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Review of hemp components as functional feed and food ingredients: impact on animal product quality traits and nutritional value

Georgios Papatzimos, Eleni Kasapidou*

Department of Agriculture, University of Western Macedonia, 53100 Florina, Greece

***Correspondence:** Eleni Kasapidou, Department of Agriculture, University of Western Macedonia, 53100 Florina, Greece. ekasapidou@uowm.gr

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Abstract

This review examined the potential of hemp components as functional feed and food ingredients, focusing on their impact on the quality and nutritional value of animal products. Following hemp legalization, there was growing interest in its potential to enhance animal diets and processed animal products due to its rich nutritional profile, including high levels of polyunsaturated fatty acids (PUFA), essential amino acids, and fibre. Incorporating hemp components into feed for monogastric animals, particularly poultry, improved lipid stability, sensory attributes, and the fatty acid composition of meat and eggs. Hemp supplementation for ruminants, especially in goats, increased PUFA and conjugated linoleic acid (CLA) content in milk, improved meat tenderness, and enhanced oxidative stability. However, research on hemp supplementation for pigs and beef remained limited, indicating the need for further exploration of these species. Hemp cake, rich in protein, fibre, and essential fatty acids, was the most widely used hemp component due to its economic viability, nutritional benefits, and sustainability, contributing to improved meat and milk quality. Regulatory concerns about the transfer of tetrahydrocannabinol (THC) residues in the produced animal products restricted the use of hemp biomass. In processed animal products, hemp components were studied for their potential to enhance nutritional value, replace animal fats, and serve as natural preservatives. Although they improved the fatty acid profile and antioxidant properties of meat products, challenges such as textural changes and increased lipid oxidation needed to be addressed for optimal use. Limited studies on dairy products indicated promising nutritional enhancements, but textural issues could impact consumer acceptance. In conclusion, hemp components show significant potential for improving the quality and nutritional value of animal products. Further research is necessary to address regulatory, sensory, and formulation challenges and to expand their application across different animal species and processed animal products.

Keywords

Hemp, food, feed, meat, milk, eggs, poultry, ruminants

Introduction

In recent years, the application of functional ingredients in feed and food has garnered significant interest due to their potential to enhance the quality characteristics and nutritional value of farm animal products. Functional ingredients are components that can favourably affect growth, immunity, and overall health in animals, as well as sensory qualities, shelf life, and the nutritional profile in the food products [1–3]. The use of functional ingredients has become essential as consumer demands evolve, with a growing preference for foods that not only have appealing sensory qualities but also provide added health benefits [4, 5]. This is particularly important for farm animal products since consumers are particularly concerned about their healthiness and safety [6, 7]. Consumers are increasingly focused on the nutritional value and health benefits of food products. There is also growing concern about the sustainability of farm animal products and the use of synthetic additives in their production [8, 9]. Sustainability issues, including greenhouse gas emissions, water usage, and land degradation, have increasingly influenced consumer preferences, driving demand for sustainably produced goods [10, 11]. In line with this, the "clean label" trend has gained attention by promoting natural preservatives and plant-based additives while minimizing artificial flavours, colours, and synthetic substances [8]. Together, these factors are pushing the food industry to innovate and reformulate products, incorporating functional ingredients that align with evolving consumer expectations.

Recent review studies have detailed the effects of supplementing animal diets with multifunctional ingredients that improve growing performance and the quality characteristics of the derived products, while also addressing consumer demands for better sustainability and product quality [3, 12–14]. Additionally, various review studies have discussed the applications and functions of different ingredients in food products. These include both technological and medicinal uses [1, 15, 16]. Ongoing research on functional ingredients is actively pursued by the feed and food industry, as they seek new ingredients that could enhance the quality properties of animal food products. In this context, hemp has garnered considerable attention as a potential feed and food ingredient, especially following its legalization in various regions. The growing interest in hemp is driven by its rich nutritional profile and the possibility of improving both the health of animals and the quality of the products they produce, making it a promising candidate in the field of functional ingredients.

Industrial hemp, also known as hemp, is a variety of the *Cannabis sativa* plant species with a concentration of Δ9-tetrahydrocannabinol (THC) lower than 0.3% on a dry weight basis [17]. In the past, cultivation of hemp was prohibited due to its high concentration of Δ9-THC, a psychoactive compound found in the plant. However, in recent times, several countries have amended their regulations to allow for the legal cultivation of industrial hemp, provided that the plant leaves and flowering heads, as well as their derivatives, do not contain more than 3 mg/kg of Δ9-THC equivalents [sum of Δ9-THC and Δ9-tetrahydrocannabinolic acid (Δ9-THCA) expressed as Δ9-THC] for Europe [18] and 0.3% Δ9-THC (wt/wt) for the USA [17]. It should be noted that the permitted Δ9-THC level in hemp products was raised from 0.2% to 0.3% since January in the countries—members of the European Union according to the new Common Agricultural Policy (CAP) [19].

Regarding farm animals, the European Food Safety Authority (EFSA) released a scientific evaluation regarding the safety of hemp (*Cannabis* genus) for animal feed. The assessment examined hemp-derived feed materials such as hemp seed, hemp seed meal/cake, hemp seed oil, and the entire hemp plant, focusing on their utilization in the diets of farm animals. The report highlighted the importance of controlling THC levels, emphasizing that they should not exceed 0.2% for European hemp varieties. The conclusions indicated that hemp can be safely included in animal feed, provided that strict regulations are adhered to in order to maintain low THC concentrations, thus ensuring the safety of the food chain [20]. Research on the usage of hemp in farm animal diets has primarily focused on the nutritional aspects related to their performance and health whereas the effect on product quality has been examined to a lesser extent [21–23].

Nowadays, the use of hemp in food and as a food ingredient has significantly increased, due to its numerous health benefits and versatile applications in the food industry [24]. Hemp components are used in food products intended for human consumption and are considered less allergenic than those produced from other edible seeds. According to Mamone et al. [25], the application of hemp at the industry level can lead to the development of new hypoallergenic, highly digestible raw materials for food preparations that meet public health requirements. The entire hemp plant, including seeds and stem, is recoverable, and its versatility allows it to be used in various forms, such as fibre, powder, seeds, and oil [26].

Hemp is commonly used in ground form as a plant protein and fibre source in cereals and bakery products. Hemp seed oil is used in pasta sauces, salads, chocolates, sweets, and ice cream, while its seeds are used to produce bread, confectionery, and protein bars. Due to its high content of minerals, unsaturated fats, fibres, and amino acids, hemp powder is used as a protein source in mass gain smoothies, mainly by athletes and bodybuilders. Nowadays, a very wide variety of products such as hemp sauce, butter, hemp meal and gluten-free flour, protein powders pasta and spaghetti, sorghum and hemp cakes, snack foods, energy bars, muesli, burger mix, crackers, pancakes, porridge, fruit crumble, chocolate, sweets, sour hemp gum, frozen dessert and ice cream, hemp cheese, etc. are available to the consumers [26]. Subsequently, as hemp is widely consumed as a food or ingredient, scientific research on hemp-derived foods has increased significantly in recent years, with many studies investigating the health and quality benefits of hemp-based foods.

The aim of this study was to provide an overview of the application of hemp components as functional feed and food ingredients for the production of farm animal products with improved quality characteristics.

