFX-2, CRS-1, CW1AS1, CS, CanMa, Canda, Santiam, Santiam, Silesia Stolker, T3H2006, UC-RGM, USO 14, USO 31, Judy, Jutta, Katani, Lauar Secord, Martha, Petera, Picolo, Judy, Quida, Rigel, Silesia, Carmen, Crag, Delores, Deni, Duchess, EL1-140, EL1-65, EL1-68/134, Eighty Eight, ESTA-1,FINOLA, Fasamo, Ferimon, Fibriko, IPB45, Georgina, GranMa,Grandi, Joey, UC-RGM, X-59 (Hemp Nut), Vicroria, Nadine, Marie, Pembina, Painted Lady, Picolo, Quida, Petera, Rigel, Zolotonosha 11, Victoria, X-59 (Hemp Nut), Umpqua, Zolotonosha 15, Vega, Yvonne
USA	B11, CRS-1, Henola, Medicine Mother, Rajan, Madre Seis,Mama Maria, NWG 2463, NWG 2730, NWG 4000, Painted Lady, Rogue, Santiam, VC Star, Ambassador, Bountiful,CW1AS1, Duchess, Eighty Eight, Henola
France	Ferimon, Fedora 17, Fedora 19, Fibrimon 24, Fibrimon 56, Dioica 88, Fedrina 74, Earlina 8 FC, Epsilon 68, Fedora 17, Futura 75, Futura 77, Futura 83, Fibrol, Fibror 79, Felina 32, Felina 34, Santhica 23, Santhica 27, Orion 33, Santhica 70, Fibrimon 21
Hungary	Uniko B, Fibriko, Balaton, Cannakomp, Fibrol, Fibror 79, KC Bonusz, KC Dora, KC Zuzana, KC Virtus, KCA Borana, Kompoliti, Lipko, Hibrid TC, Tisza, Monoica, Kompolti, UnikoB, Kompolti Hbyrid TC, Kompolti Sargaszaru, Antal, KC Dora, Tizsa, Monoica, KC Zuzana
Ukraine-Russia	Dneprovskaya Odnodomnaya-6, Zolotonosha-11, YUSO-14, YUSO-16, YUSO-31, Zolotonosha-15, Zenica, Diana, Kuban, Ermakovskaya Mestnaya, USO-11, USO-13, USO 14, USO-15
Poland	Henola, Tygra, Bialobrzeskie, Glyana, Henola, Rajan, Tygra, Wielkopolskie, Wojko
Finland	Finola
Switzerland	Monoica
Czech Republic	Bialobrzeskie, Beniko
Romania	Lovrin-110, Fibramulta 151, Secuiein 1, Irene, Ratza, Secuieni,Jubileu, Silvana, Succesiv, Teodora, Tiborszallasi, Zenit, Jubileu, Armanca, Dacia Secuieni, Lovrin 110
Nederland	Beniko, Chamaeleon, Ivory, Marcello, Markant, Uso-31
China	Lai Wu, Fei Cheng, Yunma-7, Yunma-6, Yunma-5, Yunma-4, Yunma-3, Yunma-2, Yunma-1, Mt. Tai Shan,
Italy	CS, Carmagnola, Carmagnola Selezionata, Fibranova, Eletta Campana, Superfibra, Asso, Carma, Carmaleonte, Codimono, Fibrante, Glecia, Gilana, Villanova
Latvia	Adzelvieši, Austa SK
Spain	HURV19PAN, Delta 405, Delta Liosa, Delta-Ilosa
Türkiye	Vezir, Narlı
Germany	Fasamo, Fèrimon
Serbia	Marina

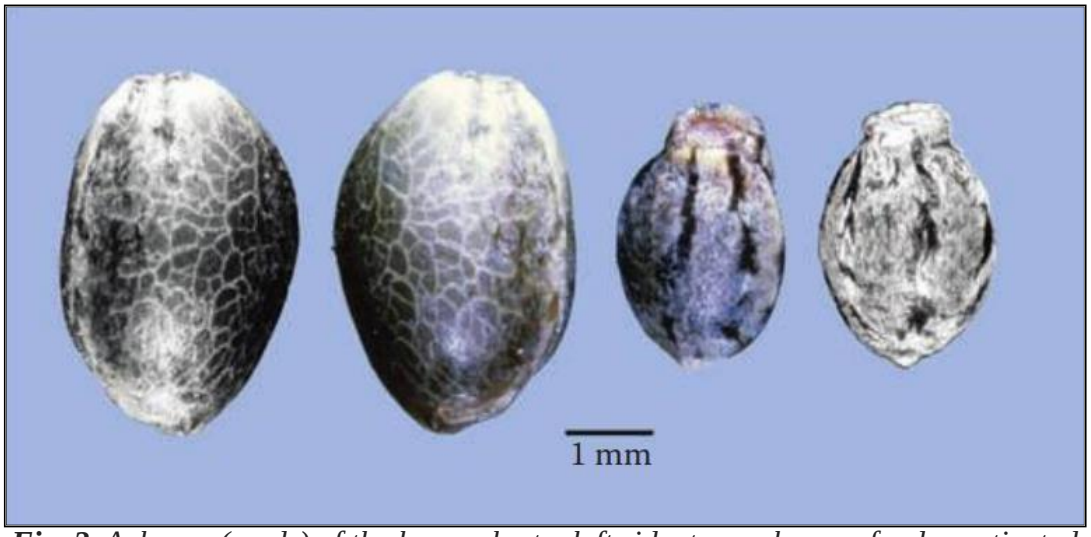

Fig. 2. *Achenes (seeds) of the hemp plants: left side, two achenes of a domesticated plant, and two achenes produced from a ruderal plant on the right side [24].*

Wild hemp seeds were significantly different from cultivated varieties in that they were tiny (1000 seed weight <10 g), seeds separated easily from the pedicel, dormancy was long, and they needed cold-moist stratification to facilitate germination [26]. Wild seeds germinate better after a certain period in cold conditions and need a chilling period to overcome germination inhibitors [27]. In contrast to wild hemp seeds, irrigation alone was considered sufficient for cultivated seeds that do not need chilling [28]. As in all plants, dormancy is a natural phenomenon that delays germination in hemp plants. However, this delay (dormancy) cannot be sustained for too long, as hemp seeds naturally do not survive for a long time [24]. After the pollination function in female plants, fruit development begins. The ripe fruit contains only one tiny, smooth, endospermic, brownish seed [29]. The seeds carried by each female flower mature in approximately 3–8 weeks. In favorable conditions in the field, the seeds germinate within 3–7 days. Each plant with a short life cycle (4-6 months) can produce up to 500 g of seeds [30].

