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Hemp and Sunflower Oilcakes Characterization: a Comparative Review

Klausz Ronald Balla[1], Silvia Mironeasa[1]

[1]*Faculty of Food Engineering, "Ștefan cel Mare" University of Suceava, Suceava, Romania*

[*]*Corresponding author: klausz.balla1@student.usv.ro*

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Abstract

The oilseed processing industry generates significant nutrient-dense by-products that offer a sustainable way to valorize agricultural waste. This review synthesizes literature on Cannabis sativa L. and Helianthus annuus L. oilcakes, highlighting their potential as plant-based ingredients for food and feed. Hemp oilcakes are characterized by essential fatty acids and unique phytochemicals, while sunflower oilcakes are noted for high protein and tocopherol content. Whether used as crude meals or protein fractions, these by-products effectively enhance the nutritional density of staple foods. Despite their economic feasibility and functional benefits, further research is required to understand the impact of processing temperatures on long-term oxidative stability. Fully optimizing these factors is essential to ensure industrial shelf-life and maximize the potential of these oilcakes as high-value, sustainable "super-ingredients".

Keywords: *by-product valorization, hemp oilcake, sunflower oilcake, chemical composition*

1. Introduction

The transition toward a circular bioeconomy has redefined the role of oilseed residues, transforming what was once considered agricultural waste into high-value functional ingredients. Hemp (*Cannabis sativa* L.) and sunflower (*Helianthus annuus* L.) oilcakes, the solid materials remaining after mechanical or solvent oil extraction, are now identified as "circular bio-ingredients" with significant potential for the food, pharmaceutical, and cosmetic sectors [1,2]. As global demand for plant-based proteins intensifies, these oilcakes offer a sustainable alternative to conventional protein sources like soy, primarily due to their balanced aminoacid profiles and lower environmental footprint.

Hemp oilcake, in particular, has emerged as a as a highly nutrient-dense food source; it typically contains approximately 30% to 35% protein, dominated by the highly digestible storage proteins edestin and albumin [3]. Beyond macronutrients, hemp residues are unique in their retention of secondary metabolites such as Cannabidiol (CBD) and Cannabidiolic Acid (CBDA), which provide powerful antioxidant and anti-inflammatory properties [4,5]. Conversely, sunflower oilcake serves as a versatile resource with a protein content reaching up to 40% depending of varieties [6]. It is notably rich in tocopherols (Vitamin E) and phenolic compounds like chlorogenic acid, which contribute to the oxidative stability of the residual lipids within the oilcake [7,8].

The chemical complexity of these cakes is further influenced by the "extraction history" of the seed. For instance, the temperature of screw pressing - often ranging from 40°C to 70°C - can significantly alter the yield and bioactive integrity of the resulting meal [9]. Furthermore, the application of these oilcakes extends into environmental science, as both

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species have shown potential in phytoremediation, with sunflower effectively extracting lead from contaminated soils and hemp showing resilience in capturing per- and poly-fluoroalkyl substances [10,11].

This review aims to synthesize these diverse findings to provide a comprehensive chemical map of hemp and sunflower oilcakes, establishing their viability as economically feasible and health-promoting resources for modern industry.

2. Chemical Composition Comparison

The industrial extraction of oil from seeds via cold-pressing or solvent extraction generates a nutrient-dense byproduct known as oilcake or meal. Historically regarded as a low-value agricultural residue for animal feed, recent scientific inquiry has refocused on these materials as primary sources of plant-based proteins, dietary fibers, and bioactive secondary metabolites. The chemical composition of hemp and sunflower oilcakes is highly influenced by several factors, including seed variety, cultivation conditions, and oil extraction methods. Both byproducts, recognized as valuable sources of macronutrients and bioactive compounds, making them suitable for applications in food and feed systems. However, notable differences exist in their compositional profiles, which directly impact their functional and nutritional value. Hemp oilcake is distinguished by its high protein bioavailability and a unique lipid residue [12]. Conversely, sunflower oilcake tends to have lower fat content when solvent extraction is used but is typically richer in crude fiber, especially when hulls are retained.

2.1. Protein content and amino acid

Historically valued primarily for their oil content, the oilcake or meal byproducts of hemp (*Cannabis sativa* L.) and sunflower (*Helianthus annuus* L.) represent dense, underutilized protein reservoirs and "circular bio-ingredients." These materials serve as sustainable alternatives for high-quality protein recovery following industrial oil extraction, positioning them as complex functional ingredients rather than simple fillers for high-tier human and animal nutritional applications [1,2,8,13].

Hemp oilcake typically contains between 30% and 50% protein on a dry matter basis, a fraction dominated by edestin (65–80%), a highly digestible 11S globulin, and albumin (20–35%) [3,14,15] (Table 1). While edestin supports the immune system through its exceptional digestibility, the smaller albumin fraction is often richer in essential amino acids, creating a balanced nutritional profile. Functionally, hemp's hydrophobic proteins (5–8%) are vital for creating stable emulsions and foams, while its free amino acids indicate high metabolic readiness and immediate bioavailability [3,14].

Table 1 Protein content

Compound Name	Concentration of hemp oilcake	Concentration of sunflower oilcake	Reference
Total Protein	30% – 50% (dry matter)	28% – 42% (dry matter)	[3,15] [8,14,16]
Edestin (Globulin)	65% – 80% of total protein	50% – 70% of total protein	[3,14] [6,14]
Albumin	20% – 35% of total protein	15% – 25% of total protein	[3,15] [6,14]
Hydrophobic Proteins	5% – 8% of total protein	-	[3,15]
Free Amino Acids	1.5% – 3.0% (total nitrogen)	-	[3,14]
Glutamic Acid	5.50 – 7.20 g/100g (dry matter)	5.80 – 7.50 g/100g 18.0 – 22.5 g/100g protein	[3,15] [15,17] [14,18]
Arginine	3.20 – 4.50 g/100g (dry matter)	2.10 – 3.20 g/100g 8.0 – 9.5 g/100g protein	[14,15] [15,19] [3,14]
Leucine	1.80 – 2.50 g/100g (dry matter)	-	[3,15]
Valine	1.30 – 1.80 g/100g (dry matter)	4.8 – 5.5 g/100g protein	[14,15] [14,18]
Phenylalanine	1.10 – 1.50 g/100g (dry matter)	-	[3,15]
Isoleucine	0.90 – 1.30 g/100g (dry matter)	3.5 – 4.2 g/100g protein	[14,15] [3,14]
Lysine	0.80 – 1.10 g/100g (dry matter)	3.2 – 3.8 g/100g protein	[3,15] [3,14]
Threonine	0.85 – 1.20 g/100g (dry matter)	-	[14,15]
Methionine	0.55 – 0.85 g/100g (dry matter)	2.1 – 2.6 g/100g protein	[3,15] [20,21]
Aspartic Acid	3.10 – 3.90 g/100g (dry matter)	-	[3,15]
Bioactive Peptides (V-L-Y)	--	Variable (Product of hydrolysis)	[18,21]
Sulfur Amino Acids	--	3.5 – 4.2 g/100g protein	[18,21]

Sunflower oilcake features a similarly high nitrogen density, with protein concentrations ranging from 28% to 42% on a dry matter basis [8,14,16]. Its structural composition is primarily defined by the 11S globulin helianthinin (50–70%) and a soluble albumin fraction (15–25%) [6,14]. Beyond these storage proteins, sunflower oilcake serves as a specialized substrate for generating bioactive peptides, such as the valine-leucine-tyrosine sequence. These peptides, released through targeted enzymatic hydrolysis, have demonstrated significant anti-inflammatory potential in clinical evaluations [18,21].

The biological utility of these meals is further distinguished by their specific amino acid sequences. Hemp is a "complete" protein source containing all nine essential amino acids and is remarkably rich in arginine (up to 4.50 g/100g), a vital precursor for nitric oxide and cardiovascular health [3,15]. It also provides branched-chain amino acids (BCAAs) like leucine, valine, and isoleucine, though their integrity remains sensitive to extraction technologies like ultrasound-assisted methods [22,23].

