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POSSIBILITIES OF USING HEMP (*CANNABIS SATIVA* L.) AND ITS BY-PRODUCTS IN SHEEP NUTRITION – A REVIEW

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Abstract

Industrial hemp (*Cannabis sativa* L.) is a highly commercialized crop used in the production processes of more than 25,000 products in many different industries. Industrial hemp is a versatile, sustainable plant with a variety of applications in its various forms, including fibre from hemp stalks, foods from hemp seeds, and oil from hemp flowers and seeds. Hemp seeds in their hulled or whole form, stalks and grass, leaves, oil and oil meal have high potential for use as an alternative raw feed material in animal nutrition. Considering the fact that the share of feed cost in overall production costs in animal husbandry is around 70%, and the most important part of this feed cost is the protein source feed raw materials, it is important to reveal the possibilities of using alternative feed raw materials. Although there are many studies in the field of animal nutrition using hemp and its by-products, studies in sheep are limited. Because of their tendency to extensive feeding and their ability to use feed resources that other animals cannot use, sheep are known to breed well with a wide range of alternative feedstuffs. Due to these characteristics, research on feeding hemp to sheep has been increasing in recent years. In this review, the nutrient contents of hemp and its products and the findings of previous studies on feeding hemp to sheep were summarized and the possibilities of using hemp in sheep feeding were strived to be revealed.

Key words: sheep, hemp, hemp seed, hemp derivatives, nutrition

High-quality, human-edible protein can be produced from feed resources deemed unsuitable or undesirable for human consumption through animal production (van Hal et al., 2019). The issue of food provision can be solved while reducing environmental effects by using livestock to transform low opportunity cost feedstuffs such as by-products, food waste, and grazing resources into human-edible protein (van Hal et al., 2019). Animal output may be severely hampered by poor animal nutrition, particularly in cases where there are insufficient feed supplies in terms of both quality and quantity (Tona, 2018). Since animal protein sources are scarce, plant protein sources are currently the primary supply of protein for animal nutrition. Protein is a limiting factor in the production of animal goods (Patsios et al., 2020).

Protein source feeds make up the majority of the feed materials used in the creation of animal's diet to be fed to animals, notwithstanding variations based on physiological and breeding practices in different species. Raw resources for feed containing protein are imported at a premium cost. Around the world, a great deal of research is being done on the potential use of substitute protein sources in place of these raw ingredients for feed. In animal nutrition, fish meal, canola meal, and soybean meal are the most popular sources of protein. There is a need for alternative and sustainable protein sources for animal feed because these traditional sources are no longer viable and their use will be further restricted by growing costs. Industrial hemp might be one substitute (Šťastník et al., 2022).

Hemp is a multifunctional plant primarily cultivated for its fibre and oil, while other constituents of the plant have medicinal properties (Ali et al., 2012; Głodowska and Łyszcz, 2017). The principal applications of hemp are contingent upon its variety, provenance, and geographical location (Schultz, 2020). Hemp cultivars are mostly cultivated for seed production, with hemp oil being the most lucrative commodity (Callaway, 2004). Hemp seed typically contains 30–35% seed oil, which can only be obtained by the process of cold pressing (Hazekamp et al., 2010). Hemp meal, on the other hand, is the solid residue that remains after the oil has been extracted. The cold pressing technique maintains the integrity of the oil's physical and chemical properties. Depending on the specific process technology employed, a portion of the oil (0.4–10%) remains in the hemp meal after extraction (House et al., 2010). Hemp stalks are utilized in several industries such as textile, livestock (as litter for animals), and automotive, as they provide substantial quantities of fibre (Hazekamp et al., 2010; Andre et al., 2016). Hemp leaves and inflorescences include bioactive chemicals that are utilized in the production of medications and human meals (Hazekamp et al., 2010; Hartsel et al., 2016). The chemical composition of cannabis by-products is mostly determined by factors such as the variety of cannabis, the methods used for pressing, and the processing of the seeds (Mihoc et al., 2012). Nevertheless, the chemical composition of hemp by-product closely resembles that of soybean meal (SFC), with the exception of the husks, which have significantly lower levels of crude protein (CP) and ether extract (EE). Hemp by-products provide a substantial amount of highly digestible protein that can effectively fulfil the nutritional requirements of ruminants and poultry.

Animal feed is one of the numerous new applications for industrial hemp that have been discovered recently, contributing to the industry's growth (Wagner et al., 2022). Animal diets are supplemented with plant feed additives to enhance animal welfare and health. Consequently, there has been a surge in interest in hemp (*Cannabis sativa*) and its derivatives, leading to several investigations on the effects of *Cannabis sativa* chemicals on animals. Hemp oil, hempseed oil, and hempseed cake have been shown in several studies to enhance the fatty acid profiles of eggs, boost milk yield, and enhance animal performance and bone strength (Fallahi et al., 2022).

From the fibres in its stems to the nutrients in its seeds to the oil in its flowers, the cannabis plant (*Cannabis sativa* L.) is a sustainable and multipurpose plant that may be used for a wide range of functions (Raihan and Bijoy, 2023). The hemp plant is made up of seeds, stems, flowers, leaves, and roots (Figure 1). Nearly every portion of the hemp plant has multiple uses (Simiyu et al., 2022). As a result, hemp is a plant with practically endless uses for almost every component of it (Simiyu et al., 2022). Over 25,000 items are made from industrial hemp worldwide in a variety of industries, largely due to the expanding global market for this product (Kaur and Kander, 2023) (Figure 2). Thus, industrial hemp is a multipurpose, sustainable plant that can be used for many different purposes in all of its forms, such as food from hemp seeds, oil from hemp flowers and seeds, and fibre from hemp stalks (Kaur and Kander, 2023). Either the whole or hulled seeds can be used as food, animal feed, cosmetics, or cold pressed to manufacture oil. Building products, paper, textiles, and animal litter can all be made from the shives (hurd) and stem fibre (Farinon et al., 2020).