Chemical Content of Hemp Seeds

The primary macronutrients in hemp seeds include 15-20% insoluble fiber, 20–25% protein, 20–30% carbohydrates, and 25–35% fat. In addition to the other nutrients,

the seeds contain several nutrient-inhibiting substances, vitamins, phytonutrients (tocopherols, carotenoids, and sterols), and minerals such as iron (Fe), sulfur (S), phosphorus (P), magnesium (Mg), potassium (K), zinc (Zn), manganese (Mn), and calcium (Ca) [31]. The seeds of hemp cultivars that produce fiber cannot be harvested since they are harvested during the flowering period. The development of industrial hemp has gained more attention since hemp seeds are abundant in macronutrients and phytochemicals. Industrial hemp seeds with less than 1% THC are gathered for food production [32].

The hemp seed consists of a seed embryo (the heart) rich in oil and protein and an outer shell high in nutritional fiber. The components found between the hemp seed coat and the embryo were reported by House et al. [33]. These researchers claimed that even though the embryo has numerous protein structures, high concentrations of xylan, a vital dietary fiber for humans, are compatible with a recent microscopic investigation [34]. A white kernel is in a brown shell with hemp seed around it [Fig. 3; 35]. Unsaturated fatty acids, dietary fiber, and proteins are abundant in kernels [10]. Like soybeans, hemp has a high protein and low carbohydrate nutritional profile.

In addition, hemp differs significantly from other outstanding food grains like wheat and rice in terms of carbohydrate/protein (%, w/w) ratio [36]. Unsaturated fatty acids and dietary fiber are also abundant in hemp. Popular hemp oil and its byproduct, oil meal, are used in various meals high in protein, and animal feeds [37]. Additionally, hemp seeds' bioactive components, which go beyond providing basic nutrition to promote health, can be used to create health products [9]. Among the most nutrient-dense foods, hemp seeds often contain deficient levels of psychotropic compounds, are known as "çedene" among Turks, and are also used as bird food. In addition, globulin (edestin) and albumin are two essential proteins found in hemp seeds that account for 60–80% of the overall protein content [38].

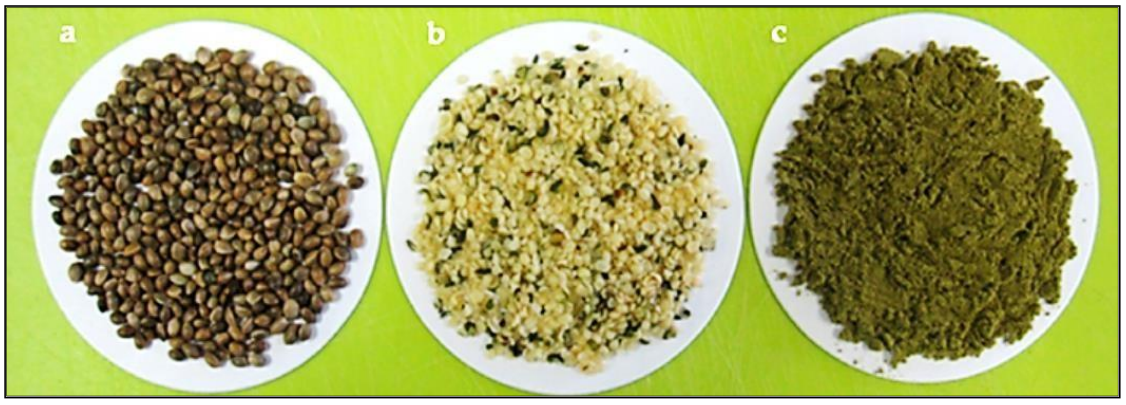

Fig. 3. *(**a**) Whole and (**b**) dehulled hemp seed (**c**) hemp flour [35].*

To create hemp oil and hemp protein isolates and concentrates, whole hemp seeds must first be processed into hemp flour. Hemp seed cake and meal leftovers from these extractions can add antioxidants and nutritional fiber to cuisine. The residue biomass from the hemp plant may also contain antioxidants and short fibers that can be used to make products [32].

Nutritional Content of Hemp Seeds (Macro and Micronutrients)

Hemp seeds and their processed derivatives (meal, flour, and oil) have received extensive research recently about their nutritional value due to their high nutritional content of lipids, proteins, minerals, vitamins, and fiber [10, 39, 40, 41]. In the past, hemp products were mainly produced for fiber and animal feed needs [10]. Hemp seeds have a high nutritional value and can be considered a balanced and beneficial food for human health. Therefore, hemp seeds have an important and increasing impact on the food industry.

The nutrient content of hemp seeds is presented in Fig. 4 [40]. As explained above in Fig. 3 and detailed in Fig. 4, hemp seeds contain macronutrients (protein, lipids, carbohydrates, and insoluble fiber), vitamins and minerals such as Mg, P, Cu, S, Mn, Fe, K, Zn, and Ca, and phytonutrients (sterols, tocopherols, and carotenoids), but seeds also have numerous anti-nutritional compounds (phytic acid, saponins, condensed tannins, cyanogenic glycosides, and trypsin inhibitors) [42, 31]. Therefore, seeds are suggested as a natural oil source for lubricants and cosmetics [31]. However, hemp seeds have recently emerged as a significant source of edible oil [24]. The ratio of α-linolenic acid (ALA; 18:33) to linoleic acid (LA; 18:26) of 2.5–3.1, which is considered the best fatty acid composition for human nutrition, increases the value of hemp seed oil [43].