Literature research methodology

The scientific literature databases Scopus, Google Scholar, and PubMed were utilized for this research. The search was limited to the decade 2014–2024 to capture current trends in farm animal nutrition and food production, as well as recent advancements in industrial hemp production. Literature review publications, conference proceedings, and publications in languages other than English were excluded. Additionally, studies on the application of hemp components for the development of either meat or dairy analogues were excluded. Only publications with full-text availability were included in the study. The keywords used included hemp, hemp seed oil, hemp seeds, hemp flour, hemp protein, meat and meat products, milk and dairy products, eggs, beef, sheep, goat, broilers, quails, laying hens, and laying quails. Publications containing these terms in the title or keywords were included in the research.

The open-source, web-based application Voyant Tools [27] was used to perform text analysis and depict the most common parameters applied in research on the application of hemp components to the quality characteristics of farm animal products. Word clouds were created, excluding words such as performance, growth, feed, diet, and animals from the search for hemp components as feed ingredients. Images (word clouds) composed of text, where the size of a word or phrase represented its frequency, were created to present the selected information in a qualitative format.

Characteristics of hemp components

Hemp seeds, hemp seed cake, hemp flour, hemp protein, and hemp oil are widely used as ingredients in feed and food. Hemp farming not only supports human and animal nutrition but also promotes sustainability by growing rapidly, suppressing weed growth, and requiring no pesticides. Its resistance to pests, ability to enhance pollination, and improvement of soil fertility make hemp a valuable tool in addressing climate change and land degradation. This dual role of providing nutritional benefits and contributing to environmental sustainability makes hemp an increasingly attractive crop worldwide [28, 29]. All edible hemp products originate from the seeds, so the nutrient profile [30] of the seeds (Table 1) is reflected, to varying degrees, in all hemp-based derivatives. A brief overview of the characteristics of each type of hemp product is provided below.

Table 1. Hemp seed chemical composition

Ingredient	Content (%)
Moisture	6
Ash	7
Fiber	20–30
Protein	20–25
Fat	25–35
Tetrahydrocannabinol (THC)	0.003
Hemp-derived cannabidiol (CBD)	0.02

Hemp seeds contain essential nutrients, such as alpha-linolenic acid and linoleic acid, with an ideal 3:1 ratio [31]. They are also a rich source of protein, containing all nine essential amino acids, along with significant amounts of vitamin E, magnesium, phosphorus, potassium, iron, zinc, polyphenols, and flavonoids [28, 32–34]. Hemp flour, which is made from milled hemp seeds, has a high carbohydrate content (50%), high protein content that is approximately 35% whereas relatively low fat content (approximately 10%), in comparison to the fat content of hemp seeds, is because hemp flour is produced from defatted seeds [35]. Hemp protein, obtained after oil extraction from hemp seeds, contains 50–70% protein by weight and includes all essential amino acids and particularly arginine [36, 37]. It also contains fat, fibre, and it has a high content of polyphenols contributing to its antioxidant capacity [21]. Hemp oil is valued for its high content of polyunsaturated fatty acids (PUFA) (75–80%), including n-3 and n-6 fatty acids and gamma-linolenic acid (GLA), which has anti-inflammatory properties. It also contains tocopherols and polyphenols functioning as antioxidants, preventing the oil from deteriorating and enhancing its nutritional value [38, 39].

Hemp seed cake, the byproduct of oil extraction, is primarily used in animal feed while it is unutilized for human consumption. Hemp seed cake has a protein content, while it contains 9–20% lipids, 6–7% dietary fibre and minerals [19].

Spent hemp biomass (SHB) is an additional product that has been examined for use in farm animal nutrition. It refers to the leftover plant material following the extraction of cannabinoids such as hemp-derived cannabidiol (CBD) from the feminized plants. As these plants do not yield seeds, the harvested flower and leaf materials, along with the low-temperature extraction methods, produce a byproduct with high nutritional value suitable for inclusion in farm animal diets as an alternative feed supplement [40]. A primary concern is the variation in cannabinoid content within the spent biomass, which can result in inconsistencies in feed quality and potential safety hazards. This variability arises from differences in the extraction process [41, 42] and the specific parts of the hemp plant used [43]. The presence of residual cannabinoids, like THC, increases the risk of these compounds transferring into animal products such as meat, milk, or eggs, potentially leading to regulatory and safety issues for human consumption [7]. According to Parker et al. [40], SHB has not been authorized by the Food and Drug Administration's Center for Veterinary Medicine (FDA-CVM) for use in livestock feed in the United States due to potential cannabinoid residues, which the FDA categorizes as drugs. Therefore, it is crucial to investigate its effects on livestock performance and health to inform the legalization process. Since cannabinoids are classified as drugs, a withdrawal period is considered as necessary.

In summary, all hemp-derived components are rich in essential fatty acids, high-quality proteins, dietary fibre, vitamins, minerals, and antioxidants like polyphenols. This nutritional profile is garnering significant interest for use in both human and animal nutrition. Detailed information on the composition of hemp components can be found in the review studies of Burton et al. [44], Rizzo et al. [45] and Šťastník et al. [46].

When used as food or a food ingredient, industrial hemp is governed by European regulations as a novel food and requires pre-market authorization [47]. However, products such as hemp seeds, hemp seed oil, ground hemp seeds, (partially) defatted hemp seeds, and other hemp seed-derived food for which a history of consumption has been demonstrated are not novel [48]. Finally, the application of hemp components as either feed or food ingredients should be conducted with regular monitoring for mycotoxins, such as aflatoxins and ochratoxin A (OTA) [49, 50]. This precaution is necessary due to concerns over fungal contamination of cannabis plants during the drying process, which may lead to mycotoxin presence in leaves and flowers, and potentially in edible hemp products derived from them proper storage and handling of hemp products to avoid fungal contamination are necessary to minimize the risk of mycotoxin exposure.

Hemp components as feed ingredients

The impact of different hemp components on the quality of animal-derived products from various animal species, including monogastric animals (such as broilers, hens, quail, and pigs) and ruminants (like dairy cows, goats, and sheep), is thoroughly outlined in Table 2. The table includes details on the specific hemp components utilized, supplementation levels and duration, observed effects on the products, and corresponding study references.

Table 2. Dietary hemp components and their effect on produced product quality characteristics

Animal category	Hemp component	Species and product	Supplementation level and duration	Effect	Reference
Monogastric animals	Hemp seed cake	Broilers; meat	5% and 10%	• Improved lipid stability in breast muscle; • Increased long-chain n-3 fatty acids; • Reduced n-6/n-3 ratio in breast and thigh muscle.	[51]
	Hemp oil & HempOmega	Broilers; meat	3% and 6% (21 days)	• Increased n-3 PUFA content (ALA, EPA, DPA, DHA); • Decreased MUFA content.	[52]
	Hemp seed expellers	Broilers; meat	50 and 150 g/kg of feed	• Improved colour and odour in breast muscle with 150 g/kg feed treatment; • Improved colour in the thigh muscle.	[53]
	Hemp seed alone or in combination with dills seeds	Cockerels; meat	Varying dietary doses of hemp seed (HS) alone or combined with dill seed (DS) as a percentage of the basal diet (BD): BD + 0.2% HS; BD + 0.2% HS + 0.3% DS; BD + 0.3% HS; BD + 0.3% HS + 0.3% DS	• Enhanced lipid profile; • Improved oxidative stability; • Better sensory attributes in both fresh and refrigerated meat (15 and 30 days).	[54]
	Hemp seed in combination with extruded flax seed	Cockerels; meat	Combination of 40 g/kg hemp seed and 60 g/kg extruded flax seed (35 days)	Lower n-6/n-3 ratio.	[55]
	Hemp seed	Quail; meat	5%, 10%, and 20% (5 weeks)	• Higher meat redness; • Lower cooking loss.	[56]
	Hemp oil & HempOmega	Laying hens; eggs	4% and 8% (6 weeks)	• Increased n-3 PUFA content (ALA, EPA, DPA, DHA); • Decreased MUFA content.	[52]