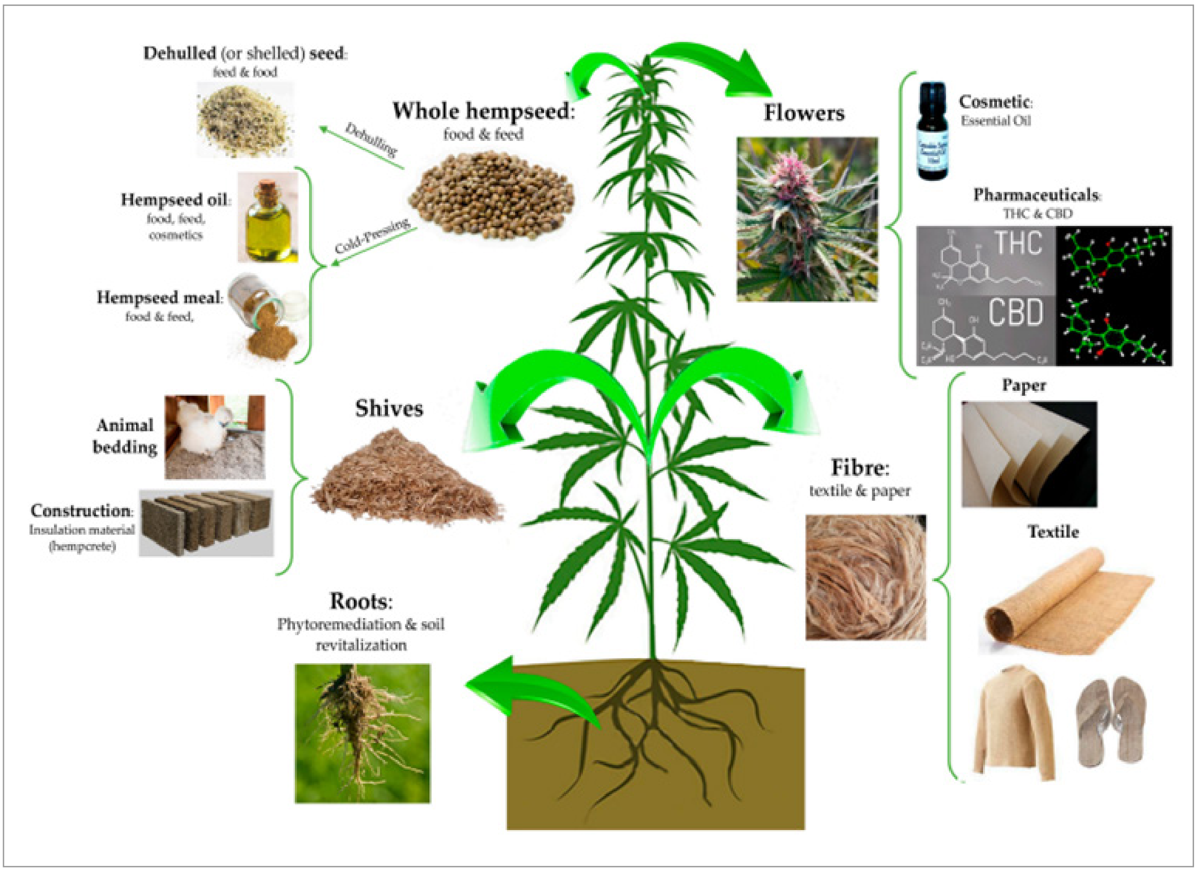

Figure 1. Components of the cannabis plant and its various uses (Farinon et al., 2020)

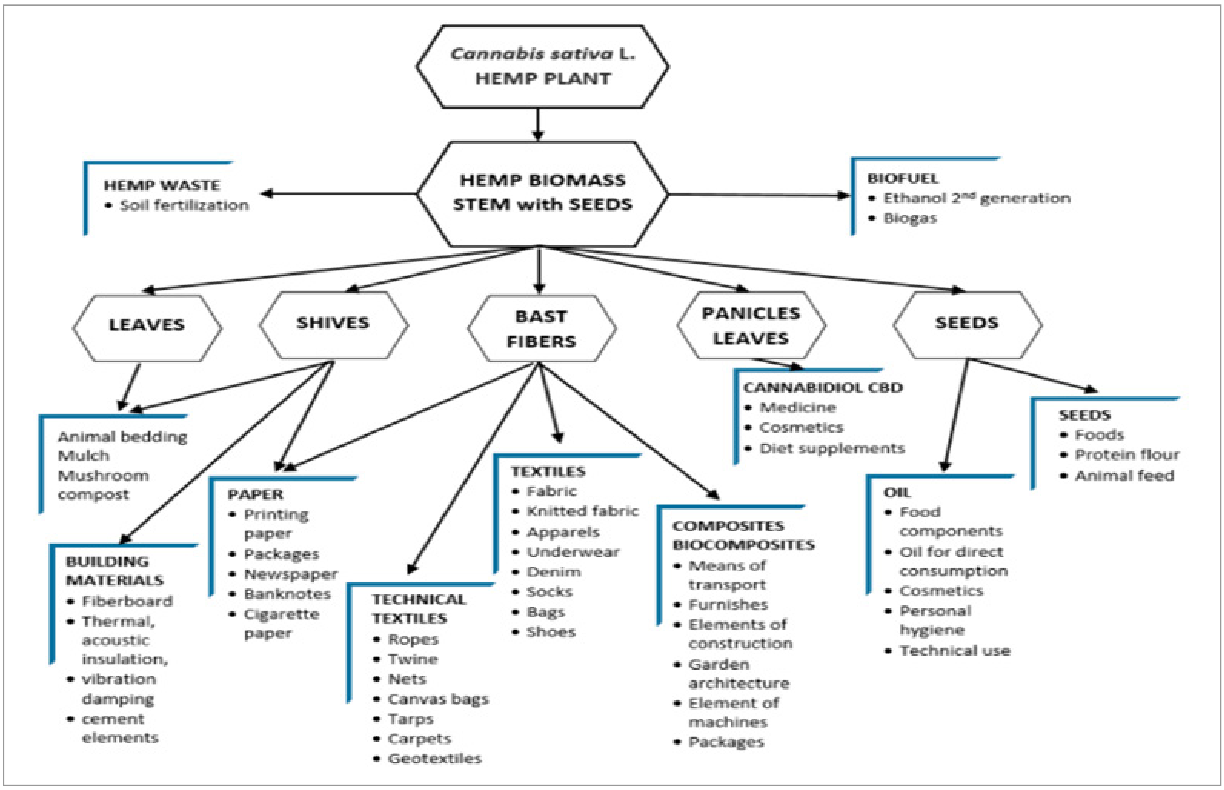

Figure 2. Various potential applications of the cannabis plant as a raw material (Zimniewska, 2022)

Table 1. Maximum permissible tetrahydrocannabinolic acid (THCA) contents in different hemp food products in Australia/New Zealand, the European Union and the USA (Burton et al., 2022)

Hemp product	Australia/New Zealand[a]	European Union[b]	USA[c]
Industrial hemp plant	0.35% or 1% dw	0.2% dw	0.3% dw
Hulled hemp seed	5 mg/kg	3 mg/kg	4 mg/kg
Hempseed oil	10 mg/kg	7.5 mg/kg	10 mg/kg
Hemp flour and hemp protein powder	10 mg/kg	3 mg/kg	Not specified
Hemp seed milk or other beverages	0.2 mg/kg	Not specified	Not specified
Milled hemp seed as ingredients	5 mg/kg	3 mg/kg	Not specified

[a]Food Standards Australia and New Zealand specify limits for *Cannabis sativa* seeds as food and ingredients in foods. FSANZ state that industrial hemp for food is limited at 1% THCA in leaves and flowering heads, though some states have set lower limits of 0.35%. Australia also specifies that hempseed products must contain no more than 75 mg/kg of CBD.

[b]The European Commission amended Regulation (EC) No. 1881/2006 to set maximum limits for hemp foods in Europe, though each state is free to set their own limits equal to or below these limits. The amended regulation takes effect 1 January 2023.

[c]The US Food and Drug Administration has not set formal limits for THCA in hemp-based foods. Though the "Generally Recognised as Safe" classification from the FDA specifies contaminant limits including THCA which are presented.

In many countries, hemp and hemp-derived products are not authorized for use in human or animal food. In the USA, food products are regulated by the Food and Drug Administration (FDA) (AAFCO, 2017). There are different limits for these components in hemp food products in various countries and jurisdictions. As an example, the permissible levels allowed in Australia, the EU and the USA for various hemp products (Government of South Australia 2020) are given in Table 1.