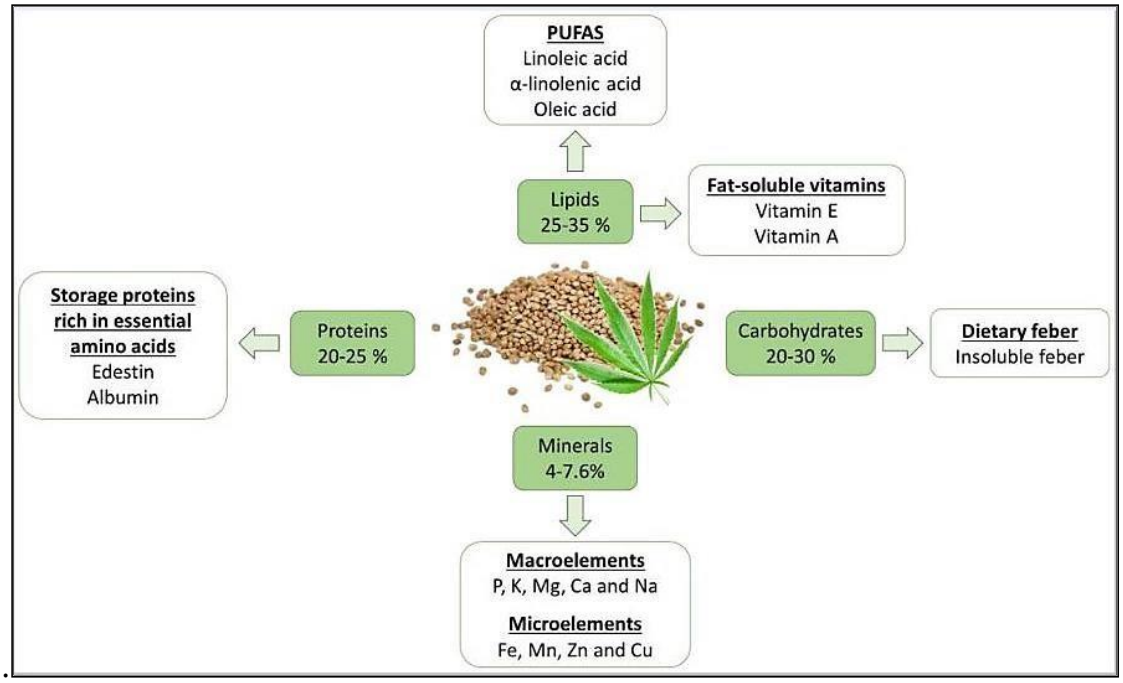

Fig. 4. *Nutritional value of hemp seeds [40].*

Whole hemp seeds have 20-30% carbohydrates, 25–35% fat, and 20–25% protein content. However, this variability in macronutrients has been reported to largely depend on agronomic conditions and cultivars [10]. According to a study on commercial hemp seeds, they include between 90.8 and 96% of dry matter, 27.2 to 36.2 percent of neutral detergent fiber, 25.4 to 33.0% of oil, 21.8 to 6.1% of acid detergent fiber, 21.3-27.3% of protein, and 3.7 to 5.9% of ash [33]. A study conducted in Italy using wild strains and 20 non-drug hemp strains found that the oil content in dry matter ranged from 28.5 to 36% and the protein content in dry matter ranged from 31.6 to 35.6%. [42]. Seed compositions of 10 industrial hemp varieties grown in Canada (Alyssa, CRS1, CanMa, Jutta, Yvonne,

Delores, Anka, Finola, CFX1, CFX2) range from 25.9 to 29.8% detergent fiber and 25.9 to 29.8% neutral detergent fiber. Fiber is reported to be 32.7–38.8% neutral detergent fiber, 25.9–29.8% acid detergent fiber, 26.9–30.6% oil, 23.8–28.0% protein, and 5.1–5.8% ash [9]. In cultivars developed primarily for fiber production, the seed component is often neglected as a by-product. However, hemp seeds have been proven to have excellent nutritional value. It typically contains 20–25 g/kg protein, 30–40 g/kg carbohydrate, and 250–350 g/kg fat [44].

In a study to determine the seed content of seven cultivars of hemp (Futura 75, Fedora 17, Tygra, Santhica 27, Felina 32, Bialobrzeskie, and Finola), the ratios of oil, protein, carbohydrates, and fiber ranged from 8.5–29.2%, 12.2–25.4%, 40.8–74.5%, and 4.4–5% [45]. By comparing the protein, oil, and fiber content of dehulled hemp and hemp, it is possible to determine how the various components are distributed in the fractions. An analysis of six dehulled hemp seeds was found to be composed of 93.7-97.0% dry matter, 37.6-52.3% oil, 30.3-38.7% protein, 4.6-18.1% neutral detergent fiber, 0.6-12.0%acidic detergent fiber, and 5.4-7.1% ash [33]. In addition to being a great source of food supplements, hempseed is additionally high in characteristic cancer prevention agents and other bioactive substances such as phenolic compounds, peptides, carotenoids, bioactive tocopherols, and phytosterols, the sum of which shows up to be for the most part affected by natural and agronomic conditions and, to a lesser degree, hereditary changeability [45].

Proteins from Hemp Seeds

Hemp seeds have a protein level that is equivalent to that of other oilseeds. Compared to soybeans, they have less protein but more than canola or sunflower seeds [46]. Hemp seeds were shown to contain more protein than other protein-rich foods, including quinoa (13.0%), buckwheat (27.8%), and linseed (20.9%), or at least as much protein as those foods [47]. Hemp seeds have a high protein content; adding them to food products can raise protein levels. Studies have shown that replacing up to 20% of wheat flour with hemp seed flour can significantly increase the protein content of bread by 38%, making it an excellent source of valuable protein [48]. The protein content of whole hemp seeds ranges from 20–25%, depending on the variety and location [10]. This percentage is for some processed hemp seeds, such as the unhulled seeds, hemp flour, or cake (also known as hemp seed meal), which is the portion of the hemp seed that remains after the oil has been removed. Commodities can be even higher [49].

There are three main types of hemp seed proteins (HSPs): 7S vicilin-like protein, 2S albumin, and 11S globulin (edestin). They make up about 5%, 13%, and about 80% of the total protein, respectively [50]. Different hemp varieties vary greatly in the protein content of their seeds. Studies on the nutritional content of hemp seeds show that it is mainly determined by the variety and ecological conditions (such as total rainfall and temperature) [51]. Edestin, which makes up about 70% of hemp protein, is the major protein in hemp kernels. Edestin is a hexamer of six identical subunits belonging to the globulin family, more commonly called globulins [52]. Each subunit is composed of a basic (18–20 kDa) and an acidic (~34 kDa) chain [53].

Understanding the functional properties and potential applications of different proteins in hemp requires insights into their structural composition and characteristics. To summarize, various proteins in hemp exhibit various structural and functional features crucial for food processing. As for these proteins, Edestin is a hemp protein cleaved into two chains post-translationally at the Asn-Gly site [52]. Edestin is composed of subunits with five cysteine residues. There is one intermolecular disulfide bond between the basic

and acidic subunits and one intramolecular disulfide bond in the acidic component. A free sulfhydryl group (SH) attaches to the last cysteine residue [51]. Edestin is more soluble in basic buffers than in water and neutral or acidic pH buffers [54]. By manipulating sonication and adjusting the pH of the edestin solution, protein structure and function can be controlled during food processing [55]. Albumin is another hemp protein and the second most prevalent hemp protein after edestin [54]. It contains fewer disulfide connections than edestin, resulting in a more flexible structure. This flexibility enhances protein solubility and foaming capacity. Hemp also contains a protein that is abundant in methionine (Met) and cysteine (Cys), two amino acids that contain sulfur [56]. This protein consists of subunits connected by two intermolecular disulfide linkages. Approximately 20% of its amino acids are sulfur-containing. Cs7S is the least common protein in hemp protein. It has a molecular weight of around 47 kDa, and hemp contains a 10 kDa protein that does not inhibit bovine trypsin. Approximately 20% of its amino acids are sulfur-containing [56].

