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Hemp seeds - nutritional, function and sustainable potential in human nutrition

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Abstract
Global protein demand is projected to increase by nearly 70% by 2025 (FAO, 2023; Montero *et al*., 2023) [1], driven by population growth and dietary shift towards protein - rich foods. However, this surge raises major sustainability issues related to conventional animal agriculture, including intensive resource use, environmental degradation, and links to chronic health disorders (Rizzo & Baroni, 2023) [9]. As a result, hemp seeds (*Cannabis sativa L*.) have gained attention as a sustainable, plant-based protein source capable of supporting both nutrition and environmental goals (cerino *et al*., 2021; Apetroaei el al., 2024) [3,10].

Hulled hemp seed contain around 25-32% complete protein (Karabulut el al., 2023; El-Sohaimy *el al*., 202) [2, 5], 35% healthy fats rich in omega-3 and omega-6 fatty acids in a near-ideal 3:1 ratio, and up to 27.5% dietary fibre (Trovato *et al*., 2023; Kamle *et al*., 2024) [4, 7]. Together, these nutrients contribute to improved cardiovascular function, reduced inflammation, better digestion, skin health and overall metabolic support. Environmentally, hemp cultivation is resource-efficient using about 77% less fertilizer, water and pesticides than crops like cotton while improving soil quality and sequestering carbon effectively (Mistry *et al*., 2025) [8].

Due to these combined benefits, hemp is being utilized in a range of functional foods, including protein-enriched flours, omega-rich oils, and fibre-fortified supplements suitable for vegetarian and vegan diets. However, further research is needed to enhance seed quality consistency, optimize processing for better bioavailability, and confirm long-term health effects across populations.

Keywords: Hemp seeds (*Cannabis sativa L*.), plant-based protein, functional foods, sustainable nutrition, bioactive peptides, polyunsaturated fatty acids (pufas), edestin, omega-3 and omega-6, nutraceuticals, carbon sequestration, food sustainability, protein fortification, gut health

Indtroduction

The world's demand for protein is growing really fast (FAO,2023; Montero *et al*., 2023) [1] because the global; population is expected to reach almost 10 billion by 2050. As more people are born, we'll need 35-56% more food than we did in 2010.At the same time, climate change is making farming harder by affecting crop yields and nutrition, People are also becoming health-conscious and looking for protein-rich diets to fight problems like obesity and heart disease. But as we eat more protein, especially form animals, it puts a lot of pressure on the planet by using land, water and creating pollution. So, there's and huge need of new protein sources that are healthy and eco-friendly.

Traditional protein sources have some problems (Rizzo & Baroni, 2023) [9]. For example, whey protein, which comes from milk, can cause allergies and take a lot of water and land to produce. Dairy farming also makes about three times more greenhouse gases than most plant-based options. Soy protein is plant-based, but it can also cause allergies and is often grown in massive single-crops farms than harm the soil and reduce biodiversity. Because of these issues, scientists and food experts are looking for better, more sustainable, and safer protein options.

That's where hemp seeds (*Cannabis sativa L*.) come in (Cerino *et al*., 2021 Apetroaei *et al*., 2024) [3, 10]. Hemp is super versatile plant that needs very little water, grows fast and even helps the soil. Its seeds are packed with around 32% complete protein, healthy fats, fibre other nutrients that are great for your body. Plus, hemp helps absorb carbon from the air, making it good for the environment too.

Hemp Plant Overview

Industrial hemp (*Cannabis sativa* L.) is distinct from psychoactive cannabis (Apetroaei *et al*., 2024) [10] primarily due to its negligible levels of delta-9-tetrahydrocannabinol (Δ9-THC), the compound responsible for psychotropic effects. Legally and botanically, hemp is defined as any cannabis plant containing 0.3% or less THC by dry weight, whereas psychoactive cannabis, often referred to as marijuana, exceeds this threshold, typically ranging from 5% to over 30% THC to induce euphoria and other mind-altering experiences. This low THC content in hemp ensures it lacks intoxicating properties, making it suitable for industrial application such as food, fibre and biofuels, while psychoactive varieties are bred for higher THC to support recreational or medicinal uses. The genetic and cultivation differences further emphasize hemp's focus on seed and stalk production rather than resin-rich flowers.