Hemp production in the world

From the equator to the poles, hemp is a plant that has adapted to a very wide range of climates and environments. It may be grown both wild and cultivated under various ecological conditions (Vavilov, 1992). Furthermore, growing interest is being shown in many locations in the production of hemp, a multipurpose industrial plant with a great potential for economic return in the form of fibres and seeds (Wimalasiri et al., 2021). France, China, Russia, Canada, Chile, Romania, Ukraine, Hungary, and the Netherlands are the most important hemp-producing nations; other nations include Austria, Italy, Czech Republic, Iran, Poland, Spain, Pakistan, Turkey, South Korea, and Japan. The highest production in North America is in Canada and in South America in Chile. France has the greatest output rate in Europe. The main three producers in Europe are France (more than

70% of EU production), the Netherlands (10%), and Austria (4%). Roughly 90% of the world's seed supply is produced in the top four seed-producing nations: France, China, Chile, and Russia (Süzerer et al., 2023; Faostat, 2023; Agreste, 2022). The hemp farming area and hempseed production statistics for 2021 are displayed in Figure 3. The most recent data available in our nation shows that there is a 6 ha hemp farming area, and the production of hemp seed, oil, cake, and leaf meal is 3, 1.05, 1.95, and 61.8 tonnes, respectively (Semwogerere et al., 2020) (Figure 4). With a projected value of USD 4.74 billion in 2022, the global industrial hemp market is projected to expand at a compound annual growth rate (CAGR) of 17.1% from 2023 to 2030. The market is being driven by an increase in demand for industrial hemp from various application industries (Yano and Fu, 2023; Burton et al., 2022; Grand View Research, 2023).

Nutrient contents

For thousands of years, people have utilized *Cannabis sativa*, sometimes known as industrial hemp, for a wide range of applications. The need for hemp cultivation has lately surged once more, despite a brief dip in interest during the 20th and 21st centuries. Above all, the broad variety of fatty acids and proteins found in hemp seed has sparked interest in the seed's nutritional profile. The availability of hemp seed and related by-products has increased in tandem with the growth in hemp production. A key element of sustainable agriculture is the capacity of animals to ingest undesirable waste products from a variety of crops and transform them into consumer commodities. Although it is unclear to what degree, research suggests that hemp fortification of diets may enhance the quality and composition of meat, milk, and eggs as a beneficial source of protein, fat, and fibre (Ely and Fike, 2022). Numerous studies suggest that supplementing ruminant animals with industrial hemp seed or by-products could be an effective feeding strategy to enhance the nutrients (lactose, fatty acids) in milk and dairy products (Šťastník et al., 2022).

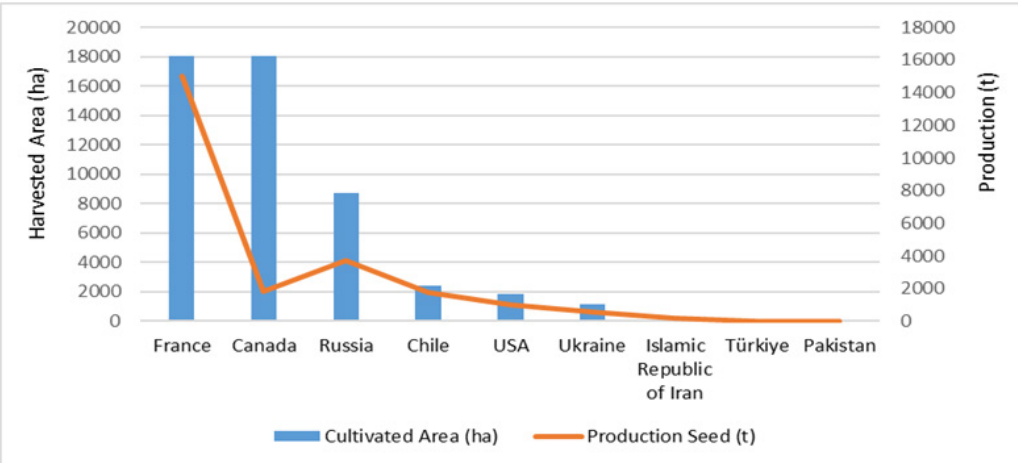

Figure 3. Hemp cultivation area and hempseed production by countries (FAOSTAT, 2023; Agreste, 2022)

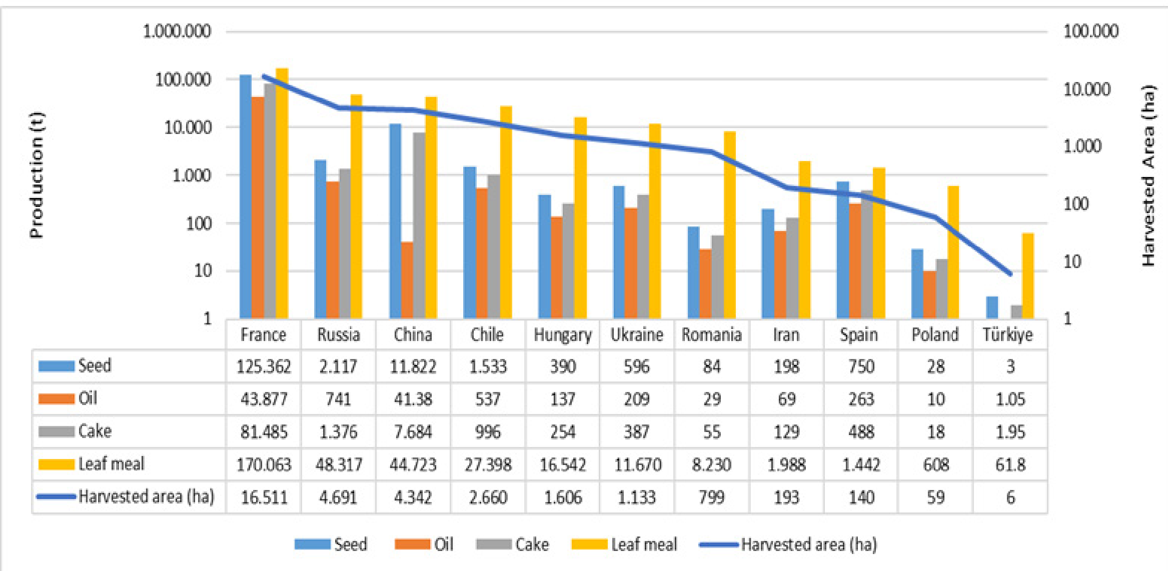

Figure 4. Global production of hemp by-products (modified from Semwogerere et al., 2020)

Table 2. Chemical composition of full-fat hemp seed, hempseed cake and hempseed meal in different studies (% on DM basis)

References	Callaway (2004)		Gibb et al. (2005)	Silversides and Lefrancois (2005)	Vonapartis et al. (2015)	Mierlita (2016)	Wang et al. (2017)	Habenau et al. (2018)	Mierlita (2018)		Arango et al. (2021)		Gurung et al. (2022)	Addo et al. (2023)	Rizzo et al. (2023)		Kalaitsidis et al. (2023)	Mierlita et al. (2024)
Type of product[1]	FFHS	HSC	FFHS	FFHS	FFHS	FFHS	FFHS	FFHS	FFHS	HSC	FFHS	HSC	HSM	HSM	FFHS	HSM	HSC	FFHS
Dry matter (%)	93.5	94.4	91.3	93.4	93.8	91.2	91.0	89.7	88.2	89.4	94.8	93.8	89.6	90.1	–	–	91.8	94.7
Crude ash (%)	6.0	7.6	–	5.8	5.5	–	4.9	–	–	–	4.7	5.8	5.8	11.9	–	–	5.6	–
Crude protein (%)	26.5	35.5	27.4	24.9	25.6	24.9	25.3	21.3	25.7	33.4	21.8	31.4	36.4	55.2	21-28	41	21.5	23.9
Crude fat (%)	38.0	11.8	28.4	33.2	29.2	32.7	33.9	27.7	31.6	11.7	23.5	12.5	11.5	8.86	24-36	10	8.27	31.9
Crude fibre (%)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	28-34	30	33.6	–
NDF (%)	–	–	33.4	37.2	35.7	29.7	37.0	–	33.4	43.6	–	–	49.5	31.3	–	–	48.2	54.1
ADF (%)	–	–	23.3	–	27.8	21.3	–	–	23.2	36.2	–	–	36.5	19.3	–	–	35.0	31.3
Gross energy[2]	5624	4304	–	5951	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ME[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Net energy[2]	–	–	–	–	–	2062	–	–	2459	1819	–	–	831	1730	–	–	–	–

[1]Type of products named as given in reference study. [2]Energy values given in different studies were converted to kcal/kg of DM. FFHS: full-fat hemp seed, HSC: hempseed cake, HSM: hempseed meal, NDF: neutral detergent fibre, ADF: acid detergent fibre, ME: metabolizable energy.