Nutritional Quality of Hemp Seed Protein

The digestibility, bioavailability, and amino acid composition of a protein are used to determine its nutritional quality. According to FAO/WHO recommendations, HSP contains adequate levels of all nine essential amino acids for children between the ages of 2 and 5 [38]. The two most common amino acids in HSP are arginine (2.28–3.10%) and glutamic acid (3.74–4.58%). While arginine, a non-essential amino acid, is used by the body to create nitric oxide (NO), which has advantageous cardiovascular properties and has been linked to optimal immunological function and muscle regeneration. Glutamate (Glu) is a neurotransmitter that the brain can use [57]. Met and Cys are sulfur-containing amino acids, both of which are high in HSP and can be used as dietary supplements to increase the body's antioxidant capacity. Although soy proteins (41.72%) have a much higher ratio of essential amino acids to total amino acids (E/T), HSP likely has a higher concentration of nutrient-dense amino acids [58]. The nutritional value of hemp seed proteins in the human diet has not been fully realized. HSP contains more necessary amino acids than soybeans, although the main limiting amino acids in hemp seeds are tryptophan (Try) and lysine (Lys) [33]. The protein from hempseed contains a sizable amount of the amino acid arginine, a crucial component in appropriately controlling blood pressure. Seed cake leftovers from oil extraction can be transformed into a protein-rich flour safe for human consumption [59].

The areas of the seed that include the cotyledon have significantly higher protein (>41.2%), fat (>15.1%), and sugar (>3.5%) content than the parts that have the hull. However, they have lower levels of crude fiber (<21.3%) [60]. The cotyledon fractions contain the greatest accumulations of condensed tannins, phytic acid, trypsin inhibitors, glucosinolates, and other anti-nutrients. Agronomic factors, such as the type of soil, the fertilizer used, the quantity of rainfall, the temperature, and the presence of anti-nutritional compounds, have an impact on the nutritional content of HSP, as assessed by the studies of the amino acid composition and protein digestibility. Variety and genetics also have an impact [33]. Hemp seeds often contain small amounts of trypsin inhibitors, phytic acid, condensed tannins, and other anti-nutritional compounds. [62]. Monoecious variants had higher levels of anti-nutritional chemicals than dioecious kinds, with unisexual male and female flowers on different plants. For instance, phytic acid was present in 63 and 75.4 g kg^{-1} of hempseed meal from the dioecious and monoecious types, respectively [58]. Recent studies have reported that trypsin inhibitor, one of the most

important anti-nutritional elements found in many gramineous, cruciferous, and leguminous plant species, does not contain HSP [63]. Hemp seed protein isolate (HPI) and hemp flour showed good levels of *in vitro* digestion assays [64]. Edestin is renowned for having high digestibility despite its lower solubility [65]. Whole hemp seed can generally be thought of as a high-protein source since it has more or around the same amount of protein as foods like chia seeds (18.2–19.7%) [66], quinoa (13.0%), linseeds (20.9%), and buckwheat seeds (27.8%) [47]. With the exception of lysine, which is the first limiting amino acid, the protein portion of hempseed is very nutritious and easily digested. It is a good choice for newborns because of its great essential amino acid (EAA) profile, which is comparable to casein's. However, this restriction only applies to young children and newborns, who need greater Lys concentrations to meet their amino acid needs [10]. The amino acid arginine is crucial for the health of the cardiovascular system because it serves as a dietary precursor for the production of NO, a potent regulator of vascular tone. Arginine (Arg) and NO in particular have also been associated with a robust immune system and muscle healing [33]. In view of the aforementioned references, hempseed proteins provide a lot of arginine that is simple to digest. As a result, hemp seed or its derivatives, including hemp protein isolate and hemp seed meal, can be regarded as an acceptable and sustainable source of vegetable-based protein for human consumption [10].

Hemp Seed Lipids

Hemp seed lipid content and fatty acid composition are two major factors in the growing interest in hemp seeds. Polyunsaturated fatty acids (PUFAs) improve or reduce inflammation and blood cholesterol levels, stabilize heart rhythm, play a role in health promotion, have excellent omega3/omega-6 (*ω*-3/ *ω*-6) ratios, account for over 90% [31]. Numerous studies examining the fatty acid composition of hemp seeds have shown that hemp seeds contain large amounts of essential fatty acids, which the body needs for proper function but cannot be manufactured by human metabolism [67]. Hemp seed oil contains about 90% unsaturated fatty acids, of which 70–80% are polyunsaturated fatty acids ($PUFA_S$). The three most important essential fatty acids are LA (55.1% to 63.7%), ALA (15.2% to 26.2%), and the monounsaturated fatty acid OA (9% to 22.5%) [67, 68]. Hemp seeds have a perfect *ω*-6/ *ω*-3 ratio of 2.5–3.5/1, as opposed to the 15–17/1 found in typical Western diets [31].

These unsaturated fatty acids are associated with protective effects against obesity, diabetes, inflammatory diseases, and cardiovascular disease. According to EFSA,the ideal value for the *ω* -6/ *ω* -3 ratio is between 3:1 and 5:1. Many studies have examinedhow environmental and genetic factors affect the content of lipids, particularly fatty acids[67, 45]. All of the investigations came to the same conclusion: the genotype significantly impacts fatty acid composition. According to Irakli et al. [45], ALA (18:3 n3) and OA (18:1 n9) are the fatty acids most affected by genetic variation, while LA is less affected. Galasso et al. [42] observed genetic variability in LA in addition to ALA variability. The fatty acid content is also influenced by geography and climate. By examining the composition of hemp seed oil from two hemp varieties grown in four distinct Moroccan locations, Taaifi et al. [67] came to the conclusion that the observed compositional diversity is not only attributable to the cultivar variety but also to the growing area and the interaction of meteorological variables. Siano et al. [69] examined the composition of three edible hemp sources: seed, oil, and flour for the Fedora hemp genotype to ascertain the potential effects of various hemp product types on fatty acid content. They found no

discernible changes in the three products' fatty acid contents. The processing of the seeds is another factor that alters the nutritional composition of hemp seeds. For instance, roasting hemp seeds results in changes to the product's physical, chemical, structural, and organoleptic properties. Babiker et al. [70] investigated the impact of roasting hemp seeds for 7, 14, and 21 minutes on their chemical composition. The fatty acid content of hemp seeds is less affected by roasting time than other nutrients. However, the fatty acid composition changed slightly during the various roasting times. For example, the most affected chemical was palmitic acid, one of the saturated fatty acids. As opposed to this, roasting for 7 minutes increased the concentration of OA and LA while decreasing the amount of ALA; nevertheless, roasting for 14 minutes resulted in a higher concentration of ALA than unroasted seeds [70].

