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Effects of Supplementing Livestock Rations with Industrial Hemp By-products on Carcass Characteristics and Meat Quality

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Abstract

The current trend in global human population growth predicts that animal protein production will need to increase by approximately 60% or more by 2050. This situation places the responsibility on the livestock industry to ensure a sustainable supply of animal products. In general, animal feed accounts for more than 70% of the total cost in animal production. Within this cost, protein and energy in the ration are among the most important components with the largest share. Therefore, it is important to explore the possibilities of using alternative feed raw materials. Industrial hemp has attracted attention in recent years not only for its use in the medical field but also as a valuable food source for animal rations, and its potential use as a valuable feed component in the livestock sector is also being focused on. Hemp seeds, whether hulled or whole, along with the stems, leaves, oil, and oil cake, have high potential for use as alternative raw materials in animal feed. This study evaluates the research on the effects of adding industrial hemp by-products to livestock rations on carcass characteristics and meat quality, aiming to highlight the significance of this subject.

Keyword: Industrial hemp (*Cannabis sativa* L.), Hemp by-products, Sustainable livestock production, Meat quality

Özet

Küresel insan nüfusu artışındaki mevcut eğilim, 2050 yılına kadar hayvansal protein üretiminde yaklaşık %60 veya daha fazla artış gerektireceğini öngörmektedir. Bu durum hayvancılık endüstrisine sürdürülebilir hayvansal ürünler arzı sağlama görevi yüklemektedir. Genel olarak hayvansal üretimde toplam maliyetin %70'inden fazlasını hayvan yemi oluşturmaktadır. Bu maliyet içinde ise rasyondaki protein ve enerji, en büyük paya sahip önemli bileşenler arasında yer almaktadır. Dolayısı ile alternatif yem ham madde kullanım olanaklarının ortaya çıkarılması önem arz etmektedir. Endüstriyel kenevir, son yıllarda sadece tıbbi alanlardaki kullanımıyla değil, aynı zamanda hayvan rasyonları için kıymetli bir besin kaynağı olarak da dikkat çekmekte ve hayvancılık sektöründe değerli bir yem bileşeni olarak potansiyel kullanımına da odaklanılmaktadır. Kabuklu veya bütün kenevir tohumları, sap ve yaprakları, yağı ve yağlı küspesi hayvan beslemede alternatif hammadde olarak kullanılma potansiyeli yüksektir. Bu çalışmada, çiftlik hayvanları rasyonlarına endüstriyel kenevir yan ürünleri ilave edilmesinin karkas özellikleri ve et kalitesi üzerindeki etkilerini inceleyen çalışmalar değerlendirilmiş ve konunun öneminin ortaya konulması amaçlanmıştır.

Anahtar kelime: Endüstriyel kenevir (*Cannabis sativa* L.), Kenevir yan ürünleri, Sürdürülebilir hayvansal üretim, Et kalitesi

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1. INTRODUCTION

Adequate and balanced nutrition involves consuming the right amounts of nutrients to maintain a healthy life, allow the body to regenerate, and provide the energy the body needs. In adequate and balanced nutrition, both plant based and animal-based products are included. One of the animal-based products, red meat, is an important source of animal protein in terms of adequate and balanced nutrition, enabling people to maintain a healthy life. Factors such as the ever increasing world population, environmental issues adversely affecting the ecosystem, and climate change are sparking serious debates regarding protein sources, which hold a vital place in human nutrition. Accordingly, for the sustainability of the environment and food supplies, quests aimed at utilizing existing resources more efficiently and reducing factors that negatively impact the climate are coming to the fore. In particular, livestock farming for nutritional purposes and the rising demand for animal-sourced foods have brought about various environmental problems (Tüfekci and Temur, 2025).