Conversely, sunflower protein remains highly competitive by offering superior levels of sulfur-containing amino acids (3.5–4.2 g/100g protein), including a significant methionine fraction [20,21]. It also maintains high levels of glutamic acid (up to 22.5 g/100g protein) and lysine (3.2–3.8 g/100g protein), the latter of which is often the limiting factor in other plant substrates. Together, these profiles ensure a high biological value for supporting brain health, cellular metabolism, and muscle synthesis [14,15,17].

2.2. Fiber content

Complementing the proteinaceous matrix, the carbohydrate and fibrous architecture of hemp (*Cannabis sativa* L.) and sunflower (*Helianthus annuus* L.) oilcakes provide significant physiological and industrial utility. While both materials are valued for their high nitrogen density, their fibrous concentrations are heavily influenced by botanical origin and processing methods [3,16]. Hemp oilcake is characterized by a high total dietary fiber (TDF) content, ranging from 20% to 35%, with crude fiber specifically accounting for 18.3% to 28.5% of the total biomass [24,25] (Table 2). In sunflower oilcake, crude fiber concentrations exhibit wider variance (12% to 32%), a factor largely contingent upon the efficiency of industrial dehulling and the inclusion of the pericarp or hull [8,10,26].

The structural integrity of both oilcakes is anchored in a lignocellulosic composition that is critical for valorization in ruminant nutrition and bio-composite development [27,28]. In hemp oilcake, cellulose is the dominant polymer, comprising 40% to 55% of the total fiber fraction, followed by hemicellulose (15–25%) and lignin (5–12%) [27,29,30]. Sunflower oilcake presents a similar structural hierarchy, with cellulose reaching levels of 25% to 35% in the hull fraction, supported by hemicellulose (12–18%) and a lignin fraction of 5% to 9% [27,29,31]. These high cellulosic levels make both byproducts attractive candidates for nanocellulose extraction and the development of isolation or bio-composite materials [30,32].

Table 2 Fiber content

Compound Name	Concentration of hemp oilcake	Concentration of sunflower oilcake	Reference
Total Dietary Fiber	20% – 35%	-	[24,28]
Crude Fiber	18.3% – 28.5%	12% – 32% (depending on dehulling)	[2,25] [8,10,16, 26]
Cellulose	40% – 55% (of total fiber)	25% – 35% (in hull fraction)	[29,30] [27,29]
Hemicellulose	15% – 25% (of total fiber)	12% – 18%	[23,27] [16,27]
Lignin	5% – 12% (of total fiber)	5% – 9%	[31,34] [16,31]
Pectin	1% – 3% (dry matter)	10% – 15% (in hull/pith fraction)	[3,33] [32,33]
Carbohydrates	15% – 25%	-	[3]
Soluble Sugars	-	4% – 7%	[8,16]
Arabinans / Galactans	-	3% – 5% (Pectic side chains)	[32,33]
Arabinose	-	3.5% – 4.2% (of total carbohydrates)	[32,33]
Galactose	-	2.1% – 2.8% (of total carbohydrates)	[33]
Xylose	-	1.5% – 2.0% (of total carbohydrates)	[27,32]

A primary biochemical distinction between the two species lies in their specialized polysaccharide and soluble sugar content. Sunflower byproducts are an exceptional source of low-methoxyl pectin, which constitutes 10% to 15% of the hull and pith fractions and is characterized by complex side chains including arabinans and galactans [32,33]. In

contrast, hemp contains a significantly lower pectin concentration of 1% to 3% on a dry matter basis [3,33]. Furthermore, the non-structural carbohydrate fraction in hemp constitutes 15% to 25% of the seed's overall composition, providing a sustained energy release. Sunflower oilcake contains soluble sugars at 4% to 7%, offering a more readily available energy source that balances its high-fiber content for effective nutrient utilization [3,8,16].

The functional implications of these fibrous profiles extend to gut health modulation and energy release in biological systems. Hemp's balanced ratio of soluble and insoluble carbohydrates supports cecal fermentation and antioxidant enzyme activity in both monogastric and ruminant systems [3,24]. Meanwhile, the complex monosaccharide profile of sunflower - dominated by arabinose (3.5–4.2%), galactose (2.1-2.8%), and xylose (1.5–2.0%) - influences the fermentability and techno-functionality of the meal [27,32,33]. These compositional differences allow for the targeted application of hemp in low-sucrose functional foods and sunflower in specialized industrial bio-composites or as a potent energy-balancing feed ingredient [3,16].

2.3. Lipid content

The secondary metabolome of both hemp (*Cannabis sativa* L.) and sunflower (*Helianthus annuus* L.) oilcakes is heavily influenced by the residual oil content persisting after primary extraction. Hemp oilcake typically retains a crude fat content of 5% to 13%, while sunflower oilcake exhibits a range of 1.5% to 12%, with lower values generally reflecting the high efficiency of solvent extraction compared to mechanical pressing [2,8,16] (Table 3). Rather than being mere caloric residues, these lipid fractions serve as complex reservoirs of bioactive fatty acids and polar lipids that enhance the biological value of the meal [13].

The fatty acid profiles of both oilcakes are predominantly unsaturated, though they offer distinct nutritional advantages. Hemp oilcake is characterized by a high concentration of polyunsaturated fatty acids, specifically linoleic acid (50–60%) and α-linolenic acid (15–25%), in a ratio essential for modulating inflammatory responses [9,35]. It is further distinguished by rare, highly bioactive metabolites such as γ-linolenic acid (1%–4%) and stearidonic acid (0.5%–2%), which are prized for unique therapeutic applications [35,36]. In sunflower oilcake, the residual fat is dominated by linoleic acid (48–74%) and oleic acid (14–40%), providing significant structural membrane integrity [13,37]. Both materials contain a complex of lipid derivatives and minor saturated fractions that support cellular signaling and stability. Hemp residues contain phospholipids (1.5%–2.5% of residual oil) and unique derivatives such as 2-monolinolein (10%–12%) and methyl eicosatetraenoate (8%–10%) [38,39]. Sunflower oilcake retains polar lipids like phosphatidylcholine (0.5%–1.1%) and phosphatidylinositol (0.2%–0.4%), alongside squalene (10–50 mg/kg), residual glycerol, and pheophytin a, which serves as both an antioxidant and a marker of thermal history [7,13,26].

Table 3 Lipid content and fatty acids

Compound Name	Concentration of hemp oilcake	Concentration of sunflower oilcake	Reference
Crude Fat (Residual Oil)	5% – 13%	1.5% – 12% (extraction method dependent)	[2,8] [13,16]
Phospholipids	1.5% – 2.5% (of residual oil)	-	[2,38]
2-Monolinolein	10% – 12% (of seed extract)	-	[39]
Linoleic Acid (C18:2 n-6)	50% – 60% (of residual fat)	48% – 74% of residual lipid	[9,35] [13,37]
α-Linolenic Acid (C18:3 n-3)	15% – 25% (of residual fat)	-	[40,41]
γ-Linolenic Acid (GLA)	1% – 4% (of residual fat)	-	[35,36]
Stearidonic Acid (SDA)	0.5% – 2% (of residual fat)	-	[35,42]
Palmitic Acid (C16:0)	5% – 7% (of residual fat)	5% – 8% (of residual lipid)	[35,40] [37,43]
Stearic Acid (C18:0)	2% – 3% (of residual fat)	2% – 6% of residual lipid	[35,37] [37,44]
Arachidic Acid (C20:0)	0.5% – 1.0% (of residual fat)	-	[35,43]
Behenic Acid (C22:0)	0.2% – 0.4% (of residual fat)	0.5% – 1.2% of residual lipids	[37,43] [37,43]
Lignoceric Acid (C24:0)	0.1% – 0.2% (of residual fat)	0.2% – 0.5% of residual lipids	[35,43] [43]
Methyl Eicosatetra-enoate	8% – 10% (of seed extract)	-	[39]
Oleic Acid (C18:1)	-	14% – 40% of residual lipid	[45,46]
Phosphatidyl-choline	-	0.5% – 1.1% of lipid fraction	[13,16]
Phosphatidyl-inositol	-	0.2% – 0.4% of lipid fraction	[13]
Squalene	-	10 – 50 mg/kg	[13,47]
Glycerol	-	0.2% – 0.5% (Residual)	[16,26]
Pheophytin a	-	2.5 – 6.0 mg/kg	[7]

Each oilcake also features minor saturated fatty acids (palmitic and stearic) and trace very-long-chain fatty acids like behenic and lignoceric acids, which are critical for membrane integrity in consumer organisms [35,37].