Hemp Seed Vitamins

Lipid-rich seeds influence the kinds of vitamins found in hemp seeds. Tocopherols, or vitamins E and A, in particular, are fat-soluble vitamins that can be found in hemp seeds. 50 mg of hemp seeds provides more than 100% of the daily needs for vitamins E, A, and D, according to Cerino et al. [41]. The antioxidant vitamin E, also referred to as the "vitamin of youth," is abundant in hemp nuts and helps to protect cells from oxidative stress. Additionally, it maintains the health of red blood cells and encourages energy metabolism. It stimulates the production of vitamin A and is important for storing sugar. Regarding vitamins, hemp oil has 79.0 mg/100 g, while hemp seeds have around 7.20 mg/100 g. The daily need for this vitamin for an adult is met by 15 g of hemp oil [41]. Vitamin E slows aging, lowers blood sugar levels, and prevents diabetes. This vitamin's availability is crucial for maintaining skin firmness because it promotes collagen production, safeguards blood vessel interiors, and lowers the risk of heart attacks and strokes. Fats can dissolve in vitamin E. Since heat treatment renders the vitamin inactive, hemp oil shouldn't be used for frying or other high-heat cooking. For vitamin E to function correctly, among other things, vitamin C must be present [41]. Hemp also has high levels of B vitamins. These vitamins are healthy for our nervous system and assist in reducing stress. Thiamine, often known as vitamin B1, is present in roughly 1.3 mg/100 g quantities and is sometimes referred to as the vitamin of well-being and happiness.

Vitamin B2, sometimes called riboflavin, is an element that supports red blood cell formation and skin energy. Hemp contains vitamin B3 (niacin), which is necessary for metabolizing proteins, lipids, and carbs. Hemp contains 0.5 mg of vitamin B6 (pyridoxine), popularly known as the digesting vitamin, which lowers excessive cholesterol levels and aids in the body's production of antibodies. Hemp seed oil has been found to contain 78 and 562.8–929.67 mg kg^{-1} of vitamins A and E, respectively [49]. Hemp seed oil contains β-tocopherol, γ-tocopherol, and α-tocopherol, with δ-tocopherol being the most prevalent form of γ-tocopherol [71]. Organic antioxidants, also known as tocopherols, have been found to lower the incidence of illnesses linked to oxidative deterioration [9]. But α-tocopherol is the isomer with the highest vitamin activity. The amount of α-tocopherol varies depending on what part of the seed is being examined; for instance, the content for the total seed should range from 0.35% to 2.56%. The amount, however, can range from 0.7% to 24.62% when expressed as oil from the seeds,depending on the genotype and environmental factors of the plant [31].

Hemp Seed Minerals

The minerals calcium, phosphorus, sodium, potassium, and magnesium are referred to as macroelements since they require more than 100 mg dL-1 of nutrition each day. By protecting the body from the harmful oxidative stress caused by free radicals, these minerals have a health-protecting effect on humans [41, 72]. In addition to those macronutrients, hemp seeds contain micronutrients such as Mn, Cu, Fe, Zn, Se, chromium (Cr), and Ni. The amount of these substances in the seed also varies considerably based on several factors, including the climate, the mineral content of the soil, fertilizers, and the type of plant [10]. The mineral content of hemp seeds has reportedly been found to vary greatly depending on the cultivar and crop year [73]. The mineral content of the various hemp flours changed noticeably, but the tested hemp flour was a good source of minerals that helped fulfill the stipulated recommended daily intake (RDI). In a study on Finola variety seeds, the following macroelement contents (in g kg^{-1}) were found: P (11.6), K (8.59), Mg (4.83), Ca (1.45), and Na (0.12), as well as the following microelement contents (in mg kg^{-1}): Zn (70), Mn (70), Cu (20), and Fe (0.14) [74]. In the mineral compositions of whole seeds and fiber hemp hulls alone, the macronutrients Mg (0.496; 0, 221), K (0.921; 0.529), P (1.17; 0.40), Ca (0.127; 0.166), and Mn (10.5; 12.1), Cu (1.89; 1.80), Fe (4.38; 3.06), and Zn (6.97; 2.92) are reported for micronutrients, respectively. The seeds and oil have a lesser concentration of macroelements than the seed flour, which has a larger concentration. The flour contains substantially higher concentrations of Ca and K, in particular. Similarly, microelements are likewise more abundant in flour, except for molybdenum (Mo), which is mostly concentrated in oil. Fe is the most abundant compound among these trace elements, with Cu, Mn, and Ni following closely behind [69]. The average Fe concentration in hemp is 12 mg per 100 g. Hemp stores the minerals it takes from the deep layers of soil with its penetrating taproots in its leaves and seeds. Calcium, one of the main substances in the structure of bones, is found in hemp seeds at approximately 150 mg/100 g levels. The ingestion of roughly 30 g of hemp nuts may cover an adult's daily need for this element [75]. Hemp has about 900 mg of potassium per 100 g. Potassium is referred to as "the element of life" because it is involved in almost all physiological processes. Its main job is to regulate water balance in the body and renal function. The effects of potassium on blood pressure, which help to keep it at an average level, support for the nervous and muscular systems, and oxygenation of the brain, are all equally important [75]. About 30 g of hemp nuts provide 15% of the daily potassium requirements for adults.

Magnesium is one of the elements required by the human cardiovascular system. However, magnesium's role in the body is much broader; in addition to stabilizing the nervous system and assisting gray cells, it also affects muscle contraction and memory, supports electrolyte balance, and helps control blood pressure. For every 100 grams of hemp seeds, there are 450 mg of Mg [41]. The Zn supply must be sufficient for the human body's almost 200 enzymes to operate properly [47]. A 30 g serving of hemp seeds provides 14% of the recommended daily intake for this element [47]. Hemp seeds also include phytates and oxalates, which are anti-nutrient components that may lower the bioavailability of minerals [76]. Phytic acid, which can also form insoluble complexes with other cations such as Mg, Fe, Ca, and Zn, is the most important form of P storage in seeds [77]. Phytates, due to their ability to chelate metals, are particularly detrimental to zinc and iron, deficiency of which poses a serious public health hazard [78]. Oxalic acid, which promotes the formation of insoluble calcium oxalates, decreases calcium absorption from plant sources [79].