The global shift toward sustainable production and consumption has significantly impacted the meat supply chain, which has served as the primary protein provider for human diets over the centuries. Growing ecological footprints linked to livestock expansion, alongside heightened ethical debates regarding animal treatment, have tarnished the reputation of meat products traditionally a dietary staple. In response, various strategies have been introduced to foster sustainability. While diversifying protein supplies by exploring alternative sources seems the most direct way to lower meat demand, altering deeply ingrained, centuries-old dietary patterns remains a formidable challenge. Consequently, scholars suggest mitigating the livestock industry's unsustainable impact through the implementation of eco-friendly nutrition and husbandry systems, complemented by advanced meat processing techniques (Andonovic et al., 2018).

Commonly recognized as an exceptionally versatile crop with over 25,000 distinct applications, industrial hemp (*Cannabis sativa* L.) is defined by a psychoactive Δ9-tetrahydrocannabinol (Δ9-THC) concentration of less than 0.3%. This sector is currently experiencing rapid global expansion (Frontier, 2022). The legislative approval of *Cannabis sativa* L. containing < 0.3% Δ9-THC across numerous jurisdictions has spurred a marked increase in its cultivation. Consequently, the processing of industrial hemp has yielded a variety of emerging potential feedstocks. These include hempseed byproducts (HSB; such as hempseed cake or meal) derived from seed processing, hemp hurds and stalks originating from fiber production, and spent hemp biomass (SHB) resulting from the extraction of cannabinoids (Irawan et al., 2025). Currently, the prices of traditional feed raw materials fluctuate greatly worldwide, and the economic returns of many farms are facing this challenge (Wang et al., 2022). Each year, numerous by-products are generated globally from agricultural processing; due to their rich nutrient contents and relatively low costs, these products are attracting increasing attention from nutritionists (Capanoglu et al., 2022; Bradford and Mullins, 2012). Industrial hemp (*Cannabis sativa* L.) is defined as an annual herbaceous plant belonging to the genus Cannabis of the Cannabaceae family (Russo, 2007). Such agricultural by-products with high nutritional value can generally be consumed by ruminants and converted into animal-derived products. Therefore, the use of industrial hemp by-products in animal feed may represent a promising solution (Capanoglu and Tomás-Barberán, 2022).

This study evaluates the research on the effects of adding industrial hemp by-products to livestock rations on carcass characteristics and meat quality, aiming to highlight the significance of this subject.

2. RUMINANTS

In their study, Wang et al. (2022) investigated the potential of industrial hemp byproducts (industrial hemp ethanol extraction byproduct, IHEEB; industrial hemp stalk, IHS; industrial hemp seed meal, IHSM; industrial hemp oil filter residue, IHOFR) in dairy cattle feed. The chemical composition, carbohydrate and protein fractions, rumen degradability, and intestinal digestibility of the feeds were examined using various analytical methods, and the results were compared with traditional feeds such as alfalfa hay and soybean meal. The findings showed that the nutritional content of hemp byproducts differed;

in particular, hemp seed meal could be a good protein source with its high protein content, while oil filter residue could provide more energy and easily degradable protein. Furthermore, the measured Tetrahydrocannabinol (THC) levels were found to be below safe limits, leading to the conclusion that these byproducts could be used as an alternative feed source in dairy cattle rations when properly planned.

In their study, Ncogo Nchama et al. (2022) investigated the use of hempseed cake, a sustainable alternative to soybean meal, in the feeding of Italian Simmental dairy cows. The main objective of the study was to determine the effects of hemp byproducts on animal performance and meat quality, and to evaluate their contribution to the circular economy. In the four-month study, hay, corn silage, and pasture-based rations were used, and hemp seed cake and soybean meal were compared as protein sources. As a result of the study, it was determined that hemp seed cake included in the ration showed similar performance to soybean meal in terms of daily live weight gain, feed conversion ratio, and carcass yield; and that it did not negatively affect basic quality parameters such as meat tenderness, color, and pH value. In conclusion, although the high unsaturated fat content of hemp due to biohydrogenation in the rumen does not directly translate into a significant advantage in the meat's fatty acid profile, it has been reported that hemp seed cake can be used as a substitute for soybean meal without compromising animal performance or meat quality.