Oxidative stability remains a shared concern given the high degree of unsaturation, yet this can be mitigated through inherent biochemical defenses and controlled processing, such as careful temperature management during screw pressing [7,40]. From a functional standpoint, the presence of these stabilized bioactive lipids elevates the status of both oilcakes to "circular bio-ingredients" suitable for high-performance diets in fisheries and livestock nutrition, ensuring nutrient bioavailability and long-term shelf-life [2,36].

2.4. Cannabinoid content

The presence of phytocannabinoids in *Cannabis sativa* L. byproducts is a critical determinant of their legal and commercial viability. While industrial hemp is characterized by its high non-psychoactive cannabinoid content, the concentration of these compounds in seeds and processed meals is significantly lower than in the inflorescences, primarily occurring as surface contamination during harvesting [5].

The dominant phytocannabinoid identified is Cannabidiolic Acid, with reported ranges of 15.0 – 45.0 mg/kg, followed by its decarboxylated form, Cannabidiol, at 5.5 – 12.5 mg/kg [5,39] (Table 4).

Table 4 Cannabinoid content of hemp oilcake

Compound Name	Concentration of hemp oilcake	Reference
Cannabidiol (CBD)	5.5 – 12.5 mg/kg	[5,39]
Cannabidiolic Acid (CBDA)	15.0 – 45.0 mg/kg	[5,48]
Δ9-Tetrahydrocannabinol (THC)	< 1.0 mg/kg (Trace/Residual)	[5,48]
Cannabigerol (CBG)	< 0.5 mg/kg (Residual)	[5,39]
Cannabichromene (CBC)	< 0.3 mg/kg (Trace)	[5,39]
Cannabinol (CBN)	< 0.2 mg/kg (Degradation product)	[5,48]

Other minor cannabinoids, including Cannabigerol, Cannabichromene, and the degradation product Cannabinol, remain at trace or residual levels (< 0.5 mg/kg), reflecting a clean profile suitable for broad industrial application [48].

Legal Framework and Thresholds (Romania and EU) as of 2026, the marketing of hemp-derived products is governed by a harmonized European framework, supplemented by specific Romanian national provisions (Table 5).

As of 2026, CBD (regardless of its source) is considered a Novel Food. This means any food product containing added CBD must receive pre-market authorization from the European Commission [49]. In early 2026, the European Food Safety Authority (EFSA) established a provisional safe intake level for purified CBD at 0.0275 mg/kg body weight per day (approximately 2 mg/day for a 70 kg adult) [50].

Table 5 Legal EU limits of Cannabinoids

Compound	Data Value (mg/kg)	EU Limit (mg/kg)	Compliance Status
Total THC	< 1.0	3.0 (Seeds) / 7.5 (Oil)	Compliant
CBD/CBDA	20.5 - 57.5 (Sum)	Novel Food Rules Apply	Marketable as natural trace

In Romania, the National Sanitary Veterinary and Food Safety Authority (ANSVSA) enforce these EU guidelines. While "technical" hemp seeds naturally containing the trace levels mentioned in our data are permitted, the intentional enrichment of food with CBD isolates remains restricted until specific dossier approvals are finalized.

Significant legislative shifts occurred in 2025/2026 regarding the cultivation of the plant. Under current Romanian law (Law 222/2025): Adults may cultivate up to 3 plants for personal consumption on private property, provided they are registered in the national central registry [51].

Industrial hemp (technical hemp) used for the production of the oils and meals discussed in this paper must be from certified varieties listed in the EU Common Catalogue of Varieties of Agricultural Plant Species [52].

2.5 Terpene content

The volatile profiles of hemp (*Cannabis sativa* L.) and sunflower (*Helianthus annuus* L.) oilcakes reveal distinct biochemical signatures that define their unique aromatic and functional properties. Hemp oilcake is characterized by a complex array of sesquiterpenes and monoterpenes, which dominate

its volatile fraction. Most notably, β-caryophyllene represents a substantial portion of the hemp volatile matrix at 15% to 35%, providing characteristic spicy notes and potential anti-inflammatory benefits [4,53]. This is supported by α-humulene (5–12%) and myrcene (2–8%), which contribute to the earthy and resinous aroma associated with the species [4,54].

In contrast, the volatile landscape of sunflower oilcake is primarily defined by lipid-derived aldehydes and specific aroma markers rather than a dominant terpene fraction. Hexanal is a significant component, found at concentrations of 50 to 500 µg/kg; its levels are highly dynamic, typically increasing during storage as a byproduct of lipid oxidation [17,45]. Furthermore, sunflower oilcake possesses unique organoleptic markers such as 1-octen-3-ol (10–45 µg/kg), which imparts a mushroom-like scent, and methional (5–20 µg/kg), responsible for a distinctive potato-like aroma [17].

While hemp volatiles include trace amounts of linalool and limonene (up to 1.2%), which offer floral and citrus undertones, sunflower byproducts utilize different terpenoid pathways, containing trace levels of alpha-pinene at up to 1.5 mg/kg [4,17] (Table 6). These divergent chemical compositions result in hemp oilcake being valued for its complex, terpene-rich therapeutic potential, whereas sunflower oilcake's volatile profile serves as a critical indicator of freshness, shelf-life, and specific culinary aroma characteristics.

Table 6 Terpene content

Compound Name	Concentration of hemp oilcake	Concentration of sunflower oilcake	Reference
B-Caryophyllene	15% – 35% (of volatile fraction)	-	[4,53]
α-Humulene	5% – 12% (of volatile fraction)	-	[4,54]
Myrcene	2% – 8% (of volatile fraction)	-	[4,53]
Linalool	Trace to 0.5% (Volatiles)	-	[4,54]
Limonene	Trace to 1.2% (Volatiles)	-	[4,53]
Hexanal	-	50 – 500 µg/kg (increases with storage)	[17,45]
1-Octen-3-ol	-	10 – 45 µg/kg (Aroma marker)	[17]
Methional	-	5 – 20 µg/kg (potato-like aroma)	[17]
Alpha-Pinene (Terpenoid)	-	Trace to 1.5 mg/kg	[17,54]

2.6. Vitamin content

The vitamin and specialized metabolite profiles of hemp (*Cannabis sativa* L.) and sunflower (*Helianthus annuus* L.) oilcakes exhibit distinct biochemical strategies for antioxidant protection and cellular support. While both byproducts are significant sources of Vitamin E (tocopherols), their isomeric distributions differ fundamentally. Hemp oilcake is dominated by γ-tocopherol, which accounts for 80% to 90% of its total tocopherol fraction (60–110 mg/100g of residual fat), providing robust protection against lipid peroxidation [7,9] (Table 7).