Dietary Fibers and Carbohydrates

Carbohydrates comprise 20 to 30 percent of the hemp seed's composition [10]. Most of the dietary fiber in these carbohydrates, about 98%, is insoluble fiber. Hemp seeds are regarded as a low-starch food matrix and a good source of fiber because most of the remaining carbs are starch [31]. The majority of the fiber is contained in the seed hull. The fraction of consumed plant matter that enzymes cannot metabolize is known as dietary fiber. This comprises lignin, a material that is not a carbohydrate, and non-cellulosic polysaccharides, including hemicellulose, mucilage, pectin, gums, and cellulose [10]. The soluble-to-insoluble fiber ratio in hemp seeds is 20:80 [11]. The insoluble fiber comprises 46% cellulose, 31% lignin, and 22% hemicellulose. One cannot exaggerate the significance of insoluble fiber or how good it is for your health. Insoluble fiber consequently lowers the risk of obesity and type 2 diabetes [31]. For these reasons, hemp seed fiber is one of the ingredients most frequently used in culinary applications to boost the quantity of fiber in other food products. Utilizing the whole seed is advisable in these situations because the seed's hull contains fiber [10]. Regarding nutrition, dietary fiber is regarded as a crucial component of the food matrix's carbohydrate portion. As indicated above, total carbohydrate content can range from 20% to 30% [10]. Indeed, only a few research papers examined the hempseed's total carbohydrate and fiber content.The total dietary fiber (TDF) of seeds was reported as 27.6 g/100 g in a study on the measurement of TDF content, and this finding demonstrated that the entire carbohydrate component was made up of dietary fiber [11]. On the other hand, according to another study, the TDF of hemp seeds is 33.8 ± 1.9 g/100 g of seeds, or 98% of total carbs [47]. A study on synthesizing ethanol from soluble fiber in hemp seeds investigated the structural characteristics of five distinct hemp cultivars. In this study, the concentrations of xylan and glucan varied from 10.62 to 15.48% and 32.63 to 44.52%, respectively. These carbohydrates were hydrolyzed to produce large amounts of xylose (73 to 88%) and glucose (63 to 85%) [80].

Hemp Seed Bioactive Substances and Their Potential Applications

Phytocannabinoids

Cannabinoids are the unique components of hemp phytochemistry, which is highly complicated [81]. They are mostly found in the bracts of female flowers, where they are virtually totally formed in glandular trichomes. However, other plant parts, such as seeds, may also contain trace amounts of cannabinoids, which are regulated in various nations worldwide [82]. Due to its psychotropic effects, 9-THC, or THC, is the most significant, and only strains with low THC content can be grown [83]. However, as of 2023, the EU's limit for these compounds is 0.3%, whereas it is 0.3% in Poland as of 2022 and 0.3% in Canada as of 2023 [84]. To create food products containing phytocannabinoids, cannabinoid oils or extracts from aerial hemp sections may be used [85]. In any case, the phytocannabinoid content more specifically, the quantity of THC or its derivates must be carefully monitored to ensure that it does not exceed the limitations stipulated by each nation's rules. Another important element to consider is the bioavailability of phytocannabinoids both before and after digestion, their stability throughout food processing (photolytic, thermal, and oxidative degradation), and their storage [40].

Phenolic Compounds and Their Derivatives

Hemp seeds contain several primary polyphenols, including cannabisins A, B, and C and caffeoyl-tyramine. Additionally, they contain hydroxybenzoic acids, hydroxycinnamic acids, and flavonoids [9]. Polyphenols and terpenes are natural compounds in hemp seed that contribute to their antioxidant activity and odor [9, 86]. The combination of polyphenols and terpenes in hemp seeds contributes to their overall antioxidant activity and aroma. These compounds work synergistically and offer potential health benefits. However, it's important to note that polyphenols and terpenes' specific composition and concentration can vary depending on the hemp variety, growing conditions, and processing methods. Flavonoids, including flavanones, flavonols, isoflavones, and flavanols, particularly naringenin, kaempferol-3-O-glucoside, and epicatechin, were the most prevalent phenolic substances found in hemp seeds [87]. Natural plant secondary metabolites called lignanamides are produced by oxidative coupling processes using hydroxycinnamic acid amides as intermediates. These compounds exhibit powerful anti-inflammatory, antioxidant, anti-cancer, and anti-hyperlipidemic activities, according to studies conducted *in vitro* on cell culture and *in vivo* [31].

Food Products Made From Hemp Seeds

Hemp ingredients have significant potential to be used alone or as additives in various food applications [40, 35, 75]. However, there are various restrictions on the amount of cannabinoids in these ingredients in hemp food products, particularly THC and its derivatives with psychoactive effects, depending on the nation and jurisdiction [32]. As revised above, in the last two decades, researchers and the food industry have become interested in the nutritional potential of systematically characterized hemp seeds. Hemp seeds can be processed into a variety of fractions, including whole and dehulled seeds, hearts, hemp flour, hemp seed cake, hemp seed meal, hemp seed oil, dietary fiber, and hemp seed protein powder, which are then used as fresh ingredients in product formulations [10, 31, 32, 40]. Hemp seed fractions can be used for food production and the feed and cosmetics industries [40]. As shown in Fig. 5, Burton et al. [32], experts in the hemp sector, have outlined the benefits of hemp seeds in the food industry. There are already a variety of hemp seed products on the market, including whole and dehulled seeds, hemp seed oil, hemp seed cake (the leftover product of mechanical oil pressing), hemp meal (the product of solvent-based protein extraction from press cake), hemp protein, and hemp hull isolates and concentrates.