In one study, the effects of adding spent hemp biomass (SHB) the residue remaining after cannabinoids are extracted from hemp to lamb diets were investigated. In an experiment conducted on 35 male lambs, SHB was included in the feed at levels of 0%, 10%, and 20%, and the animals' feed intake, weight gain, blood parameters, carcass characteristics, and meat quality were evaluated. The results showed that the nutritional value of SHB was similar to that of alfalfa, and no harmful residues were detected. Although lambs fed 20% SHB showed slightly reduced feed intake in the initial period, overall there were no significant negative effects on growth performance, health, or meat quality; only slightly higher cooking loss and carcass purge loss were observed in the group receiving the higher level. Overall, the study suggests that hemp by-products can be included in lamb diets at appropriate levels without causing major adverse effects on animal performance or health (Parker el al., 2022).

In the study conducted by Irawan et al. (2025), it was reported that the inclusion of various hemp by-products in the diets of ruminants raised for meat production did not affect carcass weight or dressing percentage. However, some positive effects were observed, particularly on the fatty acid profile of the meat. Hemp by-products used in ruminant diets possess favorable fatty acid profiles and contain various compounds with advantageous antioxidant properties that may contribute to improving meat quality. Experimental findings clearly demonstrated that feeding spent hemp biomass (HSB) increased the proportion of omega-3 fatty acids in the meat of ruminant animals. Feeding HSB to cattle increased the levels of n-6 fatty acids and n-3 polyunsaturated fatty acids in the meat, while the n-6/n-3 ratio was reported to remain unaffected.

In finishing cattle fed a diet containing 12% hemp seed cake (HC), higher levels of C18:3 n-3, C18:3 n-6, and C18:2 n-6 fatty acids were detected in the M. longissimus dorsi muscle; however, this dietary treatment did not affect the n-6/n-3 ratio compared with diets containing soybean meal (Turner et al., 2008). In a similar study, lambs fed a diet including 12% hemp seed cake (HSC) showed an increase in docosahexaenoic acid (DHA) and total n-3 fatty acid content in the musculus semimembranosus muscle compared with lambs fed a diet containing the same proportion of soybean meal (Antunović et al., 2020). Studies conducted on small ruminants have demonstrated that the use of hempseed cake can increase the omega-3 content of meat by approximately 24–44% (Antunović et al., 2020; Semwogerere et al., 2023b; Turner et al., 2008). Additionally, a linear increase in the levels of n-3 PUFA and n-6 PUFA has been observed in meat obtained from goats fed HSB (Semwogerere et al., 2023b). This increase in polyunsaturated fatty acids is considered beneficial because n-3 fatty acids may contribute to reducing the risk of cardiovascular diseases (Khan et al., 2021; Mozaffarian and Wu, 2011), while n-6 PUFA may have positive effects on improving fertility (Vahmani et al., 2020). Some studies have also reported that the inclusion of HSB does not significantly affect the moisture, fat, or protein content of meat (Gurung et al., 2022; Ncogo Nchama et al., 2022). Furthermore, it has been reported that high levels of hemp seed cake (HC) in lamb diets significantly

increased the concentrations of 18:3 n-3 and DHA in the M. longissimus dorsi muscle by approximately 21.8% (Turner et al., 2012). The fatty acids present in hemp may improve the sensory characteristics of meat and contribute to an increase in its antioxidant capacity, as observed in animals fed hemp seed based diets (Semwogerere et al., 2023b). In addition, increasing the level of hemp seed cake HSC supplementation in goats resulted in a linear improvement in the antioxidant capacity of blood, liver, and meat tissues (Semwogerere et al., 2023a).