Table 7 Vitamin content

Compound Name	Concentration of hemp oilcake	Concentration of sunflower oilcake	Reference
Vitamin E (Total)	5 – 15 mg/100g (Meal basis) 550 – 650 mg/kg (residual fat)	90% – 95% of total tocopherols	[9,35] [2,9] [7,55]
Vitamin A	70 – 85 mg/kg (residual fat)	-	[2,39]
Total Tocopherols α, γ, δ	60 – 110 mg/100g (residual fat)	30 – 100 mg/kg	[9,60] [7,55]
α-Tocopherol	-	150 – 350 mg/kg (residual fat)	[7,55]
γ-Tocopherol	80% – 90% of total tocopherols	-	[7,40]
Choline	1,500 – 2,500 mg/kg	0.2% – 0.4%	[15,57] [20,57]
α-Tocopherol (Vitamin E)	-	1.5 – 2.5 mg/100g	[16,57]
Vitamin B1 (Thiamine)	-	6.0 – 7.0 mg/100g	[57]
Vitamin B5 (Pantothenic Acid)	-	15 – 35 mg/kg	[16,56]
Inositol	0.5% – 1.2% (dry matter)	-	[3]
Myo-inositol	-	0.1% – 0.3%	[3,56]
D-pinitol (Cyclitol)	-	Trace – 0.2%	[16,56]
Lutein	-	5 – 12 mg/kg (Residual)	[7,60]
Chlorophyll a & b	-	1.0 – 2.5 mg/kg	[16,41]
Beta-Carotene	-	1.0 – 2.5 mg/kg	[16,41]
Betaine	-	0.3% – 0.6%	[20,57]
Adenosine	-	5 – 15 mg/kg	[58,59]
Guanosine	-	3 – 10 mg/kg	[59]

In contrast, sunflower oilcake is a premier source of α-tocopherol, the most biologically active form of Vitamin E for humans, which constitutes 90% to 95% of its total tocopherols [7,55].

Beyond Vitamin E, each oilcake offers a unique array of water-soluble vitamins and metabolic precursors. Hemp oilcake is particularly notable for its high concentration of inositol (0.5%–1.2% on a dry matter basis) and choline (1,500–2,500 mg/kg), both essential for lipid metabolism and cellular signaling [3,15]. It also retains significant levels of Vitamin A within its residual fat (70–85 mg/kg). Sunflower oilcake complements these with a robust B-vitamin profile, featuring thiamine (B1) at 6.0 to 7.0 mg/100g and pantothenic acid (B5) at 15 to 35 mg/kg, alongside specialized cyclitols like D-pinitol and methyl-donors such as betaine (0.3%–0.6%) [20,56,57].

The pigment and nucleoside compositions further distinguish these species. Sunflower oilcake contains a variety of carotenoids and chlorophylls, including lutein (5–12 mg/kg), beta-carotene, and chlorophyll a & b, which collectively contribute to the meal's antioxidant capacity and visual characteristics [7,41]. Additionally, sunflower byproducts contain functional nucleosides such as adenosine and guanosine, which are absent or not reported in similar concentrations in hemp [58,59]. These divergent profiles highlight hemp's strength in lipid-stabilizing tocopherols and signaling precursors, while sunflower excels in providing a broad spectrum of B-vitamins, carotenoids, and biological methyl-donors.

2.7. Mineral content

The mineral architecture of hemp (*Cannabis sativa* L.) and sunflower (*Helianthus annuus* L.) oilcakes establishes both byproducts as dense reservoirs of essential macrominerals and trace elements, though they exhibit divergent accumulation patterns. Both materials possess a robust total mineral content, with hemp oilcake typically yielding an ash content between 5.5% and 9.5% and sunflower oilcake ranging from 6.0% to 7.5% [2,15,16]. These levels reflect the high physiological value of these "circular bio-ingredients," making them ideal for supplementing mineral-deficient livestock diets and human nutritional formulations [8].

Regarding macromineral distribution, hemp oilcake is a superior source of phosphorus (1.10–1.80%) and magnesium (6,000–8,000 mg/kg), which are vital for bone mineralization and cellular energy transfer [2,57]. Sunflower oilcake, while slightly lower in phosphorus (0.60–1.30%), offers a competitive magnesium profile (0.50–0.65%) and slightly higher concentrations of potassium (1.0–1.5%) and calcium (0.20–0.45%) [16,61]. Additionally, hemp is distinguished by a specific sulfur fraction (0.2–0.4%) and a sodium content ranging from 150 to 400 mg/kg, which are essential for amino acid synthesis and osmotic balance, respectively [15] (Table 8).

Table 8 Mineral content

Compound Name	Concentration of hemp oilcake	Concentration of sunflower oilcake	Reference
Ash (Minerals)	5.5% – 9.5%	6.0% – 7.5%	[2,15] [8,16]
Magnesium (Mg)	6,000 – 8,000 mg/kg	0.50% – 0.65%	[2,15] [61]
Iron (Fe)	150 – 250 mg/kg	450 – 500 mg/kg	[15,57] [10,57]
Zinc (Zn)	80 – 120 mg/kg	50 – 80 mg/kg	[2,15] [16,61]
Phosphorus (P)	1.10% – 1.80% (dry matter)	0.60% – 1.30%	[2,57] [16,61]
Potassium (K)	0.90% – 1.30% (dry matter)	1.0% – 1.5%	[2,57] [16]
Calcium (Ca)	0.15% – 0.35% (dry matter)	0.20% – 0.45%	[2,15] [16,61]
Copper (Cu)	15 – 30 mg/kg	15 – 30 mg/kg	[15,57] [10,16]
Manganese (Mn)	90 – 150 mg/kg	25 – 45 mg/kg	[2,15] [16,61]
Sodium (Na)	150 – 400 mg/kg		[2,15]
Lead (Pb)	0.05 – 2.50 mg/kg (Soil dependent)	10 – 150 mg/kg (soil dependent)	[10,62] [10,61]
Cadmium (Cd)	0.01 – 0.80 mg/kg (Soil dependent)	-	[11,62]
Sulfur (S)	0.2% – 0.4% (dry matter)	-	[2,15]
Boron (B)	-	10 – 25 mg/kg	[10,61]
Molybdenum (Mo)	-	0.5 – 1.5 mg/kg	[10]
Selenium (Se)	-	0.1 – 0.6 mg/kg	[16,57]

The trace element profiles further highlight the specialized biological utility of each species. Hemp oilcake excels in the accumulation of manganese (90–150 mg/kg) and zinc (80–120 mg/kg), both of which serve as critical cofactors for antioxidant enzymes [2,15]. Conversely, sunflower oilcake is a potent source of iron, with concentrations reaching 450 to 500

mg/kg - nearly double that found in hemp residues [10,57]. Sunflower byproducts also provide a unique suite of microelements not typically reported in hemp, including boron (10–25 mg/kg), molybdenum (0.5–1.5 mg/kg), and the antioxidant-essential element selenium (0.1–0.6 mg/kg) [10,16].

While both oilcakes share similar concentrations of copper (15–30 mg/kg), their safety profiles regarding heavy metal accumulation are heavily contingent upon soil conditions. Sunflower oilcake has demonstrated a higher propensity for the uptake of lead (10–150 mg/kg) in specific environments compared to hemp (0.05–2.50 mg/kg), though both are utilized in phytoremediation strategies [10,61,62]. Hemp residues also show detectable but low levels of cadmium (up to 0.80 mg/kg) [62]. Ultimately, the high biological value of these mineral profiles allows for targeted nutritional applications, with hemp favoring skeletal and enzymatic support through phosphorus and manganese, while sunflower provides superior iron and selenium density for metabolic health.

2.8. Polyphenolic and pigment content

The polyphenolic and secondary metabolite profiles of hemp (*Cannabis sativa* L.) and sunflower (*Helianthus annuus* L.) oilcakes represent two distinct biochemical strategies for antioxidant defense, with sunflower displaying a significantly higher density of phenolic compounds. While hemp oilcake contains total phenolics in the range of 0.85 to 1.60 mg GAE/g, sunflower oilcake serves as an exceptional reservoir, with concentrations reaching 30.0 to 45.0 mg GAE/g (Table 9)—accounting for up to 4.5% of the total byproduct mass [8,56,63]. This disparity is largely driven by chlorogenic acid, which dominates the sunflower profile at 2.0% to 4.0%, representing 60% to 70% of its total phenolics [17].