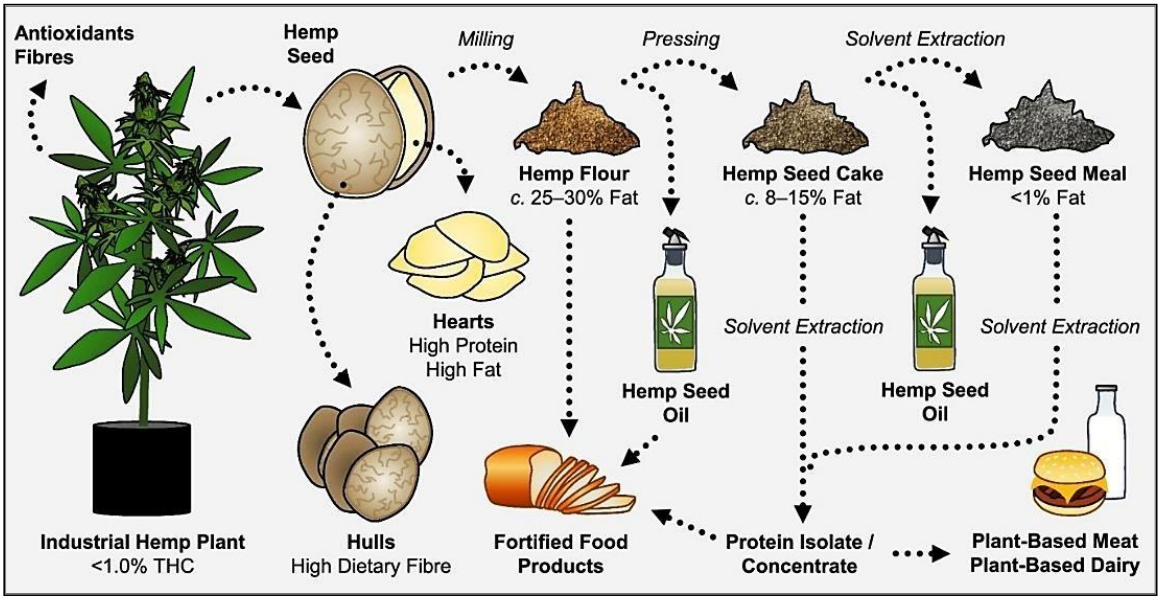

Fig. 5. *The main methods employed to produce hemp seed-based foods [32].*

Food Products Made With Hemp Seeds and Hemp Seed Oil

Today, numerous global enterprises utilize hemp seeds and oil's nutritional and health advantages.

Hemp Seed Oil

Hemp seed oil is undeniably one of the most notable products that can be obtained from hemp seeds. [10]. Given that hemp seeds have a superior fatty acid profile, high levels of protein, and a long history of therapeutic usage, the expansion of this market is not unexpected [39]. More than 30% of the oil in hemp seeds is made up of PUFAs, which account for 80% of the oil in the seeds [4, 9, 41]. As a functional food, hemp oil is an extremely rich source of nutrients in terms of two essential fatty acids, *ω*-3 (alpha-linolenic acid) and *ω*-6 (gamma-linoleic acid). The ratio of *ω*-3:*ω*-6 in hemp seed oil is between 2:1 and 3:1, which is considered suitable for human health. The Mediterranean and Japanese diets, where the risk of developing heart disease has historically been low, were found to have a fatty acid ratio of 2.5 [42]. The only known natural source of gamma-linolenic acid, which is used to treat eczema and mastalgia, is hemp oil, which contains gamma-linolenic acid and stearidonic acid, two metabolites of the important fatty acid in its oil [26]. The nearest vegan substitute, soybeans, is inferior to hemp oil interms of concentrated minerals and protein.

In order to preserve the valuable components found in the oil, it must be extracted by cold pressing from the seed that has not been heat-treated, and the oil obtained must be unrefined [26]. Before cold pressing, hemp seed oils are yellow to dark green in color. Its purified or refined oil is clear and colorless but has a pleasant taste and aroma. It is best consumed raw, in salad dressings, or as a garnish, but can be enjoyed over pasta for extra flavor. Because of its valuable essential fatty acids, it should not be consumed by heating. It is not suitable for heating as it will cause the formation of toxic trans fatty acids. Unsaturated fats also deteriorate rapidly if exposed to air, as they oxidize very easily. *Cannabis* oil is highly unstable and causes early rancidity if not stored well [26].

Hemp Seed Protein Powder

Vegan protein bars and slimming smoothies, bites, pastries, bread, snacks, energy bars, and protein bars are among the best-selling protein-boosting, exercise-ideal proteins [40]. Hemp protein powder has a brownish-green color and a flavor that can be described as earthy or grassy. Since it has a sandy texture compared to other plant-based protein powders, it should be mixed with other materials [31]. Cold-pressed hemp proteins are easily digestible. Protein powders containing all essential amino acids that the human body needs, fibers, unsaturated fats, magnesium, iron, and antioxidants are popular nutritional supplements used by vegan dieters, athletes, and bodybuilders to increase muscle mass [75]. However, there is a scientific debate about the amount and effects of essential amino acids in hemp protein powder. Also, although hemp protein powder is a safe food for most people, it can cause side effects such as digestive problems. In addition, it is reported that it is not recommended for pregnant or lactating women or people with anemia or allergies. Extruded energy bars were produced by replacing rice flour partially (up to 40%) with defatted or whole hemp powder [88].

Animal feed

The whole seed, the cheapest and most unprocessed product, is mainly used as animal feed. In contrast, hulled hemp seeds were first used in Europe, mainly for human food [89]. To generate a high protein and fiber feed for animals such as horses and dogs, a product called "praise hemp", produced from a mixture of hulled hemp seeds and hemp seeds, has been developed [90]. Hemp oil seed is a superfood that can be highly beneficial for dogs and horses. It plays a crucial role in the healthy development of their brain and eyes by maintaining optimum levels of ω-3 and ω-6 fatty acids. Organic hulled hemp seeds, organic hemp protein powder, and organic hemp seed oil are just a few of the hemp food products produced by another company, Nutiva R. [91]. In order to increase the bioactivity of hemp, Canah R. has also developed hemp feed and food products that are mixed with other foods that are well-known for having high nutritional content, such as blueberry, barberry, sour cherry, mulberry, cranberry, vanilla, chocolate, and fig [92].

Some Gourmet Food Products Derived From Hempseeds Sources

Hemp seed oil and butter are the primary materials used to prepare hemp edibles [93]. Hemp seeds have been functionalized in a variety of foods, including bakery items (bread, cookies, pasta), beverages (beer, yoghurt, wine), culinary items (sauce, bean curd, meat), snacks (lollipops, chocolates, confectionery), energy bars, breakfast cereals, gummy bears, and chocolate cookies/brownies [94]. Some gourmet product examples are presented in Fig. 6.