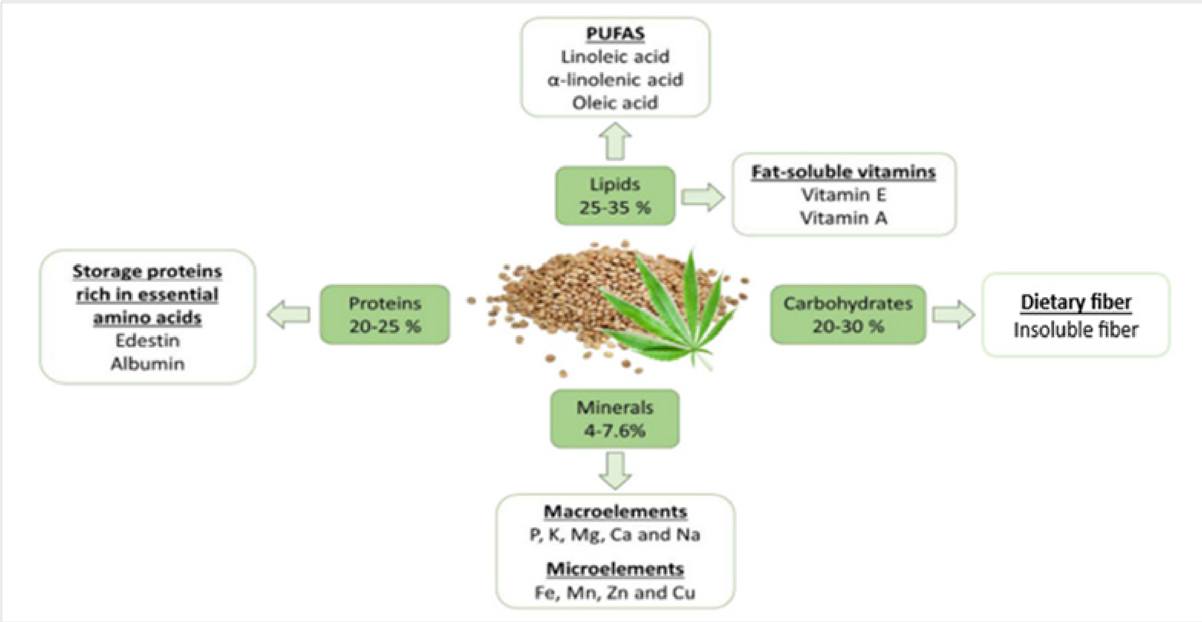

Figure 5. Macro and micronutrient value of hemp seeds (Montero et al., 2023)

Table 3. The nutrient concentration and fibre digestibility of several parts of the hemp plant, including the plants themselves, leaves, flowers, seed heads, chaff after seed harvest and cleaning, and extracted flower (Kleinhenz et al., 2020)

Outcome	Whole plant	Leaves	Stalk	Hemp flower	Seed heads	Chaff	Extracted flower
DM (%)	70.3	88.9	64.8	90.9	89.8	92.9	96.6
CP (% of DM)	6.9	13.0	5.3	21.2	23.0	20.0	24.5
Available CP (% of DM)	5.4	10.5	3.5	17.1	20.3	17.6	21.4
Calcium (% of DM)	1.4	4.3	1.0	2.3	2.6	5.7	3.6
Phosphorus (% of DM)	0.3	0.4	0.3	1.1	0.7	0.4	0.4
Magnesium (% of DM)	0.2	0.5	0.2	0.4	0.5	0.5	0.5
Potassium (% of DM)	1.1	3.3	0.9	2.4	1.3	1.9	2.4
Sulfur (% of DM)	0.1	0.4	0.1	0.4	0.3	0.2	0.3
Fat (% of DM)	2.7	8.9	1.2	12.5	13.2	4.6	3.2
Ash (% of DM)	8.8	21.2	6.3	14.1	16.6	24.9	25.7
Sugar (% of DM)	2.7	5.9	2.0	5.0	2.8	6.3	4.7
Starch (% of DM)	0.2	0.9	0.1	0.7	0.7	1.2	0.6
ADF (% of DM)	60.8	20.8	64.6	26.1	29.6	18.0	18.1
NDF (% of DM)	81.6	44.7	84.4	52.5	53.2	27.9	30.9
Acid detergent insoluble CP (% of DM)	1.5	2.5	1.8	4.2	2.7	2.4	3.1
Acid detergent insoluble CP (% of CP)	21.9	19.1	34.6	19.6	11.8	11.8	12.8
Neutral detergent insoluble CP (% of DM)	2.6	4.0	2.6	6.6	3.8	3.7	4.5
NDF digestibility at 30 h (% of NDF)	28.8	9.3	12.7	19.3	43.1	46.6	19.7
NDF digestibility at 240 h (% of NDF)	32.0	12.4	28.1	30.4	58.9	48.9	39.6
In vitro rumen NDF at 30 h (% of DM)	55.5	39.2	60.7	36.6	21.9	14.3	18.7
In vitro rumen NDF at 240 h (% of DM)	58.1	40.6	73.7	42.4	30.3	14.9	24.8
Nonfibre carbohydrate (%)	2.5	15.3	5.3	6.3	_[1]	26.3	20.2
TDN (%)	24.0	41.0	19.8	53.6	61.5	54.3	46.0

[1]Nonfibre carbohydrate was not reported because it had a negative value, likely due to ash contamination in the fibre fraction, DM: dry matter, CP: crude protein, ADF: acid detergent fibre, NDF: neutral detergent fibre, TDN: total digestible nutrients.

The composition of hemp seeds is mostly influenced by the processing of the seeds (hulled seeds or kernels), the kind of product (oil, flour, or protein powder), and the genotype and phenotype of hemp, which are affected by environmental growth variables. The physicochemical, sensory, and nutritional composition of hemp seeds varies depending on these characteristics. Montero et al. (2023) reported that hemp seeds contain around 25%–35% lipids, 20%–25% protein, 20%–30% carbohydrates, and 4%–7.6% ash, as shown in Figure 5.

Table 2 presents information on hemp seed's chemical composition that has been published in the literature. The variation between studies in terms of nutrient content is due to the use of different hemp varieties, regional and climatic differences. Pre-treatments (e.g., decortication), agronomic practises, pedological and climatic conditions, cultivar/variety, and other factors all contribute to the predicted variations in chemical composition shown in published studies. When it comes to animal nutrition, mature hemp seed is a great source of protein (mean 24.8%±2.0% dry matter (DM)). EFSA has stated that hemp seed has a CP value of 25% in DM, which is comparable to other protein sources (EFSA, 2011). Hemp seed is an intermediate source of CP between sunflower seeds (19.2%±4.2% in DM) and soybeans (39.2%±5.4% in DM), when additional protein sources that are often used in animal feeding are taken into account (NRC, 2001).