Table 2. Dietary hemp components and their effect on produced product quality characteristics (*continued*)

Animal category	Hemp component	Species and product	Supplementation level and duration	Effect	Reference
	Hemp seed alone or in combination with ginger and turmeric	Laying hens; eggs	25% hemp seed alone or 25% hemp seed and 2% ginger or turmeric (5 weeks)	• Higher n-3 PUFA and n-6/n-3 ratio; • Lower SFA in yolks stored at room temperature for 30 days.	[57]
	Hemp seed cake	Laying hens; eggs	10%, 20%, and 30% (19 weeks)	Increased levels of PUFA.	[58]
	Hemp seed	Laying Japanese quail; eggs	5%, 10%, and 20% (8 weeks)	Linear increase in egg n-3 fatty acids with increasing dietary hemp seed content.	[59]
	Hemp seed cake	Laying Estonian quail; eggs	10% of basal feed (5 weeks)	• Higher n-3 PUFA content in yolk; • No effect on yolk cholesterol or AI.	[60]
	Hemp seed	Laying Japanese quail; eggs	5%, 10%, and 20% (6 weeks)	Linear increase in egg n-3 fatty acids with increasing dietary hemp seed content	[56]
	Hemp oil	Pig; meat	Fat source in the diet	Higher content of ALA (C18:3 n-3).	[61]
Ruminants	Hemp seed cake	Cull dairy cows; meat	11% DM for animals on a hay-based diet; 19% DM for animals on a corn silage-based diet; 9% DM for animals on a pasture-based diet; (4 months)	No improvement in the content of unsaturated fatty acids.	[62]
	Hemp cake	Veal calves; meat	3% of basal diet concentrate (171 days)	Increased cooking loss and lower tenderness in meat.	[63]
	Hemp seed meal	Goat; meat	10%, 20%, or 30% as fed (60 days)	• Fluctuations in surface colour and tenderness; • Varying dietary levels of hemp seed meal inclusion affect these attributes; • Optimal inclusion level: 10%.	[64]
	Hemp-derived cannabidiol (CBD)	Goat; meat	0.1, 0.2, and 0.3 mL/30 kg body weight, (90 days)	• Improved colour redness and stability: achieved with CBD supplementation at 0.2–0.3 mL; • Lower fat content: noted with a 0.3 mL CBD dosage; • Enhanced tenderness and textural properties: softer meat texture.	[65]
	Hemp seed	Growing meat goat; meat	10%, 20%, or 30% as fed; hemp replaced ingredients of the basal concentrate diet; (60 days)	No adverse effect on meat proximate composition.	[66]
	Spent hemp biomass	Finishing lambs; meat	10% or 20% (4 weeks intervention period and 4 weeks withdrawal period) & 10% or 20% (8 weeks) in replacement of alfalfa	Increase in shrink loss and cook loss observed in meat from animals fed spent hemp biomass for 8 weeks.	[40]
	Hemp seed cake	Finishing goats; meat	25, 50, 75, or 100 g/kg DM of hemp to substitute soybean meal	• Lower content of SFA; • Improved content of n-3 PUFA and CLA; • Lower AI and TI indices; • Higher protein oxidation stability.	[67]
	Spent hemp biomass	Lactating dairy cows; milk	Basal total mixed ration (TMR) diet plus 13% pelleted hemp (4 weeks intervention period and 4 weeks withdrawal period)	• No adverse effect on milk proximate composition; • Tendency for a lower fat content.	[68]

Table 2. Dietary hemp components and their effect on produced product quality characteristics (*continued*)

Animal category	Hemp component	Species and product	Supplementation level and duration	Effect	Reference
	Hemp seed & Hemp seed cake	Dairy ewes; milk	180 g/day for hemp seed; 480 g/day for hemp seed cake; hemp components replaced ingredients of the basal concentrate diet (10 weeks)	• Increased PUFA and CLA content; • Reduced AI, TI, and n-6/n-3 fatty acids ratio, and increased h/H ratio; • Better antioxidant capacity and oxidative stability.	[69]
	Hemp seed	Dairy ewes; milk	Ewes fed on concentrates indoors or part-time grazing and supplemented with 175 g/day; (10 weeks)	• Increased PUFA content (especially n-3 and CLA); • Reduced AI, TI, and n-6/n-3 fatty acids ratio, and increased h/H ratio in milk fat; • Better results achieved with a combination of part-time grazing and hemp supplementation.	[72]
	Hemp seed	Dairy goats; milk	Hemp seed supplement (9% DM intake) in animals fed either on hay or on mixed shrubs-grass rangeland; (10 weeks)	• Increased PUFA content (especially n-3 and CLA); • Reduced AI, TI, and n-6/n-3 fatty acids ratio, and increased h/H ratio; • Better results in the combination of hemp supplementation and mixed shrubs-grass.	[73]
	Hemp seed	Dairy goats; milk	9.4% on DM intake (40 days)	• Higher MUFA and n-3 PUFA content; • Lower n-6/n-3 ratio.	[74]
	Hemp seeds	Dairy goats; milk	9.3% on DM intake supplementing corn silage and soyabean meal (30 days)	• Reduced SFA; • Increased MUFA.	[75]

PUFA: polyunsaturated fatty acids; ALA: alpha-linolenic acid; EPA: eicosapentaenoic acid; DHA: docosahexaenoic acid; DPA: docosapentaenoic acid; MUFA: monounsaturated fatty acids; DM: dry matter; SFA: saturated fatty acids; CLA: conjugated linoleic acid; AI: atherogenicity index; TI: thrombogenicity index; h/H: hypocholesterolemic/Hypercholesterolemic

For monogastric animals, including hemp seed cake in broiler diets at levels of 5% and 10% has been shown to improve the lipid stability of the breast muscle. It also increased the content of long-chain fatty acids of the n-3 series while decreasing the n-6/n-3 ratio in both breast and thigh muscle meat. This finding suggests a beneficial shift in the fatty acid composition, enhancing the nutritional quality of the meat [51]. Similarly, the use of hemp oil and a commercial supplement called HempOmega (HΩ) at 3% and 6% for 21 days in broilers led to a marked improvement in the fatty acid profile, particularly by increasing the levels of n-3 PUFA such as alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA), and docosahexaenoic acid (DHA), while decreasing the monounsaturated fatty acids (MUFA) content. This finding showed that hemp oil can enhance the nutritional value of broiler meat in terms of lipid composition [52].

Furthermore, when broilers were fed with hemp seed expellers at concentrations of 50 g/kg and 150 g/kg of feed, there was a notable improvement in the colour and odour of breast meat, especially at the higher supplementation level. The thigh muscle also exhibited improved colour, indicating that hemp seed expellers can enhance the sensory properties of poultry meat [53]. In cockerels, varying dietary doses of hemp seed, both alone and in combination with dill seeds, resulted in an enhanced lipid profile, improved oxidative stability, and better sensory attributes of broiler meat, both when it was fresh and after refrigeration for 15 and 30 days. The latter outcomes were achieved when 0.2% to 0.3% hemp seed and dill seed were included in the basal diet [54]. Additionally, when hemp seed was combined with extruded flax seed at a ratio of 40 g/kg hemp seed to 60 g/kg flax seed and provided to cockerels for 35 days, it led to a reduction in the n-6/n-3 PUFA ratio in meat, further enhancing its nutritional value [55].