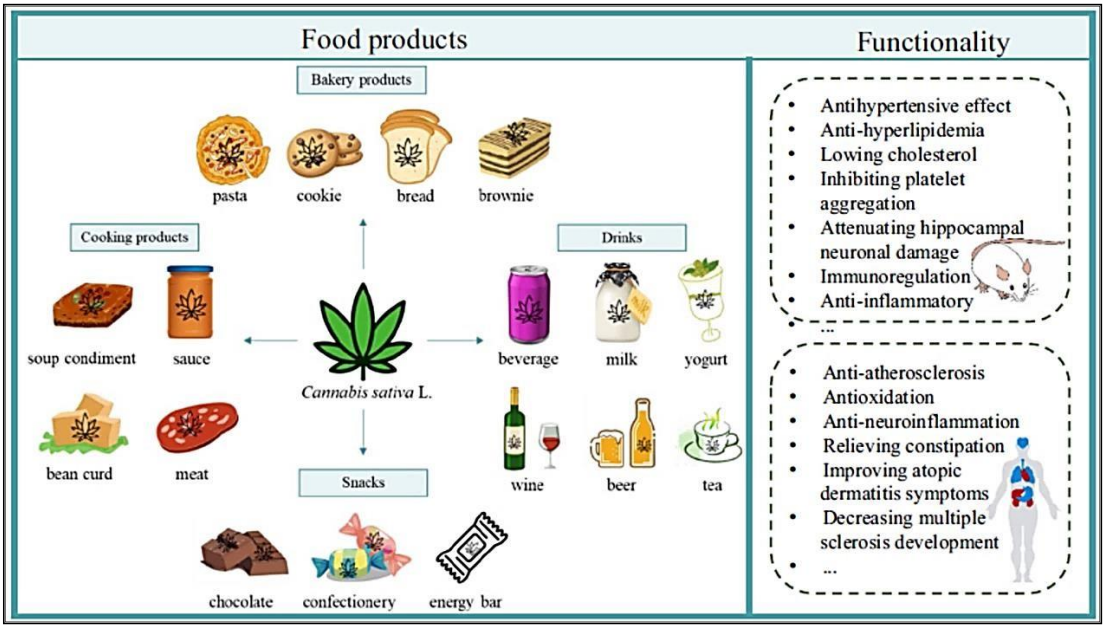

Fig. 6. *Some gourmet food product**s** derived from hemp seeds sources [94].*

Plant-Based Meat

The global market for plant-based meat, according to Grand View Research, was estimated to be worth $5 billion in 2021 and is projected to rise at a CAGR of 19.3% from now until 2030 [35]. Hemp cake, an oil-extracted hemp seed residue, has long been used as a nutritious feed for pigs, cows, roosters, quail, and broilers [35]. Due to the lack of animal stock brought on by the increased human population, demand for high-quality vegan meat manufactured from plant components is rising daily [95, 96]. High-moisture meat analogues (HMMAs), which stand for commercially available vegan meat alternatives, are primarily manufactured from soy [35]. Anisotropy and fibrousness are two of the most important characteristics to consider when creating plant-based meat with a realistic "meaty" texture [97]. The method used to extract the protein, the type of protein, and auxiliary substances like fatty acids and starches all affect how much fiber and anisotropy form in plant meat [35]. In the case of hemp protein, it is anticipated that the hemp seed protein will produce a distinctive "meaty" texture due to the high content of free sulfhydryl groups that promote the formation of fiber structures and affect the degree of texturization, the microstructure of extrudates, as well as the rheological properties [98]. These groups also reorganize cross-linking between molecules, which promotes fiber structure formation.

Bakery Products

In terms of protein, fat, minerals, fiber, essential amino acids, and fatty acids, hemp seed flour provides a higher nutritional value than wheat flour. It can therefore be applied to enhance the nutritional content of food products [99]. Bakery goods such as bread [100], gluten-free bread [101], and cookies [102] have already been successfully produced. Enriching food products, including bread, with functional additives has become very popular in recent years. Recent research has shown that incorporating hemp flour into wheat bread recipes can greatly improve the bread's physical and antioxidant properties. The study thoroughly analyzed the hemp flour's chemical composition, texture, and flavor and how they affected the bread's interior color, texture, polyphenol

profile, and furan derivative content throughout the baking process. Also, it has been recommended that for industrial manufacturing, hemp flour not make up more than 30% of the combination [43, 103].

CONCLUSION AND FUTURE PROSPECTS

For centuries, hemp has been recognized for its nutritional benefits. Although government laws once prohibited its use, the recent legalization of industrial hemp has led to its practical and valuable application in food production. Various studies have proven that hemp's nutritional and bioactive components can prevent and treat a wide range of ailments, making it a promising functional food ingredient. This review aims to highlight the nutritional and nutraceutical advantages of industrial hemp. As the world's population continues to grow, hemp seed has become a valuable raw material due to its high nutritional content, making it an ideal source of protein. Furthermore, hemp seeds can be used as a nutraceutical in food thanks to their n-6 PUFA/n-3 PUFA ratio and rich EAA content with easily absorbed proteins. However, consumers must first embrace hemp-based products and components to make them a sustainable food business venture. Products made from hemp seeds should only use seeds from hemp cultivars with minimal THC content created using standardized and trustworthy processes. Shelled hemp seeds have been used to create various high-protein snacks, including hummus, pastries, granola, plant-based milk, and animal feed. Thanks to improved processing techniques, consistent quality protein, fat, and other food fractions can be extracted from seeds to produce bread, gluten-free bread, gluten-free pasta or pizza ingredients, snacks, and alternative dairy products. Overall, industrial hemp has enormous potential for the agricultural industry, providing economic returns and promoting sustainable crop diversification.

The recent legalization of industrial hemp has opened up new opportunities for its practical and valuable use in food production. Hemp seeds, known for their exceptional nutritional benefits, offer a range of advantages as a functional food ingredient. Their high nutritional content, including protein, n-6 and n-3 fatty acids, and essential amino acids, makes them an ideal protein source and nutraceutical. The nutritional and bioactive components present in hemp seeds have been shown in numerous studies to have preventive and therapeutic properties for various ailments. This review highlights the promising potential of hemp as a functional food ingredient. To ensure the success of hemp-based products and components in the food industry, it is important to use seeds from cannabis cultivars with minimal THC content and to follow standardized and trustworthy processes. This ensures consumer acceptance and compliance with regulatory requirements. The versatility of hemp seeds has led to the creation of various food products such as high-protein snacks, hummus, pastries, granola, plant-based milk, and animal feed. Ongoing advancements in processing methods allow for the extraction of consistent quality protein, fat, and other food fractions from hemp seeds. It enables the production of bread, gluten-free bread, gluten-free pasta or pizza ingredients, snacks, and alternative dairy products. Moreover, the cultivation of industrial hemp has the potential to benefit the agricultural industry by providing economic returns and promoting sustainable crop diversification. Hemp's nutritional value and ability to thrive in different climates and soil conditions make it an attractive option for farmers. Overall, the nutritional and nutraceutical advantages of industrial hemp make it a promising ingredient in the food industry. As further research and development continue, hemp has the

potential to contribute to sustainable agriculture and offer innovative and healthy food products.

Funding: There was no external support for this study.
Conflicts of Interest: There are no conflicts of interest.
Contributions of Authors
Veysel Süzerer: Visualization, writing—original draft preparation, writing—review and editing, final manuscript reading
Engin Tilkat: Visualization, conceptualization, writing—original draft preparation, writing—review and editing, final manuscript reading
Mehmet Fidan: Visualization, writing—original draft preparation, writing—review and editing, final manuscript reading
Ahmet Onay: Review and editing, supervision, final manuscript reading

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