Multiple studies examining the fatty acid composition of hemp and its derivatives may be found in the existing literature. Bailoni et al. (2021) provides a summary of the results from various research that have examined the fatty acid compositions of hemp seeds, hemp meal, and hemp oil.

With consideration for their usage as ruminant feed, Kleinhenz et al. (2020) set out to characterize the nutritional concentration, digestibility, and cannabinoid concentration of industrial hemp (*Cannabis sativa* having <0.3% THCA) and plant by-products. Table 3 displays the findings of the study's nutritional analysis and *in vitro* fibre digestibility, whereas Table 4 displays the findings of the plant materials' cannabinoid concentrations. The findings will assist livestock producers in using industrial hemp in animal feeds, taking into account both nutritional and cannabinoid concentrations in the diet, even though the results obtained are among the first published studies on the nutritional and cannabinoid concentration of industrial hemp.

Nutrition practices of industrial hemp (*Cannabis sativa* L.) and its by-products in sheep

Energy is typically the nutrient in sheep meals that is most limited. Sheep have varying energy requirements throughout their growing period. Therefore, ensuring the quality and quantity of feed becomes even more essential, especially in breeding models that involve groups of grazing sheep (Pond et al., 2005). If animals do not consume enough food to meet their energy needs, they will experience weight loss. Enhancing an animal's feeding regimen is referred to as "flushing", which is providing the animal with feed supplements to increase its energy intake by 10%. "Flushing" is often performed approximately three to four weeks before the mating season and during the initial week of the breeding season. This enhances fertility and fulfils the elevated requirements during the mating period. Due to the fact that approximately 66% of foetal growth occurs during the last six weeks of gestation, ewes in late gestation require an increased calorie intake, similar to the beginning of the breeding season (Morrical, 2017; Pond et al., 2005). Sheep depend on the microbial population in their rumen to produce essential amino acids through synthesis. According to Pond et al. (2005), the amount of protein in the diet is more important than its quality. Nevertheless, meals that are rich in protein tend to be the most expensive. In order to minimize this expense, it is imperative to consider alternative sources of protein and energy. As ruminants, sheep can utilize agro-industrial by-products unlike monogastrics, so by-product protein supplements could be beneficial to producers (Clark, 2023).

Table 4. The lowest level of quantification (LLOQ) and cannabinoid content of various components of cannabis, including plants, leaves, flowers, seed heads, straw from seed harvesting and washing, and extracted flower (Kleinhenz et al., 2020)

Cannabinoid	Plant sample							
	LLOQ	Whole plant	Leaves	Stalks	Hemp flower	Seed heads	Cleanings	Extracted flower
Cannabinol (μg/g)	0.1	9	31	4	27	11	7	21
Δ9-Tetrahydrocannabinol (μg/g)	0.1	186	573	31	664	275	158	301
Δ9-Tetrahydrocannabinolic acid A (μg/g)	0.25	626	4,609	119	3,379	1,228	458	16
Δ8-Tetrahydrocannabinol (μg/g)	0.1	ND	ND	ND	ND	ND	ND	ND
Cannabichromene (μg/g)	0.1	192	417	49	513	68	140	ND
Cannabidiol (μg/g)	0.25	721	3,347	132	3,509	262	463	8,062
Tetrahydrocannabivarin (μg/g)	0.25	30	2	ND	1	303	2	ND
Cannabidiolic acid (μg/g)	0.1	4,870	36,920	1,705	32,900	3,184	5,309	1,960
Cannabigerolic acid (μg/g)	0.5	519	1,788	362	1938	285	654	154
Cannabichromenic (μg/g)	0.5	851	4,041	500	2,916	411	663	ND
Cannabigerol (μg/g)	0.1	67	293	28	230	23	79	ND

ND = non-detected.

Table 5. Summary of research on industrial hemp nutrition in sheep

Research Topic	Breed/Sex/Age/N	Results	Source
The effects of hemp meal supplementation (200 g/kg DM) on sheep	20 Suffolk lambs	No negative effects	Mustafa et al. (1999)
Effects of 25% hemp seed inclusion to diets of sheep on performance and carcass parameters	40 Turcana ewes at 60–80 days of lactation	Increase in total fatty acids, CLA and milk content	Mierlita (2016)
Effects of feeding with hemp seed and hemp-seed cake on milk yield and content	30 Turcana dairy ewes	Increased yield, Increased ALA, PUFA and MUFA content	Mierlita (2018)
Effects of 5% hemp seed inclusion to diets on chemical content of milk and cheese	32 crossbred dairy ewes	Increased lactose concentration	Ianni et al. (2020)
RNA sequencing of blood transcriptome of sheep fed with 0% and 5% hemp seed	10 crossbred dairy ewes	Positive effect on energy production pathway	Iannaccone et al. (2019)
Effects of feeding with diets including different levels of hemp stalks on performance, rumen parameters and cannabinoid residue	15 castrated males at 12 months of age	Increased acetic and butyric acid, Improved protein digestion, Trace levels of THCA in plasma	Krebs et al. (2021)
Effects of including 42% hemp green parts to diet on digestibility, rumen parameters and cannabinoid residue	12 Merino ewes	Lower levels of water consumption and faecal water excretion, reduced concentration of ammonia in rumen, reduced propionic acid and increased butyric acid levels	Stevens et al. (2022)
Effects of including 0%, 5%, 10%, 15% and 20% hempseed meal to diets on feed intake and digestibility.	40 Western White-Faced wethers	No difference in dry matter intake and no difference in Ca, Mg, K, Na digestibility between groups	Butts et al. (2022)
Effects of different CP and hemp seed levels on performance and carcass parameters	24 Baluchi male lambs	Hemp seed presence improved dry matter and CP digestibility, lowered ruminal NH_3-N and ciliate protozoa, improved levels of microbial protein production	Jalilvand et al. (2019)
Effects of full-fat hemp seed inclusion on performance and carcass parameters in two different CP levels	30 Baluchi male lambs	High protein and hemp seed group showed improved values of dry matter intake, daily weight gain, final body weight and hot carcass weight	Dayani et al. (2022)
Effects of hemp cake on metabolic profile and antioxidant status	20 Merinolandschaf lambs at 70 days of age	No effect on antioxidant status of the lambs	Antunović et al. (2021)
Effects of 0 ml, 5 ml and 10 ml of hemp oil addition on growth and blood serum indicators	18 Ivesi lambs	Significant differences in enzyme activity but no change in serum glucose levels. Improved growth performance	Al-Obadiy et al. (2022)
Effects of adding spent hemp biomass to diet on performance, carcass parameters, meat quality and haematological indicators	35 Polypay male lambs	No effect on blood parameters, no differences in carcass and meat quality, potential improvement in long-term feed intake	Parker et al. (2022)

There is a limited amount of research available in the literature regarding the practice of feeding sheep with hemp and its derivatives. A summary of these studies can be found in Table 5 and even a more brief summary can be seen on Figure 6, while detailed discussions of mentioned studies can be found in following sub-sections.

Studies on fattening performance and carcass characteristics

Mustafa et al. (1999) conducted one of the earliest research documented in the literature. The researchers studied 20 growing Suffolk ram lambs (initial weight 84.3±7.0 kg) and discovered that including 200 g/kg of hemp meal into the sheep's diet did not result in any changes in their feed intake or overall digestibility measurements. These findings indicate that substituting canola meal with hemp meal does not adversely affect the sheep's nutritional utilization.