In quail, the supplementation of diets with 5%, 10%, and 20% hemp seed over five weeks resulted in better meat colour, i.e. higher redness values and lower cooking loss, indicating that hemp seed can improve both the visual appeal and cooking properties of meat [56]. The inclusion of 4% and 8% hemp oil and HΩ in the diets of laying hens over six weeks significantly improved the fatty acid profile of eggs by increasing n-3 PUFA and decreasing MUFA [52]. Similarly, when 25% hemp seed was used alone or combined with 2% ginger or turmeric for five weeks, there was a notable increase in the n-3 PUFA content and an improved n-3/n-6 fatty acid ratio in the yolk of eggs stored at room temperature for 30 days. This combination also resulted in a lower saturated fatty acids (SFA) content in the yolk, which benefits health [57]. Furthermore, laying hens fed with hemp seed cake at 10%, 20%, and 30% over 19 weeks laid eggs with increased levels of PUFA [58]. Laying Japanese quail fed with 5%, 10%, and 20% hemp seed for either six or eight weeks exhibited a linear increase in egg n-3 fatty acids with increasing dietary hemp seed content [56, 59]. Similar results were observed in a six-week study with Estonian quail. These findings indicate that dietary hemp seed can enhance the nutritional profile of eggs by boosting their n-3 fatty acid content [60]. Finally, in pigs, including hemp oil as a dietary fat source increased the levels of ALA (C18:3 n-3) in the meat, indicating an improvement in the meat's fatty acid composition [61].

In ruminants, feeding cull dairy cows with hemp seed cake at levels of 11% dry matter (DM) for hay-based diets, 19% DM for corn silage-based diets, and 9% DM for pasture-based diets over four months did not result in any improvement in the content of unsaturated fatty acids in the meat [62]. In veal calves, the inclusion of hemp cake at 3% of the basal diet concentrate for 171 days increased cooking loss and resulted in lower tenderness in the meat, indicating potential adverse effects on meat quality at this supplementation level [63].

Including 10%, 20%, or 30% hemp seed meal in goat diets over 60 days caused variations in surface colour and tenderness. Among these levels, the 10% inclusion produced the most favourable results for meat quality [64]. Furthermore, the supplementation of goat diets with CBD at levels of 0.1, 0.2, and 0.3 mL per 30 kg body weight over 90 days improved colour redness and stability, reduced fat content at the highest dose, and enhanced tenderness and overall textural properties, resulting in the production of meat with softer texture [65]. When growing goats were fed diets in which hemp seed replaced ingredients of the basal concentrate diet at levels of 10%, 20%, or 30% for 60 days, there was no adverse effect on meat proximate composition. These results emphasize the adaptability of goats to hemp components in their diets, confirming the potential of hemp in animal nutrition [66].

In finishing lambs, the inclusion of SHB at 10% or 20% fed either over four weeks, followed by a four-week withdrawal period, or over eight weeks without a clearing period as a replacement for alfalfa, led to an increase in shrink loss and cook loss in meat from animals fed the biomass for eight weeks associating prolonged feeding of SHB with negative characteristics on meat quality [40]. In finishing goats, substituting soybean meal with hemp seed cake at levels of 25, 50, 75, or 100 g/kg DM improved the content of n-3 PUFA and conjugated linoleic acid (CLA) in the meat, lowering the content of SFA and the values of atherogenicity index (AI) and thrombogenicity index (TI) indices, and improving protein oxidation stability showing improved meat quality [67].

Incorporating 13% pelleted SHB into the basal total mixed ration (TMR) diet for lactating dairy cows over a four-week period, followed by a four-week withdrawal phase, did not negatively impact the proximate composition of the milk, although a slight reduction in fat content was observed [68]. For dairy ewes, supplementation with 180 g/day hemp seed or 480 g/day hemp seed cake, replacing ingredients in the concentrate-based diet over ten weeks, increased the PUFA and CLA content in milk, lowered the AI, TI, and n-6/n-3 fatty acids (FA) ratio, and increased the hypocholesterolemic/Hypercholesterolemic (h/H) ratio in milk fat. These changes were accompanied by better antioxidant capacity and oxidative stability [69]. When ewes were either fed concentrates indoors or fed on concentrates in combination with part-time grazing and supplemented with 175 g/day hemp seed for ten weeks, there was an increase in PUFA content, particularly n-3 and CLA, with reduced AI, TI, and n-6/n-3 FA ratio, and improved h/H ratio in milk fat. These effects were more profound when part-time grazing combined with concentrate feed was applied, indicating that the favourable effects of grazing [70, 71] on milk quality can be further improved with hemp supplementation [72]. In dairy goats, supplementation with hemp seed at 9% DM intake, whether fed on hay or mixed shrubs-grass rangeland, for ten weeks, resulted in increased PUFA content, particularly n-3 and CLA, with a reduction in AI, TI, and n-6/n-3 FA ratio, and an improved h/H ratio in milk fat indicating a positive effect on milk quality [73]. Similarly, when dairy goats were supplemented with 9.4% hemp seed on DM intake for 40 days, there was an increase in MUFA and n-3 PUFA content and a lower n-6/n-3 ratio [74]. Another study with 9.3% hemp seed supplementation on DM intake, replacing corn silage and soybean meal for 30 days, showed a reduction in SFA and an increase in MUFA in milk, further highlighting the beneficial effects of hemp seed on milk quality in dairy goats [75].

There is a noticeable difference in the types of monogastric and ruminant animals that have been the focus of studies involving including hemp components in their diets. While poultry, particularly broilers and laying hens, have been the primary subjects among monogastric animals, research involving hemp supplementation in pigs has been relatively limited. In contrast, within ruminants, most studies have concentrated on sheep and goats rather than cows and beef cattle. These differences reflect varying factors such as the digestive physiology of these animals, the economic importance of their respective industries, and specific market demands, all of which influence the research priorities and applications of hemp in animal nutrition.

As seen, hemp components have been mainly utilized in poultry in monogastric species, whereas the application of hemp ingredients in pig diets has been relatively limited. Similarly, research on ruminants has focused more on sheep and goats rather than cows and beef cattle. This distribution of research attention can be attributed to several factors related to digestive physiology, economic importance, and market demands for these species.

Regarding poultry, supplementation of feed with hemp components can be related to many factors such as bird well-being, growth rate, production cost, feed formulations and nutritional requirements [76]. In poultry production, feed costs account for approximately 60–70% of the total production expenses. Exploring the use of unconventional and less conventional ingredients, such as locally available agro-industrial by-products, is essential for reducing these costs [77, 78]. Currently, poultry diets primarily rely on corn and soybeans. However, these feed ingredients are also in high demand for other livestock (soybean meal) and human consumption (yellow corn). As the global consumption of poultry products like meat and eggs is projected to rise in developing countries, the demand for these primary feedstuffs will also increase [79]. This growing demand makes it increasingly urgent to explore alternative protein sources for poultry and other livestock. Additionally, in poultry, it is easier to observe and measure the effects of dietary changes within a short time frame. Finally, hemp products, such as commercial supplements of hemp oil, may be more economically viable for poultry feed than pig feed.