Both oilcakes provide a complex array of phenolic acids, including ferulic, caffeic, syringic, and vanillic acids, though sunflower consistently maintains higher industrial-scale concentrations. For instance, caffeic acid levels in sunflower range from 0.1% to 0.5% (up to 3.0 mg/g), while hemp contains more modest levels of 30 to 90 µg/g [56,59]. Sunflower oilcake is further distinguished by its sinapic and proto-catechuic acid content, alongside organic acids like malic acid (0.5–0.9%), which contribute to its techno-functionality and metabolic utility [8,16].

Hemp oilcake, while lower in total phenolic content, is unique for its profile lignanamides and pigments. It contains bioactive lignans such as cannabisin A, B, and F, alongside grossamide and N-trans-caffeoyltyramine, which are appreciate for their specific neuroprotective and anti-inflammatory potential [39,59].

Furthermore, hemp residues retain a notable pigment profile within their residual oil, including chlorophyll *a* and *b* (1.5–6.5 mg/kg) and carotenoids like lutein and zeaxanthin (1.2–3.8 mg/kg), which serve as critical lipid-stabilizing antioxidants [9,35].

Ultimately, the functional value of these byproducts is defined by their "circular" utility: sunflower oilcake acts as a potent source of bulk polyphenols and flavonoids (0.4–1.2%) for antioxidant-rich feed and food applications, whereas hemp oilcake offers a more targeted profile of rare lignans and fat-soluble pigments that elevate its status as a specialized functional bio-ingredient [3,59,63].

Table 9 Polyphenolic and pigment content

Compound Name	Concentration of hemp oilcake	Concentration of sunflower oilcake	Reference
Total Phenolics	0.85 – 1.60 mg GAE/g	30.0 – 45.0 mg GAE/g	[8,56] [63]
Total Polyphenols	-	1.0% – 4.5% (Expressed as GAE)	[63]
Total Flavonoids	20 – 50 mg RE/100g	0.4% – 1.2%	[56,59] [8,56]
Ferulic Acid	150 – 350 µg/g	0.05% – 0.15%	[56,59] [56]
p-Coumaric Acid	80 – 200 µg/g	-	[8,56]
Caffeic Acid	30 – 90 µg/g	0.1% – 0.5% 1.5 – 3.0 mg/g	[56,59] [56] [8,56]
Syringic Acid	65 – 75 µg/100g	0.01% – 0.04%	[54] [56]
Vanillic Acid	1.4 – 1.7 µg/100g	0.01% – 0.03%	[54] [56]
Cannabisin B (Lignan)	40 – 120 µg/g	-	[39,59]
Cannabisin A (Lignan)	30 – 100 µg/g	-	[39,59]
Cannabisin F	5 – 20 µg/g	-	[39,59]
Grossamide (Lignanamide)	10 – 45 µg/g	-	[15,59]
N-trans-caffeoyltyramine	5 – 25 µg/g	-	[39,59]
Chlorogenic Acid	-	2.0% – 4.0% 60% – 70% of total phenolics	[63] [17]
Guaiacol (Phenolic)	-	Trace (Aroma marker)	[17]
Proto-Catechuic Acid	-	0.02% – 0.05%	[56,58]
Sinapic Acid	-	0.05% – 0.12%	[8,56]
Chlorophyll *a* and *b*	1.5 – 6.5 mg/kg (residual oil)	-	[9,60]
Carotenoids (Lutein/Zeaxanthin)	1.2 – 3.8 mg/kg (residual oil)	-	[9,35]
Malic Acid	-	0.5% – 0.9%	[16,56]

2.9. Sterolic content

The phytosterol and phytoestrogen profiles of hemp (*Cannabis sativa* L.) and sunflower (*Helianthus annuus* L.) oilcakes provide a complex layer of bioactivity to these materials, particularly regarding cholesterol-modulating potential and endocrine-related health. Both oilcakes are rich in β-sitosterol, which serves as the primary sterol component. In hemp oilcake, this compound is found at concentrations of 1,500 to 2,500 mg/kg of residual fat, while in sunflower, it dominates the sterol fraction at 50% to 65% of the total sterol content [5,64]. These high levels of β-sitosterol are critical for the oxidative stability of the residual lipids and offer significant potential for developing functional ingredients with heart-health claims [56].

Despite sharing a common primary sterol, the two species exhibit distinct secondary sterol distributions. Hemp oilcake is uniquely characterized by γ-sitosterol, which constitutes 12% to 15% of the seed extract and is noted for its specific metabolic utility [39,64]. Conversely, sunflower oilcake possesses a more diverse sterol landscape, featuring stigmasterol at 8% to 12% and trace amounts of campestanol (< 1%), alongside campesterol, which is present in both species [47,64]. In hemp, campesterol remains a notable fraction at 400 to 600 mg/kg of the residual fat, whereas in sunflower, it accounts for 6% to 9% of total sterols.The presence of phytoestrogens further distinguishes the biological utility of sunflower residues. Sunflower oilcake contains measurable levels of coumestrol (0.5–1.8 mg/kg), a potent phytoestrogen that contributes to its overall physiological profile, along with trace amounts of daidzein and genistein [3,56] (Table 10).

Table 10 Sterolic content

Compound Name	Concentration of hemp oilcake	Concentration of sunflower oilcake	Reference
B-Sitosterol	1,500 – 2,500 mg/kg (residual fat)	50% – 65% of total sterols	[5,64] [13,64]
γ-Sitosterol	12% – 15% (of seed extract)	-	[39,64]
Campesterol	400 – 600 mg/kg (residual fat)	6% – 9% of total sterols	[5,47] [47,64]
Campestanol	-	< 1% of total sterols	[47,64]
Stigmasterol	-	8% – 12% of total sterols	[47,64]
Coumestrol (Phytoestrogen)	-	0.5 – 1.8 mg/kg	[16,56]
Daidzein / Genistein	-	Trace (< 0.1 mg/kg)	[3]

While hemp oilcake focuses on a high-density sterol profile for lipid stability and metabolic health, sunflower oilcake offers a broader spectrum of sterols and specified endocrine-active compounds. These differences allow for the targeted application of these oilcakes in specialized human and animal nutrition, where specific sterol ratios or phytoestrogen contents are required for therapeutic outcomes [64].

2.10. Antinutritional factors content

The safety and digestibility of hemp (*Cannabis sativa* L.) and sunflower (*Helianthus annuus* L.) oilcakes are influenced by a diverse range of antinutritional factors, which require careful consideration during food and feed formulation. Both materials contain significant but comparable levels of phytic acid, ranging from 1.0% to 5.5%, which can act as a chelating agent for essential minerals [3,15,56]. Despite this commonality, the two species exhibit starkly different profiles regarding protein-digestibility inhibitors and bioactive secondary metabolites.

Hemp oilcake is characterized by a higher concentration of trypsin inhibitors (10.5–20.2 TIU/mg) compared to the remarkably low levels found in sunflower oilcake (0.5–1.8 TIU/mg). This suggests that while sunflower protein is inherently more accessible to digestive enzymes without extensive processing, hemp may benefit from targeted thermal treatments to optimize protein utilization [3]. Furthermore, hemp contains a more robust fraction of saponins (1.5%–2.8%) and a measurable presence of condensed tannins (0.05%–0.15%), whereas sunflower remains below 0.5% for saponins and contains negligible tannins. Hemp also retains trace amounts of alkaloids, though its glucosinolate content is considered negligible [65,66] (Table 11).

Conversely, sunflower oilcake maintains an exceptionally clean profile regarding these specific inhibitors, though it does contain trace levels of calcium oxalate (< 0.1%), a compound not typically highlighted in hemp residues [3].

These divergent -antinutritional factors landscapes dictate the processing requirements for each meal: hemp's profile necessitates monitoring for enzyme inhibition and saponin-related bitterness, while sunflower's primary challenge remains the management of phytic acid and its high phenolic density. Understanding these limits ensures that both oilcakes can be safely transitioned from industrial byproducts into high-value, bioactive ingredients [67].