Hemp cultivation offers significant advantages in sustainability (Mistry *et al*., 2025; Rizzo & Baroni, 2023) [8, 9], including minimal requirements for pesticides or herbicides compared to conventional crops like cotton or corn, which can lower environmental pollution and production costs. Hemp's deep root system improves soil structure by preventing erosion, increasing organic matter through residue incorporation, and enhancing biodiversity, which supports long-term agricultural health and reduces on synthetic fertilizers.

Additionally, hemp excels in carbon sequestration, absorbing 10-15 tons of CO2 per hectare annually, more than many forests or commercial crops, through rapid biomass growth and soil carbon storage, contributing to climate mitigation efforts.

Global production trends for industrial hemp indicate robust growth (FAO,2023; USDA Agricultural Data, 2024), driven by expanding legalization, diverse applications, and sustainability demands. In 2023, the global market was valued at approximately USA 5.49 – 9.6 billion, with projections for 2024 reaching USA 6.3 – 11.03 billion in 2025 and further expansion to USD 11.42 – 13.54 billion in 2025, reflecting compound annual growth rates (CAGR) of 19.6 – 25.2% through the decade. Key regions include Asia-Pacific, expected to surge from USD 2.73 billion in 2025 to over USD 19 billion by 2033 at a 27.47% CAGR, alongside North America and Europe, where planted acreage in the U.S alone increased 64% to 45,294 acres in 2024 from 2023, fuelled by demand for hemp seeds, fibres, and CBD products. This upward trajectory underscores hemp's role in transitioning to eco-friendly agriculture amid regulatory advancements.

Nutritional Composition of Hemp Seeds

Hemp seeds *(Cannabis sativa L.)* are highly nutritious and known for their rich protein content (Karabulut *et al*., 2023; El-Sohaimy *et al*., 2022) [2, 5], usually around 25-35% of their dry weight. Their protein mainly comes from edestin (60-80%) and albumin, which makes it easy to digest and ideal for vegan or allergy-sensitive diets. Hulled hemp seeds, often called hemp hearts, provide around 31-32 gm of protein 100gm, making them comparable to or even better than most plant proteins. These proteins support muscle repair, energy, and immune health.

Hemp's amino acid profile includes all nine essential amino acids (Montero *et al*., 2023) [1], making it a complete protein. However, it's slightly low in lysine and leucine, which are important for muscle and collagen formation. Still, its high arginine content (around 3.5gm / 100gm) helps improve heart health by promoting nitric oxide production and better blood flow.

The seeds also contain about 30-35% fats, mainly polyunsaturated fatty acids (PUFAs) (Trovato *et al*., 2023; Kamle *et al*., 2024) [4, 7] like omega-3 (ALA) and omega-6 (LA) in an ideal 1:3 ratio, great for reducing inflammation and supporting brain and heart function. Small amounts of gamma-linolenic acid (GLA) add extra anti – inflammatory benefits.

Hemp seeds are also a good source of fibre (Cerino *et al*., 2021) [3] especially insoluble fibre that promotes healthy digestion and gut balance. Whole seeds can contain up to 30 – 35% fibre, while hulled ones have less (around 8-9gm / 100gm). With almost sugars, hemp fits well into low – glycaemic or diabetic – friendly diets. Also, they're packed with important minerals like magnesium, iron and zinc, vitamin E, which protects against cell damage. These nutrients support metabolism muscle function and immunity making hemp seeds a true all-rounder for health and sustainable nutrition.

Nutrient (per 100 gm)	Hemp Seeds	Soybeans	Flax Seeds
Protein (gm)	31-32	36	18
Fat (gm)	49-50	20	42
Carbohydrates (gm)	8-9	30	29
Fibre (gm)	4	9	27
Omega-3 (ALA, gm)	9-10	1.3	22-23
Omega-6 (LA, gm)	27-30	9	5-6
Magnesium (mg)	700	280	392
Iron (mg)	7-8	16	5.7
Zinc (mg)	9-10	4.9	4.3
Vitamin E (mg)	5-90	0.85	0.31

Hemp Seed Protein – Functional & Bioactive Properties

Hemp seed protein show several useful functional properties (Karabulut *et al*., 2023) [2] that make it valuable in food product development, such as emulsification, foaming, gelling, and solubility, though it has also some challenges. One of its strongest features is emulsification, hemp proteins like edestin can form stable films around oil droplets, preventing then from clumping together. This makes hemp protein great for products like salad dressings, sauces and plant-based milks. It also has a good foaming ability, especially in more acidic conditions (around pH 3.0), where its structure allows more air to be trapped and stabilized. This property is useful for whipped toppings and baked products. However, its gelling properties are weaker compared to other plant proteins, so its less suitable for gel-type foods unless modified using methods such as ultra-sonification or pH shifting, which can improve gel strength. Another limitation is its low solubility, especially near neutral pH, because hemp's globular proteins don't have dissolve easily in water. Still, alkaline extraction or enzymatic treatments can enhance its solubility, making it easier to use in beverage and nutritional drinks.