Most studies involving hemp components have been conducted on sheep and goats rather than cows and beef cattle in ruminant animals. This focus can be explained by parameters such as physiological and metabolic differences as well as economic and practical considerations. In detail, small ruminants, particularly goats, have a highly adaptable digestive system that can efficiently process a wide variety of unconventional fibrous feedstuffs like hemp. This adaptability allows researchers to experiment with various hemp components (such as seeds, seed cake, and biomass) in goat diets, evaluating their effects on meat and milk quality without significant risk to animal health or productivity. Moreover, sheep and goats are often raised in environments where access to conventional feed sources may be limited or expensive, making alternative feeds like hemp more attractive [80, 81].

The information presented in Table 2 shows that hemp cake has been primarily used as a feed ingredient, unlike hemp seed oil, hemp seeds, or SHB. The broad application of hemp cake in farm animal diets is driven by several factors, including its nutritional profile, economic viability, and sustainability.

Hemp cake is rich in protein, fibre, and essential fatty acids, making it a valuable feed ingredient. It contains all essential amino acids, making it a complete protein source, which is crucial for animal growth and development [36]. The residual oil in hemp cake also provides a good source of PUFA, particularly n-3 and n-6 FA, contributing to improved meat and milk quality [32].

Hemp cake, being a byproduct, is generally more affordable than whole hemp seeds or hemp oil, making it a cost-effective feed ingredient [82]. Its availability as a byproduct of the expanding hemp industry [26] allows it to be sourced at a relatively low cost, which is particularly advantageous for large-scale animal production operations. The high value of the oil restricted its use to being tested in poultry diets [52], making hemp seed cake the primary hemp ingredient in farm animal diets.

The use of hemp cake in animal feed aligns with sustainable agricultural practices. By utilising a byproduct of hemp oil production, the feed industry can reduce waste and promote a circular economy. The ability of livestock to consume unusable by-products or waste products from various commodities and convert them into consumable goods significantly contributes to sustainable agriculture [83].

There is limited research on the use of SHB in animal feed, mainly due to regulatory obstacles [20, 40]. One major challenge is the concern about THC levels and the establishment of suitable withdrawal periods. Hemp, including its biomass and byproducts like hemp cake, is subject to strict regulations due to its association with *Cannabis sativa* L., which contains varieties that produce the psychoactive compound THC. Meeting these limits requires thorough testing and compliance, which can be expensive and time-consuming. These limitations have restricted the widespread use and study of hemp cake biomass in animal feed. Even when hemp products adhere to regulatory standards, concerns about residual THC or other cannabinoids in animal products (meat and milk) have led to cautious approaches, including the implementation of withdrawal periods [40, 68] in the case of SHB.

The research on the effects of hemp components in animal diets has mainly been conducted from 2016 onwards. There has been a noticeable increase in research output from 2019, indicating a growing interest and expanding opportunities in the field. As legal restrictions on hemp use as a feed ingredient were progressively relaxed, it highlights the increasing recognition of hemp's potential benefits and its broader acceptance in animal nutrition research.

In summary, hemp components added to poultry diets enhance the lipid profile, sensory attributes, and fatty acid composition of meat and eggs, thereby improving their nutritional value. Similarly, in ruminants, particularly goats, the addition of hemp boosts the content of PUFA and CLA in milk, while also enhancing meat tenderness and oxidative stability. It's important to note that the existing research primarily focuses on poultry and small ruminants, with limited studies conducted on pigs and cows. Hemp cake is the most commonly utilized product due to its nutritional benefits and cost-effectiveness, while constraints related to regulations restrict the use of SHB. The research highlights hemp's potential in enhancing the quality of animal products, although further studies are necessary to tackle existing challenges and optimize its use across different species.

Voyant Tools was used to create a visual representation of the research profile of the application of hemp components in farm animal nutrition (Figure 1). The visualization shows that hemp seed was more widely used in the diets of poultry and goats. Meat and milk were examined in relation to characteristics such as colour, oxidation and texture.

Hemp components as food ingredients

A comprehensive summary of the utilization of various hemp components in processed animal products is presented in Table 3. It includes their intended purposes, the types of products used, inclusion levels, storage duration, and the observed effects. The application of hemp in dairy products is less explored in comparison to that of meat products. Due to the limited number of studies on dairy products, no categorization related to the primary intended function was performed.

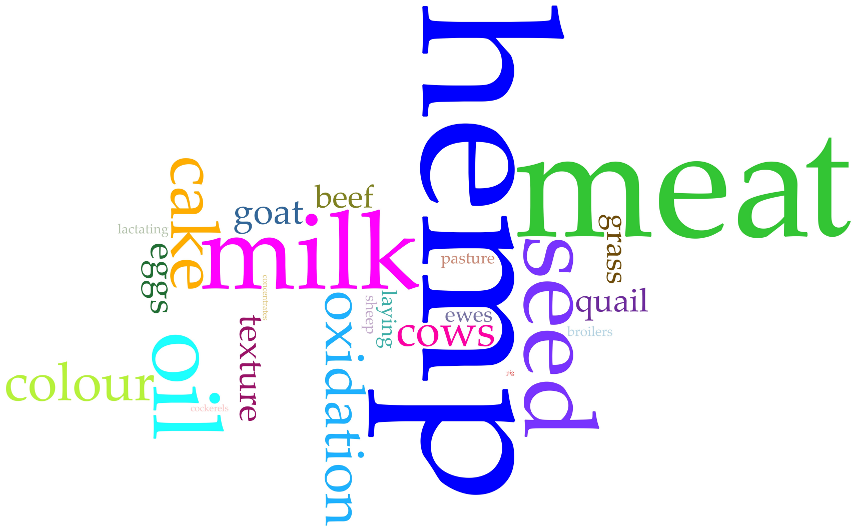

Figure 1. Word cloud visualization of the research profile of studies included in Table 2 for farm animal nutrition

Table 3. Application of hemp components in processed animal products in relation to their intended function

Food type	Hemp component	Species and product	Inclusion level	Effect	Reference
Dairy products	Hemp seed protein	Cheese	10%, 15%, 20%, and 25% of the milk-vegetable mixture	• Increased yield and dry matter content; • Improved amino acid content; • Brittle consistency.	[84]
	Hemp press cake flour	Yoghurt	2%, 4%, 6%, 8%, and 10%	Increased polyphenol content and antioxidant activity.	[85]
Meat products: improve nutritional value: application of plant-based ingredient	Hemp seeds or dehulled hemp seeds or hemp protein or hemp flour	Pork meat loaves	5% (15 days)	• Higher mineral and fibre content; • Increased hardness; • Higher PUFA content with de-hulled and whole hemp seeds; • Slower oxidation with hemp hull ingredients; • Lower overall acceptability; • Comparable taste for meatloaf with dehulled hemp seeds to control.	[86]
	Hemp seed alone or in combination with linseed	Liver pâtés	Approximately 5.7% for products containing hemp seed alone; approximately 5.5% for products containing hemp seed and linseed	• Increased hardness and chewiness; • Lower content of SFA; • Higher content of PUFA; • Improved n-6/n-3 fatty acid ratio.	[87]
	Hemp flour	Meat loaf	8–12%	• Higher protein, fat, and mineral content; • Better minced meat molding properties.	[88]
	Hemp seed press-cake (dried raw and defatted)	Cooked pork burger patties	1–2% as protein-rich ingredients (burger patties stored for 21 days in modified atmosphere)	• Higher oxidation in non-defatted hemp seed press cake;	[89]