Table 11 Antinutritional content of hemp oilcake

Compound Name	Concentration of hemp oilcake	Concentration of sunflower oilcake	Reference
Phytic Acid (Antinutrient)	2.5% – 5.5%	1.0% – 5.5%	[3,15] [3,56]
Trypsin Inhibitors	10.5 – 20.2 TIU/mg	0.5 – 1.8 TUI/mg	[3] [3,56]
Saponins	1.5% – 2.8% (dry matter)	< 0.5%	[3] [3]
Total Glucosinolates	< 1.0 µmol/g (Negligible)	-	[3]
Condensed Tannins	0.05% – 0.15% (dry matter)	-	[3,15]
Total Alkaloids	Trace amounts	--	[65,66]
Calcium Oxalate	-	< 0.1%	[3]

4. Conclusion

In conclusion, the comparative analysis of these oilseed byproducts reveals that hemp and sunflower oilcakes are both high-value "circular bio-ingredients" that offer distinct advantages based on their biochemical profiles. Hemp oilcake stands as the superior choice for high-digestibility applications, particularly in specialized human nutrition or juvenile animal feed, due to its edestin-dominant protein fraction and high arginine content. In contrast, sunflower oilcake is the preferred substrate for addressing sulfur-amino acid deficiencies, providing significantly higher levels of methionine compared to most other plant-based oilseed residues.

From a micronutrient and industrial perspective, the differences between the two are evident and provide targeted opportunities for fortification. Sunflower oilcake is markedly more effective for the formulation of iron-dense diets, offering nearly double the iron concentration of hemp, while also possessing a more robust "antioxidant shield" due to its high total phenolic content and the dominance of chlorogenic acid. Hemp oilcake, however, offers unique therapeutic and bioactive potential through its retention of specialized lignanamides and β-caryophyllene, providing anti-inflammatory benefits that extend beyond basic macronutrient delivery.

Ultimately, the successful industrial integration of both oilcakes depends on addressing specific botanical constraints and regulatory requirements. The high phytic acid levels found in both species necessitate specialized processing, such as thermal treatment or enzyme supplementation, to unlock mineral bioavailability. Furthermore, because both plants are hyperaccumulators, rigorous soil-to-product monitoring is essential to ensure compliance with stringent 2026 legal limits for heavy metals. By leveraging sunflower's pectin-rich hulls for food stabilization and hemp's high cellulosic content for sustainable bio-composites, these byproducts establish themselves as the most viable, sustainable alternatives to conventional protein sources in the modern agricultural landscape.

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References

1. Bapat K, Kailas L, Pask C, Kee TP, Russell S. Study of Hemp Fiber Properties Modified via Long-Duration Low-Pressure Argon and Oxygen Plasma Treatments. *ACS Omega*. **2025**;10:61435–51. https://doi.org/ 10.1021/acsomega.5c06420
2. Voicea I, Nenciu F, Popa D, Onisei T, Rascol M, Vlaicu P, et al. Valorizing Hempseed Meal as a Circular Bio-Ingredient for Sustainable Fisheries Development. *Sustainability*. **2025**;17:10656. https://doi.org/10.3390/ su172310656
3. Axentii M, Codină GG. Exploring the Nutritional Potential and Functionality of Hemp and Rapeseed Proteins: A Review on Unveiling Anti-Nutritional Factors, Bioactive Compounds, and Functional Attributes. *Plants*. Multidisciplinary Digital Publishing Institute; **2024**;13:1195. https://doi.org/10.3390/ plants13091195
4. Haczkiewicz M, Świtalska M, Łyczko J, Pluta M, Wietrzyk J, Gliszczyńska A. Extraction of Cannabinoids and Terpenes from Hemp Flowers and Leaves (Cannabis sativa L., Futura 75): Chemical Profiling and Evaluation of Anticancer Properties. *Molecules*. **2025**;30:1325. https://doi.org/10.3390/ molecules30061325
5. Izzo L, Pacifico S, Piccolella S, Castaldo L, Narváez A, Grosso M, et al. Chemical Analysis of Minor Bioactive Components and Cannabidiolic Acid in Commercial Hemp Seed Oil. *Molecules*. **2020**;25:3710. https://doi.org/10.3390/molecules25163710
6. Cecile L-G, Pierre C, Camille H, Christelle F, Marion L, Virginie M-T, et al. Non-Destructive Analysis Using Near-Infrared Spectroscopy to Predict Albumin, Globulin, Glutelin, and Total Protein Content in Sunflower Seeds. *Laboratoire de Chimie Agro-Industrielle (LCA), Toulouse University*; **2024** [cited 2026 Mar 2]; https://www.mdpi.com/2071-1050/16/2/737. Accessed 2 Mar 2026
7. Alberdi-Cedeño J, Martinez-Yusta A, Ruiz-Aracama

A, Goicoechea-Oses E, Nieva-Echevarria B. Different effects of tocopherol natural extract on sunflower oil stability under frying and accelerated storage conditions: A comprehensive study on the fate of major and minor components of oil, and added tocopherols. *Food Chem*. **2025**;472:142871. https://doi.org/10.1016 /j.foodchem.2025.142871