Lately, there has been a surge of interest in studying the potential benefits of adding hemp seeds and hempseed meal into sheep diets. Incorporating 25% hemp seed into concentrate meals, Mierlita (2016) investigated the fattening capabilities of 40 multiparous Turcana ewes (body weight (BW) 45.7±1.71 kg) in mid lactation (60–80 days of lactation and three months postpartum). One of the main treatment factors was the feeding system: indoors during the entire experiment and receiving 1400 g DM grass hay/d; or part-time grazing of 4 h/day + 700 g DM grass hay/d. All animals received 700 g DM concentrate for lactating sheep per day, divided into equal halves and given at the morning and evening milkings. The second main treatment was the supplementation of fat vs. no fat. As a source of fat, hemp seed was used, which contained 32.7% crude fat and had a high content of linoleic acid (56.5% of total fatty acid methyl esters (FAME)) and linolenic acid (21.2% of FAME). Reports indicate that this feeding schedule leads to an augmentation in the fat content of milk and the energy-adjusted milk production. Researchers suggest that the slow release of unsaturated fatty acids from hemp seeds in the rumen may be responsible for reducing the levels of trans fatty acids and preventing milk fat depression. The feeding regimens did not influence the protein content in milk. Incorporating hemp seed resulted in an increase in the levels of n-3 and n-6 fatty acids, which are classified as total polyunsaturated fats. Hemp seed supplementation resulted in a twofold rise in the conjugated linoleic acid (CLA) content in the indoor feeding system, from 1.13% to 2.29% of total fatty acids. Additionally, it led to a 37% increase in the milk content of grazing ewes, as reported by Mierlita in 2016.

In the research they conducted, Jalilvand et al. (2019) investigated the effects of different diets on 24 Baluchi male lambs, with 24±1 kg body weight and 4–5 months of age. The lambs were divided into three groups: a control group that received a diet with 14% crude protein, a treatment group that received a diet with 14% CP and 10% HS, and another treatment group that received a diet with 12% CP and 10% HS. The duration of weight growth persisted for a cumulative period of 84 days, subsequent to an initial phase of 21 days for adaptation. The study assessed dry matter intake, daily body weight increase, cold and hot carcass weights, and apparent digestibility. Urine spot sampling was used to ascertain the presence of purine derivatives. Rumen fluid samples were obtained using an oesophagus tube connected to a vacuum pump. This was conducted both prior to and three hours following the morning meal on the concluding day of the trial. Subsequently, the pH and ammonia nitrogen (NH_3-N) levels were examined. The incorporation of HS into the lambs' diets had a significant effect on their dry matter intake, average daily growth, and final body weight. Lambs that were provided a diet containing 14% CP displayed the greatest levels of dry matter intake and average daily growth. The lambs that were nourished with a diet consisting of HS containing 14% and 12% CP had final body weights of 46.11 kg and 43.03 kg, respectively. The weights of the experimental group exceeded those of the control group, which had a final weight of 42 kg. Lamb diets supplemented with HS significantly affected the digestibility of DM and CP ($P<0.05$). The concentration of ruminal NH_3-N, as well as the total protozoa and *Holotricha* population, were significantly affected by the experimental diets. Lambs that were fed with hempseed diet had the least amount of ciliate protozoa and the lowest levels of ruminal NH_3-N. Lambs that were fed with hempseed diet showed a higher level of microbial protein production in comparison to the control group. According to Jalilvand et al. (2019), it is advised to include 10% hemp seed in lamb diets in order to improve microbial protein production, leading to increased average daily gain and final body weight.

Parallel to previously mentioned study of Jalilvand et al. (2019), Dayani et al. (2022) sought to investigate the impact of including full-fat hemp seed (HS) and varying levels of CP in the diet on the performance, carcass parameters, and haemato-chemical parameters of lambs. A total of thirty male lambs of the Baluchi breed were observed for a period of 84 days. The lambs were divided into three distinct groups: (1) lambs that were fed a diet containing 14% CP without any hemp seed (control), (2) lambs that were fed a diet containing 14% CP with 10% hemp seed (HPHS), and (3) lambs that were fed a diet containing 12% CP with 10% hemp seed (LPHS). The study found that lambs who received HPHS had notably greater dry matter intake (DMI), daily weight gain (DWG), final live weight, hot carcass weight, and fat-tail weight compared to the other groups. Furthermore, it was observed that the feed conversion ratio showed a considerable improvement while using HS feeding. The serum of lambs fed HPHS and LPHS exhibited the most elevated levels of glucose, total protein, and albumin. The inclusion of HS in the diet was found to dramatically elevate the levels of high-density lipoproteins and cholesterol in the bloodstream of lambs.

Studies on dairy ewes

Mierlita (2018) enhanced a feed mixture given to 30 Turcana dairy ewes selected to form three groups, which were balanced for milk production (0.75±0.02 kg/d per head), body weight (BW) (44.6±0.8 kg), dry matter intake (2.12±0.04 kg/d), and number of lactations (2–3 lactations). Groups were randomly assigned to three dietary treatments consisting of a control diet composed of hay and completed with concentrates (high-energy concentrate and sunflower meal) and two experimental diets designed to provide the same amount of fat via hemp seed (180 g/d) (HS diet) or hempseed cake (480 g/d) (HC diet). Each diet was formulated based on isoenergetic principles. Furthermore, it is worth noting that ewes that were provided with hemp meal or seeds exhibited a higher milk output compared to the control group. This can be attributed to the fact that the amino acids included in hemp are optimally balanced to facilitate the development of both milk fat and milk protein. The inclusion of hemp seeds in sheep diets, as observed in the Mierlita (2016) study, resulted in an improved fatty acid composition of sheep milk. This was characterized by a higher proportion of total n-3 fatty acids and rumenic acid (also known as CLA, having the chemical formula C18:2 c9 t11). This enhancement was noted without any detrimental impact on milk yield. In the study conducted by Mierlita (2018), it was found that the inclusion of hemp seed in sheep milk increased the concentration of ALA by 66%. Similarly, the addition of hempseed cake resulted in a 49% rise in the concentration of ALA. The levels of polyunsaturated fatty acids (PUFA), monounsaturated fatty acids (MUFA), and long-chain fatty acids (LCFA) increased, whereas the levels of saturated fatty acids (SFA), short-chain fatty acids (SCFA), and medium-chain fatty acids (MCFA) decreased.

According to Mierlita (2018), hemp meal was found to be less effective than whole seeds in increasing the amount of ALA in milk. This is because hemp meal directly provides fatty acids to the rumen fluid. This occurs because hemp meal greatly enhances the process of biohydrogenation of ALA in the rumen. Moreover, replacing hempseed diets with hemp meal in sheep feed increases the likelihood of raising the levels of CLA and vaccenic acid (VA) in milk. The transfer of fatty acids from feed to milk is influenced by several parameters, including the type of fat supplement and the interaction between the fat supply and rumen microbes. During this process, fatty acids undergo lipolysis and biohydrogenation to create C18:0 (Cremonesi et al., 2018). The study conducted by Mierlita (2018) showed that sheep milk had a greater overall antioxidant capacity when sheep were provided with diets containing hemp seed or hempseed meal. This was apparent from the elevated amounts of α-tocopherol and reduced levels of malondialdehyde in the milk. These data indicate that incorporating hemp seed or hempseed meal into the sheep's diet contributed to the preservation of the milk's oxidative stability.

In 2019, Klir et al. (2019) published a review on hemp usage in animal nutrition. Researchers summarized above mentioned studies on sheep by Mustafa et al. (1999) and Mierlita (2016, 2018) and concluded feeding ewes with addition of hemp seeds (180 g/day) or hempseed cake (480 g/day), higher milk fat content was observed with higher proportions of LA, CLA and ALA. These authors indicated the possibility of using hemp in diets of sheep without major changes in production, and with possible increase of desirable fatty acids in sheep products.