Table 3. Application of hemp components in processed animal products in relation to their intended function (*continued*)

Food type	Hemp component	Species and product	Inclusion level	Effect	Reference
				• Lower lightness in burgers with defatted hemp seed press cake; • Lower grilling losses in burgers with defatted hemp seed press cake.	
	Combination of hemp seeds, amaranth and golden flaxseed	Poultry pâté	Treatment 1: 8% hemp seed, 10% amaranth seed and 6% flaxseed; Treatment 2: 8% hemp seed, 6% amaranth seed and 10% flaxseed; Treatment 3: 8% of each ingredient (wheat roll replacer)	• Higher protein, essential amino acids, fibre, and vitamin E; • Favourable fatty acid profile with a healthy n-6/n-3 fatty acids ratio (3:1); • Lower tenderness; • Higher flavour desirability.	[90]
Meat products: fat replacer	Hemp oil GE mixed with buckwheat flour (partial animal fat replacer)	Alheiras (traditional Portuguese fermented sausages)	25% and 50%	• Lower levels of SFA; • Higher levels of PUFA; • Increased lipid oxidation in samples with the 50% replacement of animal fat.	[91]
	Hemp oil GE mixed with amaranth flour (partial animal fat replacer)	Beef burgers	25% and 50% as a fat replacer	• Lower fat content and SFA; • Improved n-6/n-3 and PUFA/SFA ratios, AI, TI, and h/H indices; • Higher cooking loss, shrinkage, and thickness changes.	[92]
	Hemp oil GE mixed with buckwheat flour	Frankfurters	25%, 50%, 75%, and 100%	• Lower fat and SFA content, higher PUFA and n-3 fatty acids; • No effect on emulsion stability and lipid oxidation; • Extensive texture and sensory changes with total fat replacement; • Partial fat substitution produced sausages similar to control frankfurters	[93]
	Hemp oil	Cooked and vacuum-packed meat balls	0.8%, 2.5%, 4.2%, and 7.5% for 12 days	• Higher cooking and storage losses with a higher content of hemp oil; • Lower content of SFA and higher content of PUFA; • Lower protein and lipid oxidation.	[94]

Table 3. Application of hemp components in processed animal products in relation to their intended function (*continued*)

Food type	Hemp component	Species and product	Inclusion level	Effect	Reference
	Hemp cake	Cooked and vacuum-packed meat balls	0.9%, 2.6%, 4.2%, and 7.4% for 12 days	• Lower lightness (L*) and redness (a*) with increased hemp seed content; • Reduced protein and lipid oxidation, especially at the highest hemp content; • Higher sensory scores for meatballs with 0.9% and 2.6% hemp cake.	[95]
	Hemp seed meal	Chicken sausage	10%, 20%, 30%, and 40%	• Lower moisture, protein, and lipid content with increased hemp seed meal; • Improved emulsion stability and lower cooking loss; • Higher phenolic content and DPPH activity; • Higher lipid oxidation; • Lower lightness (L*) and redness (a*); • Modified texture: decreased hardness, cohesiveness, gumminess, springiness, chewiness, and resilience.	[96]
	Combination of hemp seeds, flour, and oil	Poultry meat roast	Treatment 1: 8% seed, 0.20% flour and 2% oil; Treatment 2:4 % seed, 0.20% flour and 6% oil	• Treatment 1: higher protein and fibre, more intense yellow colour (b*), lower cooking losses, better taste and binding; • Treatment 2: lower cholesterol and saturated fat, higher n-3 fatty acids, lower taste and binding score.	[97]
Meat products: antioxidant/antimicrobial function (replacement of synthetic preservatives)	Micronized cold-pressed hemp seed cake	Frankfurters	1%, 2%, 3%, 4%, and 5% w/w (phosphate replacer)	• Dose-dependent reduction in lipid oxidation in reduced-phosphate frankfurters; • Optimal replacement: 50% phosphates with 2% (w/w) addition.	[98]
	Hemp oil addition to gelatin-based edible coating (alone or in combination with sage oil)	Coated pork loin	1% or 2% of each oil (different combinations), 12 days	Stable colour and lower aerobic plate count with gelatin coating containing 1% of each oil.	[99]

Table 3. Application of hemp components in processed animal products in relation to their intended function (*continued*)

Food type	Hemp component	Species and product	Inclusion level	Effect	Reference
	Hemp oil	Fermented salami	2% and 4% as partial replacement of animal fat (partial or entire replacement of sodium nitrite)	• Improved PUFA/SFA ratios, AI, TI, and h/H indices; • No effect on microbial growth in all treatments; • Decreased redness (a*) and colour saturation (Chroma) values in salamis containing only hemp seed oil; • Increased lipid oxidation in samples containing hemp seed oil, reduced when combined with sodium nitrite; • Softer texture in samples with higher hemp seed oil; • No adverse consumer acceptance.	[100]
	Hemp flour	Minced meat model	4% and 6% (partial replacement of sodium nitrite)	• Lower lipid oxidation; • Greater colour deterioration; • Lower tenderness.	[101]

PUFA: polyunsaturated fatty acids; SFA: saturated fatty acids; AI: atherogenicity index; TI: thrombogenicity index; h/H: hypocholesterolemic/Hypercholesterolemic; GE: gelled emulsion

The development of a hybrid cheese product, combining animal and plant ingredients, was studied, and positive effects such as increased yield, higher dry matter content, and an improved amino acid profile were achieved by adding hemp seed protein. However, a challenge with the cheese's texture was encountered, which could potentially impact consumer acceptance [84]. In another study focused on yogurt, the utilization of cold-pressed hemp seed cake led to higher polyphenol content and antioxidant activity, pointing to potential health benefits [85]. These findings highlight the promising nutritional enhancements that hemp components can offer, while also underscoring the need to address textural challenges for improved product quality and consumer acceptance.

In the studies on meat products, the incorporation of hemp components has shown significant promise in enhancing nutritional profiles, replacing animal fats, and providing antioxidant/antimicrobial effects. For example, increased mineral, fibre, and PUFA contents were noted in pork meat loaves with the addition of hemp components, despite encountering some texture and acceptability issues [86, 87]. Similarly, in meat loaf and burger patties, improvements in protein and fat content were observed with hemp flour and press-cake, though texture and oxidation properties were influenced [88, 89]. These results demonstrate the potential of hemp components in elevating the nutritional value of meat products, while also highlighting the importance of addressing texture-related challenges to meet consumer preferences. The combination of hemp seeds, amaranth, and flaxseed in poultry pâté resulted in a more favourable nutritional profile with higher protein, essential amino acids, fibre, and vitamin E content. The pâtés also had a healthier FA profile with a better n-6/n-3 ratio of 3:1. While this formulation improved flavour desirability, it did lead to lower tenderness, which could affect consumer preferences for texture-sensitive products [90].