Beyond its functional properties, hemp protein is also a source of bioactive peptides (EL-Sohaimy *et al*., 2022; Kamle *et al*., 2024) [5, 7], short protein fragments that can support health. When hemp protein is broken fragments that can support health. When hemp protein is broken down by enzymes like alcalase or pepsin, these peptides show antioxidant and anti-inflammatory effects. They help neutralize free radicals and reduce oxidative stress, protecting cells and lowering the risk of chronic diseases such as heart disease. Some peptides can also inhibit inflammation pathways (like NF-κB) and decrease cytokine levels, helping to reduce inflammation linked to conditions such as arthritis or metabolic syndrome. Specific sequences, like WVSPLARGT and IGFLIIWV, have even shown positive effects in liver cell studies, reducing harmful reactive oxygen species and inflammatory makers.

In terms of digestibility, hemp protein performs fairly well (Montero *et al*., 2023) [1]. Its Protein Digestibility-Corrected Amino Acid Score (PDCAAS) usually ranges between 0.6 and 0.7, reflecting its good amino acid balance but slightly low lysine levels. Animal studies show *in vivo* digestibility rates of 84 - 97%, which are higher than lab-based estimates, meaning the body can absorb it efficiently, though still less than animal proteins like casein (PDCAAS 1.0).

To improve its nutritional value, hemp protein can be fortified or blended with other protein sources. Adding lysine can help boost its PDCAAS close to 1.0 and improve immune and muscle functions, while adding leucine supports muscle repair and recovery, especially useful for sports or elderly nutrition. Alternatively, blending hemp with pea or rice protein creates a more balanced amino acid profile without sacrificing sustainability, making hemp-based formulation both healthy and eco – friendly.

Hemp Seed Oil & Fibre Benefits

Hemp seed oil stands out for its exceptionally high content of polyunsaturated fatty acids (PUFAs) (Trovato *et al*., 2023; Kamle *et al*., 2024) [4, 7], which make up about 70 – 80% of its total fat. It contains and ideal Omega – 6 to Omega - 3 ratio of roughly 3:1, a balance known to support anti – inflammatory activity and promotes overall metabolic

and heart health. The main fatty acids and linoleic acid (LA, 50 – 60%) and alpha linolenic acid (ALA, 15 – 25%), along small amounts of gamma – linoleic acid (GLA, 1 - 6%), a rare omega – 6 fatty acid that helps the body produce anti – inflammatory compounds. Together, these fats may help lower triglyceride levels, improve cholesterol balance, and protect the heart. Studies have shown that hemp oil can improve blood vessels function and reduce heart rhythm disturbances, offering protective effects in both human and animal trails.

The fibre in hemp seeds, mostly insoluble (Cerino *et al*., 2021; Apetroaei *et al*., 2024) [3, 10] and making up around 30 – 40% of whole seeds, plays a major role in supporting digestive and gut health. It helps maintain the integrity of the intestinal barrier, reduces inflammation in the gut, and supports a healthy balance of bacteria in the digestive system. By slowing digestion and promoting a feeling of fullness, hemp fibre can also help with weight management and blood sugar control. When fermented by gut microbes, it produces short – chain fatty acids, which nourish colon cells, lower inflammation, and contribute to better overall gut function. Additionally, hemp fibre has prebiotic properties, encouraging the growth of beneficial bacteria such as Bifidobacterium and lactobacillus, which enhance nutrient absorption, immune health, and microbial diversity.

Using whole hemp seeds fits perfectly with zero – waste and sustainable food production principles (Mistry *et al*., 2025) [8]. Every part of the seed, including the hulls and by-products like press cakes, can be reused for food, animal feed, or industrial materials, minimizing waste and environmental harm. These residues can even be turned into biofuels or fertilizers, helping or fertilizers, helping close the loop in production systems and supporting a circular economy in agriculture. This make hemp not just nutritionally valuable, but also an environmentally responsible crop for the future.