After aforementioned review of Klir et al. (2019), recently in 2024 two separate reviews on hemp (*Cannabis sativa* L.) usage in farm animal nutrition have been published. Altman et al. (2024) focused on utilizing hemp by-products in livestock diets, while Muedi et al. (2024) were focusing on farm animal's productivity, health and reproductive performance. Although these reviews include studies about sheep, since the relevant data is scarce and sheep was not the only focus of both reviews, there is only limited information about the species regarding the hemp usage in nutrition. It can be said that increased milk yields were observed in sheep supplemented with either hemp seed or hempseed cake relative to non-supplemented controls. Similarly, protein yield (g/d), milk protein composition, and milk urea nitrogen have been reported to not be influenced by hemp seed or hempseed cake inclusion. Total saturated fatty acid content in milk has been reported to decrease with hemp seed inclusion in sheep. Compared with no supplementation, linoleic acid tended to be greater in hemp seed fed sheep, but α-linolenic acid was not different (Altman et al., 2024; Muedi et al., 2024).

Ianni et al. (2020) evaluated the effect of including hemp seeds (at a concentration of 5% on a dry matter basis) into the diet of thirty-two crossbred dairy ewes on the chemical content of the milk and cheese they produced. Upon including HS into the diet of dairy ewes, the lactose concentration increased significantly from 4.69% to 5.84%. However, no noticeable alterations were observed in the levels of casein, urea, protein, or milk fat. Moreover, no modifications in the overall fat, protein, or ash composition of the final cheeses were detected. Iannaccone et al. (2019) conducted the initial RNA sequencing of the complete blood transcriptome in sheep belonging to two experimental groups (0% and 5% hemp seeds in DM) during the experiment documented by Ianni et al. (2020). Feeding ewes with hemp seeds enhances the processes involved in energy production. This may also enhance the ability to withstand adverse weather conditions such as frigid temperatures.

Studies on biochemical parameters

In a recent study, Krebs et al. (2021) examined the impact of incorporating hemp stalks in pelleted diets on feed intake, nutrient digestibility, performance, rumen parameters, and carcass characteristics in 15 castrated male sheep (body weight (BW) 54.09±6.09 kg) of approximately 12 months of age. Animals were individually housed in separate pens and provided with one of three pelleted diets. These diets consisted of 0%, 28%, or 56% hemp stalks. The addition of hemp stalks had no impact on body weight gain, dry matter intake, or feed conversion ratio. However, it was seen to enhance nutritional digestibility. Supplementing with hemp stalks has been found to increase the levels of acetic and butyric acids. Additionally, it was discovered that changes in the composition of bacteria in the rumen, namely those that break down cellulose, resulted in higher levels and proportions of butyric, valeric, hexanoic, and heptanoic acids. This also led to an improvement in the ability to digest proteins. The study indicated that only trace levels (<16 μg/L) of tetrahydrocannabinolic acid (THCA) were detected in the plasma of sheep. This was the only remnant of cannabinoid observed in the groups that had undergone cannabis treatment. None of the plasma samples tested positive for the hallucinogenic cannabinoid delta-9-tetrahydrocannabinol. However, it is important to note that all sheep that were given hemp stalks as feed had THCA present in their kidney and subcutaneous fat. Additionally, the meat from the groups of sheep that received the hemp stalk treatment contained measurable quantities of THCA. Although no further cannabinoid residues were found, the researchers emphasized the need to seek legal permissions in order to improve upon the existing findings.

In a correlated investigation, Stevens et al. (2022) employed a control group and incorporated 42% hemp green parts into the diet of 12 Merino ewes (BW 45.2±1.40 kg; mean ± SE) to scrutinize the digestibility of nutrients, rumen parameters, and the presence of cannabinoid residues in sheep-derived products. No disparities were observed in the groups' ability to digest dry materials, organic matter, or crude protein. In contrast, the hemp group demonstrated significantly lower levels of water consumption, faecal water excretion, and digestion of ADF and NDF. The hemp group had a reduced concentration of ammonia in the rumen, whereas the rumen pH remained unchanged among all the groups. Sheep that were given hemp as feed exhibited reduced levels of propionic acid and elevated levels of butyric and hexanoic acids. Upon comparing the cannabinoid residues of the two groups, it was seen that all sheep in the hemp group had cannabinoid residues in their plasma, while no residues were detected in the control group. Green hemp biomass is a suitable source of nutrition for sheep in this scenario. However, due to the presence of cannabinoid residues, it is not permissible to include it in sheep diets according to the relevant rules.

Clark (2023) sought to assess the ecological consequences of incorporating hempseed meal as a protein supplement in sheep farming. By using the data obtained by Butts et al. (2022), in which 5 isonitrogenous and isocaloric diets, with 0, 5, 10, 15, or 20% of diet DM as hempseed meal, were fed to 40 Western White-Faced wethers (eight per treatment). The wethers were fed for 90 days, followed by a five-day balance trial with total collection of urine and faeces. The study found no difference in DMI or ADG between treatments, and no difference in Ca, Mg, K, or Na digestibility (Butts et al., 2022). The authors concluded that hempseed meal has no harmful effects and is comparable to other protein supplements (Butts et al., 2022). The Clark's (2023) study was conducted in three distinct production systems, including the soybean meal diet, hemp diet, and organic hemp diet. Upon completion of the study, it was documented that incorporating hempseed meal into the fattening feed resulted in a decrease in the environmental footprint of sheep production systems.

Antunović et al. (2021) examined the impact of hemp cake on the production characteristics, metabolic profile, and antioxidant status of lambs. The duration of the experiment was 30 days and it involved a group of twenty Merinolandschaf lambs after they were weaned at the average age of 70 days. The control group lambs were provided with feed mixtures including soybean meal and extruded soybeans (SB) as the primary protein source, whereas the experimental group lambs were given feed mixtures in which soybeans were substituted with 12% hempseed cake (HSC). The diets of lambs fed with hempseed cake had no significant impact on the activity of enzymes such as aspartate aminotransferase (AST), alanine aminotransferase (ALT), alkaline phosphatase (ALP), γ-glutamyl transferase (GGT), creatine kinase (CK), superoxide dismutase (SOD), and glutathione peroxidase (GPx) ($P>0.05$). Consequently, the antioxidant status of the lambs' blood remained unaffected. Overall, this study has indicated that replacing soybeans with up to 12% HSC in the diet of lambs is justifiable. This conclusion is based on the analysis of various factors including the production characteristics of the lambs, the metabolic profile of their blood, and the fatty acids and antioxidant status of the meat. Furthermore, further investigation is required to explore the administration of elevated quantities of haematopoietic stem cells (HSCs) in the diets of lambs through a more extensive and prolonged experiment. This is necessary to ascertain a substantial enhancement in the fatty acid composition of lamb flesh, as well as an improvement in their antioxidant capacity.