8. Multescu M, Marinas IC, Susman IE, Belc N. Byproducts (Flour, Meals, and Groats) from the Vegetable Oil Industry as a Potential Source of Antioxidants. *Foods*. Multidisciplinary Digital Publishing Institute; **2022**;11:253. https://doi.org/ 10.3390/foods11030253
9. Allay A, Ati R, Rbah Y, Fauconnier M-L, Caid H, Elamrani A, et al. Extraction technologies for hemp seed oil: a comparative study of yield, bioactive compound extractability, and oxidative stability. *Sustain Food Technol*. **2025**;4:709–26. https://doi.org/ 10.1039/D5FB00424A
10. Al-Jobori K, Kadhim A. Evaluation of sunflower (Helianthus annuus L.) for phytoremediation of lead contaminated soil. *J Pharm Sci Res*. **2019**;11:847–54.
11. Nassazzi W, Wu T-C, Jass J, Lai FY, Ahrens L. Phytoextraction of per- and poly-fluoroalkyl substances (PFAS) and the influence of supplements on the performance of short–rotation crops. *Environ Pollut*. **2023**;333:122038. https://doi.org/10.1016/ j.envpol.2023.122038
12. Buburuz A-A, Naie M, Mîrzan O, Popa L-D, Enea A. Research Regarding the Influence of Some Technological Factors on the Productivity of Some Monoecious Hemp Varieties Cultivated at Agricultural Research and Development Station Secuieni in Romania. *Agronomy*. Multidisciplinary Digital Publishing Institute; **2024**;14:2946. https://doi.org/ 10.3390/agronomy14122946
13. Petraru A, Sonia A, Lacramioara S. Lipids from Oilcakes—High Quality Ingredients for Functional Food Products. *Molecules 2025*; **2025** [cited 2026 Mar 1]; https://www.mdpi.com/1420-3049/30/17/3640. Accessed 1 Mar 2026
14. Alpiger SB, Gregersen SB, Ellermann AM, Dissing TJJ, Corredig M. Extraction of Protein-Enriched Fractions from Sunflower and Hemp Seeds: Composition and Colloidal Stability of Less Refined Fractions as a Function of Initial pH. *Future Foods*. **2025**; 11:100541. https://doi.org/10.1016/j.fufo.2025.100541
15. Karabulut G, Kahraman O, Pandalaneni K, Kapoor R, Feng H. A comprehensive review on hempseed protein: Production, functional and nutritional properties, novel modification methods, applications, and limitations. *Int J Biol Macromol*. **2023**;253:127240. https://doi.org/ 10.1016/j.ijbiomac.2023.127240
16. Smeu I, Dobre AA, Cucu EM, Mustățea G, Belc N, Ungureanu EL. Byproducts from the Vegetable Oil Industry: The Challenges of Safety and Sustainability. *IBA Bucharest*; **2022** [cited 2026 Feb 18]; https://www.mdpi.com/2071-1050/14/4/2039. Accessed 18 Feb 2026
17. Huseynli L, Walser C, Blumenthaler L, Vene K, Dawid C. Toward a Comprehensive Understanding of Flavor of Sunflower Products: A Review of Confirmed and Prospective Aroma- and Taste-Active Compounds. *Foods*. Multidisciplinary Digital Publishing Institute; **2025**;14:1940. https://doi.org/10.3390/foods14111940
18. Taha F, Yamamah G, Mohamed G, Mohamed SS, Wagdy SM. Biological activities of sunflower protein hydrolysate. *World Appl Sci J*. **2014**;30:1462–70. https://doi.org/10.5829/idosi.wasj.2014.30.11.14185
19. Ishii AK, Toto Pacioles C, Were L. Color and structural modifications of alkaline extracted sunflower protein concentrates and isolates using L-cysteine and glutathione. *Food Res Int*. **2021**;147:110574. https://doi.org/10.1016/j.foodres.2021.110574
20. Sen B, Bhowmik A, Singh G, Mishra V, Debnath S, Zairov R, et al. Alumina-enriched sunflower bio-oil in machining of Hastelloy C-276: a fuzzy Mamdani model-aided sustainable manufacturing paradigm. *Sci Rep*. Nature Publishing Group; **2024**;14:29194. https://doi.org/10.1038/s41598-024-80254-z
21. Velliquette RA, Fast DJ, Maly ER, Alashi AM, Aluko RE. Enzymatically derived sunflower protein hydrolysate and peptides inhibit NFκB and promote monocyte differentiation to a dendritic cell phenotype. *Food Chem*. **2020**;319:126563. https://doi.org/ 10.1016/j.foodchem.2020.126563
22. Casiraghi A, Gentile A, Selmin F, Gennari CGM, Casagni E, Roda G, et al. Ultrasound-Assisted Extraction of Cannabinoids from Cannabis Sativa for Medicinal Purpose. *Pharmaceutics*. Multidisciplinary Digital Publishing Institute; **2022**;14:2718. https://doi.org/10.3390/pharmaceutics14122718
23. Firouzi M, Siddiqua S, Kazemian H, Kiamahalleh MV. Green solvent-based extraction of cellulose from hemp bast fibers: From treatment efficacy to characterizations and optimization. *Int J Biol Macromol*. **2025**;288:138689. https://doi.org/10.1016/ j.ijbiomac.2024.138689
24. Leonard W, Zhang P, Ying D, Nie S, Liu S, Fang Z. Post-extrusion physical properties, techno-functionality and microbiota-modulating potential of hempseed (*Cannabis sativa* L.) hull fiber. *Food Hydrocoll*. **2022**;131:107836. https://doi.org/10.1016/ j.foodhyd.2022.107836
25. Quispe A, Shumyko SJ. Industrial Hemp (Cannabis sativa L.) for a sustainable feeding of ruminants: nutritional characterization and effects on animal performance. *Università degli studi di Padova*; **2024** [cited 2026 Mar 1]; https://tesidottorato. depositolegale.it/handle/20.500.14242/158421. Accessed 1 Mar 2026
26. Filon D, Anastopoulos G, Karonis D. Synthesis and Evaluation of Sunflower-Oil-Based Esters as Biolubricant Base Oils Using Ca/TEA Alkoxide Catalyst. *Lubricants*. **2025**;13:345. https://doi.org/

10.3390/lubricants13080345
27. Kabir MM, Al-Haik M, Aldajah S, Lau K tak, Wang H, Islam MM. Effect of Hemp Fibre Surface Treatment on the Fibre-Matrix Interface and the Influence of Cellulose, Hemicellulose, and Lignin Contents on Composite Strength Properties. *Adv Mater Sci Eng*. **2021**;2021:1–17. https://doi.org/10.1155/2021/9753779
28. Shariatmadari F. Emergence of hemp as feed for poultry. *Worlds Poult Sci J*. **2023**;79:1–14. https://doi.org/10.1080/00439339.2023.2234871
29. Ahmed B, Gwon J, Thapaliya M, Adhikari A, Ren S, Wu Q. Combined effects of deep eutectic solvent and microwave energy treatments on cellulose fiber extraction from hemp bast. *Cellulose*. **2023**;30:1–17. https://doi.org/10.1007/s10570-023-05081-3
30. Kaya G, Belibağlı P, Acir S, Ozdemir S, Tollu G, Demirdogen RE, et al. Cellulose extraction from hemp fiber and carbonized nanocellulose production, characterization, antibiotic loading, and comparison of antibacterial properties. *Cellulose*. **2025**;32:6551–72. https://doi.org/10.1007/s10570-025-06630-8
31. Nnaemeka E, Courage A, Lili C, Armando G. M. Evaluation of Polybutylene Succinate Composites Reinforced with Lignin and Milled Hemp Stalks. *Department of Forest, Rangeland and Fire Sciences, University of Idaho*; **2026** [cited 2026 Mar 1]; https://www.mdpi.com/1996-1944/19/2/275. Accessed 1 Mar 2026
32. Novi V, Labonne L, Ballas S, Véronèse T, Evon Ph. Insulation blocks made from sunflower pith with improved durability properties. *Ind Crops Prod*. **2024**;210:118161. https://doi.org/10.1016/j.indcrop.2024.118161
33. Muñoz-Almagro N, Garrido-Galand S, Taladrid D, Moreno-Arribas MV, Villamiel M, Montilla A. Use of natural low-methoxyl pectin from sunflower by-products for the formulation of low-sucrose strawberry jams. *J Sci Food Agric*. **2022**;102. https://doi.org/ 10.1002/jsfa.11948
34. Kabir MM, Wang H, Lau KT, Cardona F. Effects of chemical treatments on hemp fibre structure. *Appl Surf Sci*. **2013**;276:13–23. https://doi.org/10.1016/ j.apsusc.2013.02.086
35. Rosso E, Armone R, Costale A, Giorgia M, Chiofalo B. Hemp Seed (Cannabis sativa L.) Varieties: Lipids Profile and Antioxidant Capacity for Monogastric Nutrition. *Animals*. **2024**;14. https://doi.org/ 10.3390/ani14182699
36. Szmek J, Englmaierová M, Skřivan M, Pěchoučková E. Evaluation of hemp seeds (Cannabis sativa L.) and flax seeds (Linum usitatissimum L.) as feed ingredients in laying hen diets: effects on the performance, egg quality, and n-3 fatty acid composition of egg yolks. *Front Anim Sci [Internet]*. Frontiers; **2025** [cited 2026 Mar 1];6. https://doi.org/10.3389/fanim.2025.1685765
37. Ghaffari M, Gholizadeh A, Rauf S, Shariati F. Drought-stress induced changes of fatty acid composition affecting sunflower grain yield and oil quality. *Food Sci Nutr*. **2023**;11:7718–31. https://doi.org/10.1002/fsn3.3690
38. Suhag R, Razem M, Ferrentino G, Morozova K, Zatelli D, Scampicchio M. Real-time monitoring of vegetable oils photo-oxidation kinetics using differential photocalorimetry. *Food Chem*. **2024**;456. https://doi.org/10.1016/j.foodchem.2024.140011
39. Tiziana M. S, Gianfranco D, Alessia F, Simona F, Tatiana C, Martina C, et al. Nutrients and Bioactive Compounds from Cannabis sativa Seeds: A Review Focused on Omics-Based Investigations. *Italian National Agency for New Technologies*; **2025** [cited 2026 Mar 1]; https://www.mdpi.com/1422-0067/26/11/5219. Accessed 1 Mar 2026
40. Allay A, Moumen AB, Rbah Y, Fauconnier M-L, Nkengurutse J, Caid HS, et al. Effect of screw pressing temperature on yield, bioactive compounds, and quality of hemp (Cannabis sativa L.) seed oil. *J Cannabis Res*. **2025**;7:37. https://doi.org/10.1186/s42238-025-00296-6
41. Sopian Y, Sivapirunthep P, Jayanegara A, Chaosap C. Dietary Hemp (Cannabis sativa L.) Products Enhance Egg Yolk Omega-3 Fatty Acids and Color Without Compromising Laying-Hen Performance: A Meta-Analysis. *Anim Open Access J MDPI*. **2025**;15:2062. https://doi.org/10.3390/ani15142062
42. Gakhar N, Goldberg E, Jing M, Gibson R, House J. Effect of feeding hemp seed and hemp seed oil on laying hen performance and egg yolk fatty acid content: Evidence of their safety and efficacy for laying hen diets. *Poult Sci*. **2012**;91:701–11. https://doi.org/ 10.3382/ps.2011-01825
43. Salas JJ, Martínez-Force E, Garcés R. Very long chain fatty acid synthesis in sunflower kernels. *J Agric Food Chem*. **2005**;53:2710–6. https://doi.org/10.1021/ jf047939e
44. Salas J, Martínez Force E, Harwood J, Venegas-Calerón M, Aznar-Moreno J, Moreno Perez A, et al. Biochemistry of high stearic sunflower, a new source of saturated fats. *Prog Lipid Res*. **2014**; https://doi.org/10.1016/j.plipres.2014.05.001
45. Belingheri C, Giussani B, Rodriguez-Estrada MT, Ferrillo A, Vittadini E. Oxidative stability of high-oleic sunflower oil in a porous starch carrier. *Food Chem*. **2015**;166:346–51. https://doi.org/10.1016/j.foodchem.2014.06.029
46. Fernández-Martínez J, Pérez-Vich B, Velasco L, Dominguez J. Breeding for specialty oil types in sunflower. *Helia*. **2014**;75–80. https://doi.org/10.2298/ HEL0746075F
47. Ryan E, McCarthy FO, Maguire AR, O'Brien NM. Phytosterol Oxidation Products: Their Formation, Occurrence, and Biological Effects. *Food Rev Int*. Taylor & Francis; **2009**;25:157–74. https://doi.org/ 10.1080/87559120802682797
48. Citti C, Linciano P, Panseri S, Vezzalini F, Forni F, Vandelli MA, et al. Cannabinoid Profiling of Hemp Seed Oil by Liquid Chromatography Coupled to High-