Sustainability Aspects

The growing interest in hemp as a food ingredient in strongly linked to its environmental sustainability and low ecological footprint. Industrial hemp (*Cannabis sativa L.)* stands out among protein sources for its efficient resources use, minimal agricultural inputs, and complete crop utilization. These features make it a highly sustainable alternative compared to conventional protein sources such as whey and soy.

a. Low Input Requirements

Hemp is classified as a low – input (Rizzo & Baroni, 2023; Mistry *et al*., 2025) [9, 8], requiring relatively small amounts of water, fertilizers, and pesticides. Its deep root system enables it to access groundwater efficiently, reducing irrigation needs. Moreover, the plant's natural resistance to pests and diseases minimizes the dependence on synthetic chemicals, which are often associated with soil and water contamination. These factors make hemp a more environmentally friendly crop compared to high-input crops like soy.

b. Carbon Sequestration and Soil Improvement

Hemp cultivation contributes significantly to carbon sequestration (Mistry *et al*., 2025) [8] the process of capturing and storing atmospheric carbon dioxide. Hemp absorbs large quantities of CO2 during its rapid growth cycle and converts it into biomass, thereby reducing greenhouse gas concentrations. Additionally, the crop enhances soil structure and fertility by preventing erosion and adding organic matter back into the soil after harvest. This regenerative aligns hemp farming with sustainable and climate-resilient agricultural practices.

c. Zero – Waste Utilization (Cerino *et al*., 2021) [3]

One of the defining features of hemp is its potential for zero-waste processing. Every part of the plant can be utilized effectively

- **Seeds:** Used for protein, oil and fibre products
- **Stalks:** Processed for fibre, paper and bioplastics
- **Leaves and roots:** Applied in medical and soil – enriching uses

This holistic use ensures maximum resource efficiency and minimal production waste, setting hemp apart from other protein crops and animal – based sources that often leave behind by - products requiring disposal or treatment.

d. Comparison with Whey and Soy (FAO, 2023; USDA Agricultural Data, 2024)

Comparison to whey (animal-based) and soy (plant–based), hemp demonstrates a superior balance between nutritional value and sustainability. Why protein, while nutritionally complete, depends on dairy farming, which is associated with high greenhouse gas emissions and significant water use. Soy, thought widely cultivated, often contributes to deforestation and monoculture practices that harm biodiversity. Hemp offers a middle ground, nutritionally rich and environmentally responsible

Table 2: Nutritional and Sustainability Comparison – Hemp vs Whey vs Soy

Parameters	Hemp Protein	Whey Protein	Soy protein
Source Types	Plant (Hemp Seeds)	Animal (Milk)	Plant (Soybeans)
Protein content (%)	25 - 35	80 – 90 (isolated)	36 – 40
Amino Acid Profile	All EAAs (low lysine, leu)	Complete	Complete (allergenicity)
PDCAAS	0.6 – 0.7	1.0	0.9
Fat Content (%)	30 – 35 (PUFAs, GLA)	< 1	18 – 20
Fibre Content (%)	~ 30	0	~ 15
Water Requirement	Low	Very High	Moderate - High
Fertilizer / Pesticide Use	Minimal	Moderate (for feed crops)	High (monoculture)
Carbon Footprint	Very low	High	Moderate
Soil Benefits	Improves soil, adds organic Matter	Neutral	Moderate
Allergenicity	Rare	Possible (Milk allergy)	Common (soy allergy)
Waste Generation	Near–Zero (whole plant use)	High (dairy by products	Moderate

Sources: FAO (2023), USDA Agriculture Data (2024), Peer – Reviewed literature on crop sustainability

Application in Functional Foods

The versatile composition of hemp seeds allows them to be incorporated (Trovato *et al*., 2023; Rizzo & Baroni, 2023) [4, 9] into a wide range of functional food products. Due to their balanced nutritional profile, rich in protein, healthy fats, fibre and bioactive compounds, hemp-based ingredients to both health promotion and products innovation. The use of hemp seed derivatives in foods aligns with the increasing global demand for sustainable, plant-based, and nutrient - dense alternatives.

a. Protein Powders and Bars (Karabulut *et al*., 2023; El – Sohaimy *et al*., 2022) [2, 5]