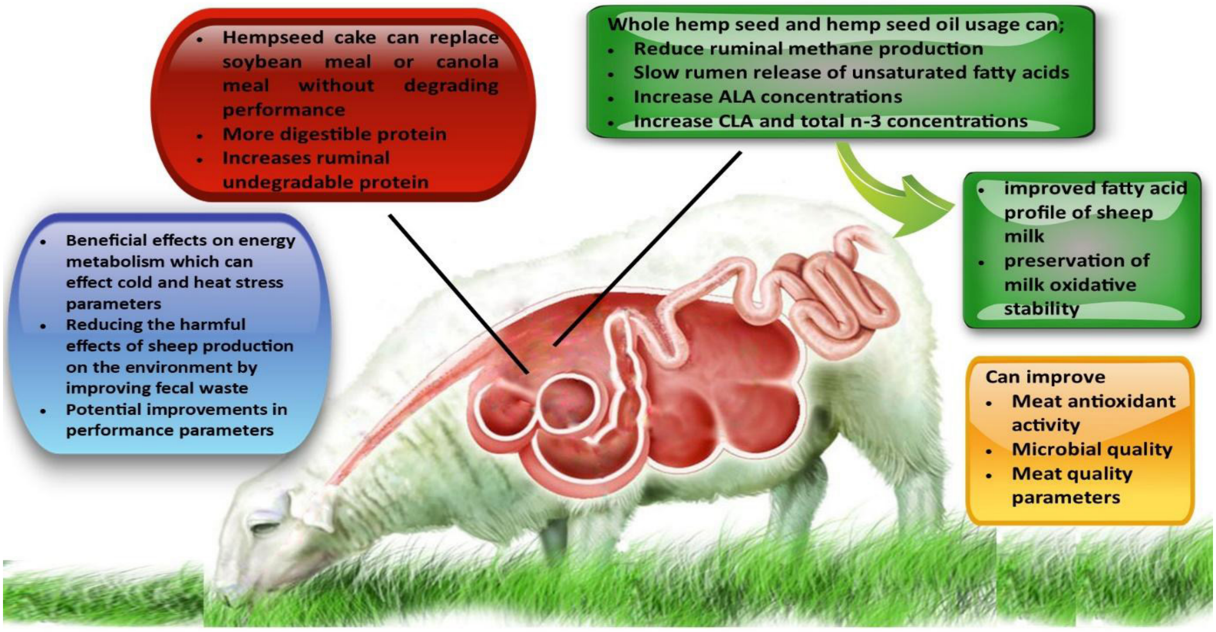

Figure 6. Summarizing the effects of feeding hemp products in sheep

Al-Obaidy et al. (2022) examined the impact of cannabis oil as a food supplement on the growth characteristics and biochemical indicators in the blood serum of 18 Awassi lambs aged 6–8 months and weighing 25–30 kg. During the 30-day experiment, lambs were separated into three groups. The first group served as a control group and did not receive any treatment. The second group was treated with a dose of 5 ml of cannabis oil, while the third group was given a dose of 10 ml of cannabis oil. The investigation revealed significant variations ($P \leq 0.05$) in cholesterol, total protein, albumin, globulin, blood urea, and ALT and AST enzyme activity. However, no significant change was seen in serum glucose levels. The current study showcased the advantageous impacts of administering hemp oil at a dosage of 10 ml on the growth performance and some biochemical characteristics in the blood serum of rams. This supplementation may offer enhanced defence against oxidative harm.

The most common methods of hemp oil extraction are based on the use of cold ethanol or high-pressurized liquid CO_2 which yields a byproduct called spent hemp biomass which is the main byproduct of the extraction process and currently has little to no other economic value for the hemp industry (Parker et al., 2022). In their study, Parker et al. (2022) examined the impact of adding spent hemp biomass (SHB) to the diet of lambs. They assessed how this supplementation affected the lambs' performance, carcass features, meat quality, and haematological indicators. The study involved 35 male lambs of the Polypay breed that had been weaned. The lambs were divided into five groups, with each group consisting of seven lambs. The lambs were fed different diets for a period of four weeks. Some diets contained no SHB (control), while others contained SHB at a concentration of 10% (LH1) or 20% (HH1). After the four-week feeding period, there was a four-week period during which the lambs were not fed SHB. Another set of lambs were fed SHB at a concentration of 10% (LH2) or 20% (HH2) for a total of eight weeks. Upon conclusion of the study, chemical analysis revealed that SHB had a nutritional composition comparable to that of lucerne, devoid of any mycotoxins, terpenes, or organic residues as a consequence of the extraction procedure. The feed consumption of lambs was adversely impacted by a 20% reduction in the availability of high-quality feed during period 1. However, this detrimental effect was not observed during period 2, which had the maximum feed intake levels at high-quality feed source 1 and low-quality feed source 2. However, there were no significant differences observed in any of the performance data, such as body weight gains, between the groups and time periods. During period 1, the levels of blood glucose, cholesterol, calcium, paraoxonase, and tocopherol were reduced, whereas the levels of bilirubin and alkaline phosphatase (ALP) increased compared to the levels of SHB fed. During period 2, LH2 and HH2 exhibited greater levels of blood urea, magnesium, bilirubin, ALP concentration, and ferric reducing ability of plasma (FRAP) compared to control. Conversely, HH2 showed lower levels of β-hydroxybutyrate. The diet of SHB did not have any impact on blood parameters associated with liver health, kidney function, immunological status, and inflammation. There were no significant differences observed in carcass and meat quality measures across the different feeding groups. Furthermore, while the initial decreased consumption of lambs fed 20% SHB in period 1 may suggest that SHB is not appetizing to lambs, the subsequent increase in feed intake at a lower level of 10% in period 2 may indicate a beneficial impact on long-term feed consumption.

Conclusions

Hemp and its by-products are ideal as novel feed sources for ruminant animals. However, few studies have evaluated their nutritional value and residues in animal products. The use of hemp seed and hemp meal as an alternative protein source in sheep diets is suitable for breeding without loss of performance. Increased milk yield was observed in ewes supplemented with hemp seed or hempseed meal compared to non-supplemented controls. Similarly, protein yield (g/d), milk protein composition and milk urea nitrogen were not affected by the addition of hemp seed or hempseed meal. No differences in intake and growth performance were observed in ewes fed pellets containing different proportions of hemp stubble compared to those fed pellets containing oat straw. However, the data are difficult to interpret due to the very limited number of studies and the presence of multiple variables in these studies. There is a need to bridge the gap in understanding the effect of hemp and its by-products on growth performance, nutrient digestibility, ruminal fermentation, blood metabolites, carcass and meat quality. The presence of any cannabinoid residues in commercial products such as meat and milk is prohibited by many countries; therefore, the inclusion of hemp-related by-products in livestock diets should be done with caution.

Hempseed meal can replace soybean meal or canola meal without reducing performance. More digestible protein increases ruminal undegradable protein. In addition, the use of hemp seed and hempseed oil can reduce ruminal methane production, slow release of unsaturated fatty acids in the rumen, increase ALA concentrations, increase CLA and total n-3 concentrations, improve the fatty acid profile of sheep milk, contribute to the maintenance of oxidative stability of milk. With the use of hempseed meal in different ratios in diets, beneficial effects on energy metabolism, which can affect cold and heat stress parameters, can be observed. By improving faecal wastes, the harmful effects of sheep production on the environment can be reduced. Meat quality parameters can be improved by increasing meat antioxidant activity and microbial quality.

The use of hemp seed and meal as an alternative feed ingredient in sheep feeding, both as a roughage source under grazing-based feeding conditions and as a protein source, has positive effects not only in terms of preventing performance loss, but also in terms of antioxidant effect, improving fatty acid profile, regulating rumen metabolism, improving meat quality and blood parameters. These benefits include improved nutrition, potential anti-inflammatory effects and support of overall sheep health. However, further research is required to determine optimum inclusion levels, assess potential interactions and ensure compliance with regulatory standards to utilize the full potential of industrial hemp while maintaining animal welfare.

Author contributions

All authors contributed equally to the writing of this paper. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no competing interests.

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