Resolution Mass Spectrometry. *Front Plant Sci [Internet]*. Frontiers; **2019** [cited 2026 Mar 1];10. https://doi.org/10.3389/fpls.2019.00120
49. Regulation (EU) 2015/2283 of the European Parliament and of the Council of 25 November 2015 on novel foods, amending Regulation (EU) No 1169/2011 of the European Parliament and of the Council and repealing Regulation (EC) No 258/97 of the European Parliament and of the Council and Commission Regulation (EC) No 1852/2001 (Text with EEA relevance) [Internet]. *OJ L* Nov 25, **2015**. http://data.europa.eu/eli/reg/2015/2283/oj. Accessed 29 Apr 2026
50. Provisional safe level for cannabidiol as a novel food | *EFSA [Internet]*. **2026** [cited 2026 Apr 29]. https://www.efsa.europa.eu/en/news/provisional-safe-level-cannabidiol-novel-food. Accessed 29 Apr 2026
51. HOTĂRÂRE privind aprobarea Strategiei locale de asistență și prevenire a adicțiilor pentru perioada **2025-2030** în Sectorul 1 al Municipiului București.
52. Plant variety catalogues, databases & information systems - *Food Safety [Internet]*. [cited **2026** Apr 29]. https://food.ec.europa.eu/plants/plant-reproductive-material/plant-variety-catalogues-databases-information-systems_en. Accessed 29 Apr 2026
53. Luca SV, Kittl T, Minceva M. Supercritical CO2 extraction of hemp flowers: A systematic study to produce terpene-rich and terpene-depleted cannabidiol fractions. *Ind Crops Prod*. **2022**;187:115395. https://doi.org/10.1016/j.indcrop.2022.115395
54. Przybylska-Balcerek A, Frankowski J, Graczyk M, Niedziela G, Sieracka D, Wacławek S, et al. Profile of Polyphenols, Fatty Acids, and Terpenes in Henola Hemp Seeds Depending on the Method of Fertilization. *Molecules*. Multidisciplinary Digital Publishing Institute; **2024**;29:4178. https://doi.org/10.3390/ molecules29174178
55. Velasco L, Pérez-Vich B, Fernández-Martínez J. Evaluation of Wild Sunflower Species for Tocopherol Content and Composition. *Helia*. **2014**;27:107–12. https://doi.org/10.2298/HEL0440107V
56. Petraru A, Amariei S. Recovery of bioactive compounds from oilcakes-a review. *Food Environ Saf J*. USV; **2022**;21.
57. Puraikalan Y, Scott M. Sunflower Seeds (Helianthus Annuus) and Health Benefits: A Review. *Recent Prog Nutr*. LIDSEN Publishing Inc; **2023**;3:1–5. https://doi.org/10.21926/rpn.2303010
58. Kuang C, Bi J, Cheng C, Dong Z, Li Y, Chen J, et al. Exploring nutritional profiles, bioactive compounds, and functional potential of Chinese hempseed (*Cannabis sativa* L.) varieties. *Ind Crops Prod*. **2025**;238:122360. https://doi.org/10.1016/j.indcrop.2025.122360
59. Ning K, Hou C, Wei X, Zhou Y, Zhang S, Chen Y, et al. Metabolomics Analysis Revealed the Characteristic Metabolites of Hemp Seeds Varieties and Metabolites Responsible for Antioxidant Properties. *Front Plant Sci*. **2022**;13:904163.https://doi.org/10.3389/ fpls.2022.904163
60. Tura M, Ansorena D, Astiasarán I, Mandrioli M, Toschi TG. Evaluation of Hemp Seed Oils Stability under Accelerated Storage Test. *Antioxidants*. **2022**;11:490. https://doi.org/10.3390/antiox11030490
61. Petraru A, Sonia A, Lacramioara S. Flaxseed Oilcake: An Ingredient with High Nutritional Value in the Realization of Innovative Food Products. *Foods 2025*; **2025** [cited 2026 Mar 1]; https://www.mdpi.com/2304-8158/14/7/1087. Accessed 1 Mar 2026
62. Najjapak S, Duangrat I, Apisit C, Alisa V. Phytoextraction Potential of Sunn Hemp, Sunflower, and Marigold for Carbaryl Contamination: Hydroponic Experiment. *ResearchGate [Internet]*. **2025** [cited 2026 Mar 1]; https://doi.org/10.3390/ijerph192416482
63. Bozan B, Temelli F. Chemical composition and oxidative stability of flax, safflower and poppy seed and seed oils. *Bioresour Technol*. **2008**;99:6354–9. https://doi.org/10.1016/j.biortech.2007.12.009
64. Bonciolini A, Vissio A, Calaminici R, Forte E, Cardenia V. Comparative study on phytosterol oxidation products determination in high oleic sunflower oil by using cholesterol oxidation products or purified phytosterol oxidation products as reference materials. *J Agric Food Res*. **2025**;21:101961. https://doi.org/10.1016/j.jafr.2025.101961
65. Chalannavar R, M S D, Malabadi R. Cannabis sativa: Phytochemistry-An updated Review. *Int J Biol Pharm Sci Arch*. **2026**;11:20–027. https://doi.org/10.53771/ ijbpsa.2026.11.1.0012
66. Hourfane S, Mechqoq H, Bekkali AY, Rocha JM, El Aouad N. A Comprehensive Review on Cannabis sativa Ethnobotany, Phytochemistry, Molecular Docking and Biological Activities. *Plants*. **2023**;12:1245. https://doi.org/10.3390/plants12061245
67. Nikša B, Korina K, Ana S, Dunja Š, Anita Š, Maja B, et al. Valorization of Food Waste: Extracting Bioactive Compounds for Sustainable Health and Environmental Solutions. *University of Zagreb Faculty of Food Technology and Biotechnology*; **2025** [cited 2026 Mar 2]; https://www.mdpi.com/2076-3921/14/6/714. Accessed 2 Mar 2026.