Hemp oil, often combined with other plant-based flours, has been explored as a partial or complete replacer of animal fat [91–94]. In traditional Portuguese sausages (alheiras), hemp oil replacement resulted in lower SFA and higher PUFA content but also increased lipid oxidation at higher replacement levels [91]. In beef burgers and frankfurters, hemp oil mixed with amaranth or buckwheat flour reduced SFA and improved the FA composition, demonstrating the potential of hemp to improve the health profile of processed animal products. However, it sometimes leads to higher cooking loss and significant texture changes, such as increased firmness or chewiness [92, 93]. Application of hemp cake in meatballs showed that higher hemp cake content reduced lightness and redness but significantly decreased protein and lipid oxidation. Sensory scores were highest at the two lowest levels of the addition of hemp cake, suggesting moderate inclusion improves stability and taste without affecting appearance [95]. In chicken sausage, increased hemp seed meal lowered moisture, protein, and lipid content but improved emulsion stability and reduced cooking loss. However, higher inclusion levels increased lipid oxidation and negatively impacted colour and texture [96]. Finally, a combination of hemp seeds, flour, and oil in poultry roast improved protein, fibre, and enhanced n-3 FA but reduced taste and binding [97].

Hemp components have also been evaluated as natural preservatives, demonstrating antioxidant and antimicrobial functions [98–101]. In frankfurters and burger patties (minced meat model), micronized hemp seed cake and hemp flour were effective in reducing lipid oxidation and could partially replace synthetic preservatives like phosphates and sodium nitrite, underscoring the potential of hemp in extending the shelf life of processed animal products [98, 101]. Although they affected colour and texture properties, the use of hemp components as natural preservatives is a promising area for further research. Furthermore, in the study by Papatzimos et al. [100] where hemp oil was used as a substitute for animal fat along with partial or complete replacement of sodium nitrite in fermented salamis, it was found that hemp oil improved the fatty acid profile without altering the proximate composition or affecting microbial growth. However, salamis containing only hemp oil showed reduced redness and colour saturation during storage, as well as increased lipid peroxidation, which sodium nitrite helped mitigate. Texture changes included increased hardness with more nitrite and softening with more hemp oil. Sensory evaluations confirmed consumer acceptance, but due to colour and oxidation changes, storage should be limited to 60 days, as hemp oil cannot fully replace the functions of nitrites in meat products. Finally, the addition of hemp oil and sage oil to a gelatin-based coating for pork loin maintained a stable colour and reduced the aerobic plate counts, enhancing both microbial safety and shelf life [99].

The studies incorporated various hemp components, including hemp seeds (whole and dehulled), hemp seed protein, hemp press cake (both defatted and non-defatted), hemp flour, and hemp oil. Each component offered distinct benefits and challenges, highlighting the versatility of the available hemp component and the need for careful formulation to balance nutritional gains with acceptable sensory properties. For dairy products, the main challenges were textural issues, while for meat products, the focus was on managing texture and oxidation while maximizing nutritional improvements. With regard to meat products, the most profound effects regarding a healthier FA composition, while associated with adverse textural properties and colour, were observed when hemp oil or hemp seeds, a product rich in oil, were applied. The effect of hemp components on lipid oxidation was variable and dependent on the content of the easily oxidasable PUFA and the concentration of endogenous antioxidants such as polyphenols present in hemp components as well as other antioxidants and the presence of prooxidants such as salt [102]. The changes in texture parameters are related to the amounts and interactions between the components of the resulting meat batter that affect the matrix [94]. Finally, colour changes are associated with the green colour of hemp ingredients due to their chlorophyll content [96].

Additionally, it is worth mentioning that most of these studies were conducted in recent years, particularly after 2018. This timing correlates with the legalization and regulatory approval of hemp in various regions (USA, European Union) following significant legislative changes. The changes in the regulations regarding permission to use hemp components in food products facilitated more extensive research into its applications and benefits.

Overall, incorporating hemp components generally enhanced the nutritional value of dairy and meat products by increasing beneficial nutrients like fibre, protein, PUFA, and antioxidants. This potential to improve the nutritional value of processed animal products is very important for the meat industry that is actively looking for alternative food ingredients to improve the quality characteristics of meat products and to address consumers' demands for healthier food products [101]. However, these benefits sometimes came at the cost of altered texture, increased oxidation in some cases, and varying degrees of consumer acceptance. With regard to consumer acceptance, Zając et al. [86] reported that consumers are more likely to buy familiar meat products like burgers or sausages after being informed about the presence of a healthy ingredient despite defects in sensory characteristics such as colour and texture. Papatzimos et al. [101] also reported higher acceptability of burger patties containing hemp flour compared to those without hemp, despite noticeable differences in the colour of both raw and cooked products. Additionally, consumer acceptance was observed in fermented salamis containing hemp oil, despite decreased redness (a*) and colour saturation values [100]. These findings underscore the need for further research and development to optimise the use of hemp components in processed meat products and to mitigate any adverse effects on product quality.

Voyant Tools was used to visualize the research profile, specifically focusing on the frequency of hemp components and the examined parameters in relation to various meat products to which they have been applied (Figure 2). The visualization indicates a strong emphasis on the application of hemp flour and oil, which were predominantly used in minced meat products with pork as the primary ingredient. In terms of analyses, the nutritional profile and sensory characteristics, such as colour and texture, were most frequently examined, while antioxidant capacity was less frequently assessed.

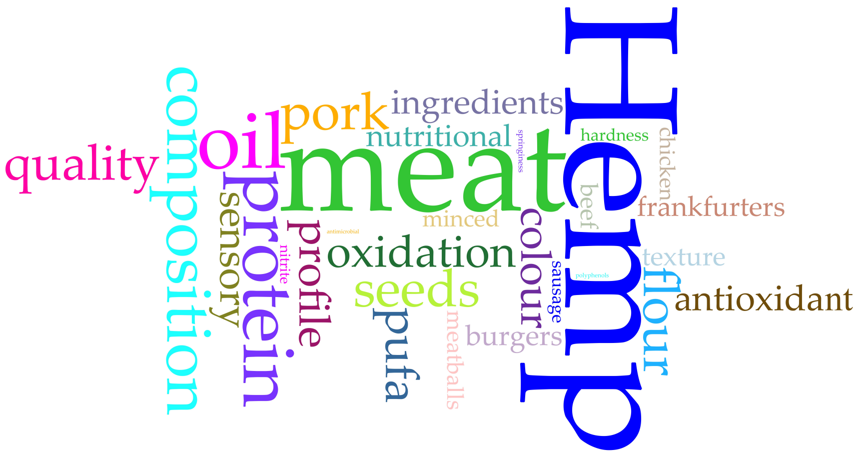

Figure 2. Word cloud visualization of the research profile of studies included in Table 3 for meat products

Overall influence of hemp ingredients on animal product quality

The reported studies demonstrated that the beneficial effects of hemp ingredients on animal product quality were primarily related to their high content of PUFAs, polyphenols, and other bioactive components. The inclusion of hemp components in animal diets or processed products enriched by meat and dairy products with PUFA, such as n-3 and n-6, improved the n-6/n-3 ratio and enhanced antioxidant capacity. Polyphenols and bioactive compounds, like tocopherols, contributed to the antioxidant properties, improving oxidative stability and overall product quality. Additionally, the fibre content in hemp resulted in better texture in products like meat loaves and pâtés.

However, it's important to note that there are concerns about the presence of cannabinoids, such as THC, in animal products. While research has shown that the levels of cannabinoids in meat, milk, or eggs were generally below legal-acceptable limits, it's crucial to implement safety precautions. Regulatory scrutiny and further investigation are essential to ensure product safety and consumer acceptance, particularly regarding the transfer of THC into animal-derived food products. This regulatory oversight would provide a sense of reassurance and confidence in the safety of these products.