Hemp protein powder, obtained from defatted hemp seed meal, is a popular ingredient in protein supplements and energy bars. It provides a natural, vegan and allergen-friendly protein source, making it suitable for consumers seeking dairy and soy-free options. Its mild, nutty flavour enhances palatability, while its digestibility and amino acid content support muscle recovery and satiety. Hemp protein is also being blended with other plant proteins (such as pea or rice) to improve the amino acid balance and texture of finished products.

b. Bakery Products

Hemp flour and protein concentrated are increasingly used in bakery applications such as bread, biscuits, muffins, and cookies. Their inclusion enhances the protein, fibre and mineral content of baked goods without significantly altering taste or texture when used at moderate levels. Additionally, hemp's natural greenish colour and nutty aroma provide a distinctive sensory appeal. In gluten-free formulations, hemp flour contributes to improved structure and moisture retention.

c. Beverages

Hemp Protein and oil are also utilized in plant-based beverages, including protein shakes, smoothies, and dairy alternatives. Hemp milk, prepared by blending soaked seeds with water, offers a creamy texture and a balanced nutritional composition. However, improving the solubility and suspension stability of hemp protein remains focus of ongoing research to enhance its application in beverage systems.

d. Nutraceuticals (Kamle *et al*., 2024; Trovato *et al*., 2023) [7, 4]

Beyond conventional foods, hemp-derived ingredients have found applications in the nutraceutical sector. Hemp seed oil is encapsulated and marketed as a dietary supplement due to its high content of polyunsaturated fatty acid (PUFAs), particularly omega-3, omega-6 and γ-linolenic acid. Furthermore, bioactive peptides derived from hemp protein hydrolysates exhibit antioxidant, anti-inflammatory, and antihypertensive effects, making them valuable components in functional foods and health-promoting formulations.

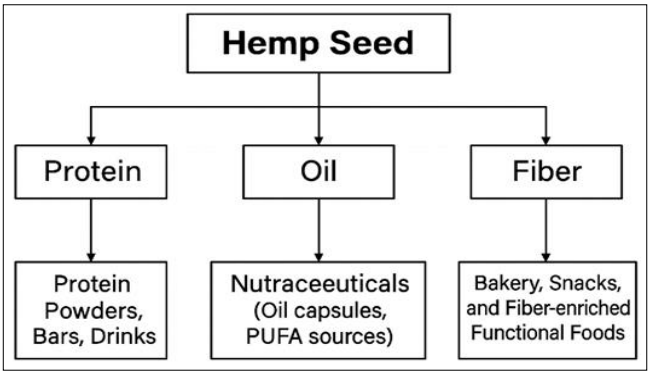

Fig 1: Hemp Seed Utilization Pathway

This integrated utilization of hemp seed components, protein, oil and fibre demonstrates its multifunctionality and strong potential in the global functional food market. With ongoing research and technological development, hemp-based foods are expected to play a major role in the future of sustainable nutrition.

Challenges & Research Gaps

Although hemp seeds show strong potential as a sustainable and nutritious source of plant-based protein, several technical, economic and regulatory challenges still limit their large-scale application in the food industry. Addressing these challenges through focused research and innovation is essential to fully utilize hemp's potential in human nutrition.

a. Amino Acid Limitations

One of the main nutritional limitations of hemp protein is its low concentration of certain essential amino acids, particularly lysine and leucine (Karabulut *et al*., 2023) [2]. This imbalance affects its overall Protein Digestibility Corrected Amino Acid Score (PDCAAS), which is lower than of soy or whey protein. Formulating protein blends by combining hemp with lysine or leucine rich sources (such as pea, lentil or rice protein) could improve amino acid balance and enhance the biological value of hemp-based products.

b. Solubility and Sensory Challenges

Hemp protein exhibits poor solubility (El-Sohaimy *et al*., 2022) [5], especially near neutral pH, which reduces its applicability in beverages and emulsified systems. Moreover, the gritty texture, greenish colour and earthy flavour of hemp protein can negatively effect consumer acceptance in certain product categories. Research into processing modifications, including enzymatic hydrolysis, ultrafiltration and microencapsulation, may help improve, flavour and overall sensory quality of hemp protein formulations.