Limitations on the application of hemp components as feed or food ingredients

While current research highlights the potential of hemp components as a valuable source of protein, fat, fibre, and bioactive compounds in both livestock diets and farm animal products, several limitations hinder its widespread adoption. These limitations can be broadly categorised into three areas: (a) residual levels of THC content in food products, (b) consumer acceptance of these products, and (c) the financial impact of using hemp components for food producers.

Regarding the residual levels of cannabinoids in farm animal products, many countries have banned hemp in animal feed due to insufficient research, making it difficult to establish safety conclusively. Additionally, evaluating the full range of hemp-based products and ensuring safety for both livestock and human consumers further complicates progress. Concerns about THC contamination in animal-derived products like meat, milk, and eggs pose significant challenges [83]. For instance, Wagner et al. [103] reported that the transfer of cannabinoids into the milk of dairy cows fed industrial hemp could result in THC levels exceeding the acute reference dose (ARfD) for some consumer groups when evaluated in exposure scenarios. Similarly, Krebs et al. [104] found detectable levels of THC in loins from sheep-fed pelleted rations containing hemp stubble, with an average total THC content in a cooked loin sample calculated to be less than 7.5 μg per serving. They also noted that Australian regulations, where the study was conducted, currently enforce zero tolerance for THC in animal-derived foods until Food Standards Australia and New Zealand (FSANZ) establish a safe or "maximum level". Furthermore, Smith et al. [105] concluded that the likelihood of human exposure to CBD/THC residues at levels equivalent to an ARfD through consuming beef fat from animals fed hempseed cake is minimal. Kasula et al. [58] found that levels of hemp cannabinoids, including cannabidiol and THC, were below the laboratory detectable limit of 0.005% in eggs and breast meat from laying hens fed diets containing hemp seed cake as a partial replacement for soy meal and corn. They also reported that the inclusion levels were non-contributory, as cannabinoids were not detected in the blood, organs, tissues, or eggs after 16 weeks of feeding hemp seed cake.

The Panel on Contaminants in the Food Chain (CONTAM Panel) reported no residual cannabinoids in "cold meat with hemp" but found 39 μg/kg of THC in a "cooked sausage" product. This residual THC was linked to the addition of dried/fresh herbs during sausage preparation to achieve different flavours [106]. However, there is a scarcity of studies examining the cannabinoid content of processed farm animal products in which hemp components have been used as a formulation ingredient. Even though all products listed in Table 3 contain very low levels of hemp ingredients, the possibility of psychoactive THC presence requires further investigation, especially considering that the CONTAM Panel could not conclude on the possible risks to public health from THC exposure via animal tissues and eggs due to a lack of data on the potential transfer and fate of THC.

Therefore, extensive research on the presence of THC compounds in both unprocessed and processed farm animal products is necessary. This research would help consumers gain confidence in consuming these products and encourage producers to invest in their development. Additionally, it would provide a scientific basis for regulatory guidelines, ensuring both safety and consumer acceptance.

The previous illegal status of hemp continues to influence consumer attitudes towards THC in hemp foods, as many consumers still associate hemp with marijuana. This misunderstanding complicates the acceptance of hemp-based products, as consumers may remain skeptical about their safety and efficacy. Additionally, consumers are often misinformed about the properties of hemp foods, further complicating acceptance [107, 108].

Finally, regarding the financial impact of using hemp components, for hemp to be competitive as a commodity feed resource, it must either match or undercut the cost of existing feedstuffs while offering comparable value. Alternatively, producers would need to capitalize on the enhanced quality of animal products resulting from hemp feeds to justify higher costs [83]. It should also be noted that hemp and its products, such as hemp seed cake, have not yet been confirmed as economical substitutes for traditional protein sources in animal feeding [77]. Today, hemp is mainly valued in the foods, supplements, nutraceuticals, and cosmetics industries for its expected health and disease-prevention benefits for human use, making those markets more profitable than its potential as an animal feed, thereby making hemp components a rather expensive choice.

Furthermore, most studies on the application of hemp components in meat products focus on experimental products, meaning that the economic potential and consumer acceptance of such products have not been fully evaluated. Therefore, additional research on consumer acceptance and market analysis is needed to explore the potential success of hemp-based animal products in the marketplace.

Conclusions

The incorporation of hemp components as functional ingredients in feed and food products has shown significant potential for enhancing the quality and nutritional value of animal-derived products. Studies have shown that hemp seeds, hemp seed cake, and hemp oil can have a positive impact on the lipid profile, sensory attributes, and fatty acid composition of eggs as well as meat and milk particularly from small ruminants like goats. The inclusion of hemp components has been associated with higher levels of PUFA and CLA in milk and meat, as well as improved oxidative stability and overall nutritional quality.

However, research has predominantly focused on poultry and small ruminants, with limited studies on other species such as pigs, steers, and cows. This highlights the need for further investigation into the effects of hemp components across a broader range of livestock. While the prevalent use of hemp seed cake as a feed ingredient underscores its nutritional benefits and cost-effectiveness, regulatory challenges, and concerns about residual THC levels in animal-derived products pose limitations to the broader application of hemp byproducts, such as SHB.

In food products, hemp components have shown potential in improving nutritional profiles, particularly by increasing PUFA content and acting as natural preservatives. Nonetheless, challenges remain, particularly regarding the textural properties of dairy products and potential negative effects on the sensory attributes of meat products. Future research should focus on optimizing formulations to balance these challenges with the nutritional benefits of hemp, expanding the scope of studies across different animal species, and addressing regulatory concerns to fully harness the potential of hemp in animal nutrition and food production.

Hemp components, particularly hemp seed oil, protein, and fibre, offer valuable functional and nutritional benefits in meat products. Their incorporation can improve lipid profiles, enhance texture, and increase fibre content, contributing to the development of healthier meat alternatives. Additionally, underexplored areas like the use of hemp protein isolates hold promise for further enhancing meat products. These components could improve emulsification, water-holding capacity, and potentially offer antioxidant and anti-inflammatory benefits. Further research is needed to fully realize these potential applications and their effects on product quality and consumer acceptance.

As the hemp industry starts to thrive globally, realizing its full economic potential as a sustainable source of valuable functional feed or food ingredients, regulatory agencies must clearly distinguish industrial hemp from medical *Cannabis* (marijuana). Additionally, consumer acceptance and market viability of farm animal products, whether derived from animals fed a hemp-based diet or containing hemp ingredients, hinge on ensuring safety concerning cannabinoids. This highlights the critical need for extensive research to establish maximum allowable THC levels in both processed and unprocessed farm animal products.

Abbreviations

AI: atherogenicity index

ALA: alpha-linolenic acid

ARfD: acute reference dose

CBD: hemp-derived cannabidiol

CLA: conjugated linoleic acid

CONTAM Panel: Panel on Contaminants in the Food Chain

DM: dry matter

FA: fatty acids

h/H: hypocholesterolemic/Hypercholesterolemic

HΩ: HempOmega

MUFA: monounsaturated fatty acids

PUFA: polyunsaturated fatty acids

SFA: saturated fatty acids

SHB: spent hemp biomass

THC: tetrahydrocannabinol

TI: thrombogenicity index

Declarations

Author contributions

GP: Investigation, Methodology, Visualization, Writing—original draft, Writing—review & editing. EK: Conceptualization, Investigation, Methodology, Validation, Supervision, Writing—review & editing. Both authors read and approved the submitted version.

Conflicts of interest

Both authors declare that they have no conflicts of interest.

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publication

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