c. Processing Costs and Technological Barriers

The cost of processing hemp seeds into high-purity protein isolates or concentrates remains relatively high compared to conventional sources. This partly due to limited large-scale infrastructure and the need for specialized extraction and purification methods. Developing cost-effective, energy-efficient and scalable processing technologies will be crucial for making hemp-based proteins more competitive in the market.

d. Consumer Acceptance and Regulatory Issues

While awareness of plant-based proteins is increasing, consumer perception of hemp is still influenced by its association with psychoactive cannabis. Misunderstanding about THC content and legal restrictions in some countries continue to pose challenges to market expansion. Establishing clear regulatory guidelines, standardizing product labelling and conducting public awareness campaigns are important for improving consumer confidence and acceptance.

e. Need for Clinical and Functional Research (Montero *et al*., 2023 Kamle *et al*., 2024) [1, 7]

Despite the growing body of laboratory studies on hemp seed composition and bioactivity, there remains a lack of clinical evidence validating its long-term health benefits in humans. More *in vivo* and clinical trials are needed to confirm the effects of hemp-derived peptides, oils and fibres on cardiovascular health, inflammation, digestion and overall metabolic function. Future research should also explore the interaction of hemp components with complex food matrices and their bioavailability after processing and digestion.

Conclusion & Future Outlook

Hemp Seeds (*Cannabis sativa* L.) represent a nutritionally rich, functional and eco-friendly ingredient (Cerino *et al*., 2021; Rizzo & Baroni 2023) [3, 9] with immense potential to contribute to global food and protein security. Their balanced composition of high-quality proteins, essential fatty acids, dietary fibre and micronutrients positions them as a valuable alternative to conventional protein sources such as soy and whey. Beyond their nutritional merits, hemp cultivation supports sustainable agriculture through low input requirements, soil regeneration and carbon sequestration, making it a model crop for climate resilient food systems

The functional and bioactive properties of hemp seeds proteins and oils and new avenues (Karabulut *et al*., 2023; Trovato *et al*., 2023) [2, 4] in product innovation, functional food development and nutraceutical applications. Hemp-based ingredients can be effectively utilized in protein powders, energy bars, bakery items, beverages and dietary supplements, catering to the rising demand for plant-based and clean-label products. Furthermore, the zero-waste potential of hemp processing aligns with modern sustainability goals and circular economy principles.

Looking forward, the future on hemp in the food industry depends on continued research (Montero *et al*., 2023; Kamle *et al*., 2024) [1, 7] and technological advancements. Efforts should focus on improving protein solubility, enhancing amino acid balance through fortification or blending, reducing processing costs and expanding consumer awareness about the safety and benefits of industrial hemp. Additionally, clinical studies are needed to substantiate the health-promoting claims of hemp-derived peptides and oils.

References

1. Montero L, Fernández-Ruiz V, Torija ME. Hemp Seeds: Nutritional value, associated bioactivities, and health benefits. Frontiers in Nutrition, 2023, 10.
2. Karabulut G, Yildiz M, Sarioglu K. A comprehensive review on hempseed protein: Production, composition and functional properties. Food Research International,2023:164.
3. Cerino P, Chianese G, Leone A, Mollo E. A review of hemp as food and nutritional supplement. Nutrients, 2021, 13(9).
4. Trovato E, Fiorini D, Nabissi M. Hemp seed-based food products as functional foods. Food Research International, 2023, 165.
5. El-Sohaimy SA, Refaay TM, Zaytom MA. Nutritional quality, chemical and functional properties of hemp protein isolate. Food Science and Technology International,2022:28(1):3–13.
6. Presa-Lombardi J, Morales R, Lázaro M. Hemp Seed's (*Cannabis sativa* L.) nutritional potential for functional foods. OCL – Oilseeds and Fats Crops and Lipids,2023:30(1):1–10.
7. Kamle M, Singh A, Meena KK. Nutraceutical potential and phytochemistry of hemp seed (*Cannabis sativa* L.). Food Chemistry, 2024, 375.
8. Mistry M, Patel R, Gupta S. Harnessing hemp seed oil for a circular bio economy. Journal of Cleaner Production, 2025, 276.
9. Rizzo G, Baroni L. The role of hemp (*Cannabis sativa* L.) as a functional food. Nutrients, 2023, 15(5).
10. Apetroaei VT, Istrate A, Dinu M. Hemp Seeds (*Cannabis sativa* L.) as a valuable source of nutrients. Nutrients, 2024, 16(2).