Semwogerere et al. (2020) reported in their study that the use of hemp by-products in ruminant feeding generally showed neutral effects on growth performance and meat quality. Karlsson and Martinsson (2011) noted that in some studies, diets with high protein but low energy intake could limit lamb growth. However, no significant differences in live weight and daily weight gain were observed in cattle fed with whole hemp seeds or hemp seed cake (HSC) (Gibb et al., 2005; Turner et al., 2008) or in dairy cows (Karlsson et al., 2010). Growth and meat quality traits were also similar in animals fed HSC and soybean/canola cake due to comparable chemical composition, feed intake, and digestibility (EFSA, 2011; Mierliță, 2019).

In the study conducted by Tathong et al. (2024), the effects of hemp-derived cannabidiol (CBD) oil on goats were investigated. Sixteen Boer crossbred goats were fed a basal diet supplemented with 0, 0.1, 0.2, or 0.3 mL of CBD per 30 kg of body weight for 90 days. CBD did not affect growth, carcass traits, or meat pH but altered certain blood and meat quality parameters. Specifically, 0.1-0.3 mL of CBD increased white blood cell counts, while 0.3 mL raised serum total protein, globulin, sodium, and carbon dioxide levels. Meat from goats receiving 0.2-0.3 mL of CBD showed improved color, stability, tenderness, and texture, although higher CBD levels also increased ammonia and solvent-like odors. In conclusion, CBD supplementation up to 0.3 mL per 30 kg of body weight positively affected blood biomarkers and meat quality without negatively impacting growth or carcass characteristics.

Chaosap et al. (2025) investigated the effects of adding hemp leaves at levels of 0%, 2%, and 4% to goat kid diets on carcass traits and meat quality. The results showed that the inclusion of 2-4% hemp leaves increased hot and cold carcass weights, elevated total polyunsaturated fatty acids, and improved the oxidative stability of the meat. It also contributed to a reduction in cooking loss, while the main meat quality characteristics (color, chemical composition, and texture) remained largely unchanged. These findings suggest that hemp leaves may serve as a natural feed additive capable of improving the quality and shelf life of goat meat.

In their study, Taşkesen and Tüfekci (2025) aimed to reveal the potential use of industrial hemp and its derivatives in sheep nutrition as a sustainable alternative to high feed costs, in light of nutrient contents and existing literature findings. Consequently, it was concluded that hemp and its derivatives possess the potential to enhance meat quality. They improve the antioxidant activity and microbial quality of the meat, making it healthier and more shelf stable. Furthermore, it was reported that the use of hemp in nutrition can improve the fatty acid profile of the meat by increasing the levels of health-promoting components such as alpha-linolenic acid, conjugated linoleic acid, and total n-3.

3. MONOGASTRICS

In the study by Mourot and Guillevic (2015), adding hemp oil (HO) to the diet of pigs did not lead to significant changes in physical traits such as carcass weight, lean meat proportion, or back fat thickness, but it substantially improved the nutritional quality of the meat. Hemp oil supplementation increased the lipid content in the longissimus dorsi muscle and also enhanced the accumulation of ALA (alpha-linolenic acid) in lean meat and fat tissues. According to the study results, the total omega-3 fatty acid content in the meat of the HO fed group was 2.6 times higher than in the palm oil group and 0.7 times higher than in the rapeseed oil group, indicating that hemp oil is an effective dietary strategy to enrich pork with omega-3 fatty acids.

In the study conducted by Kemp (2022), the use of hempseed meal as an alternative protein source in grow-finish pig diets was investigated. The results showed that hempseed meal had no significant effect on feed intake, feed efficiency, average daily gain, or carcass traits. However, in terms of meat quality, the group fed soybean meal had lower drip loss, more tender meat, and lower microbial load and lipid oxidation. Low levels of CBD were detected in animals fed hempseed meal, while THC was not detected.

Mihăilă et al. (2024) reported that hempseed is a rich source of essential amino acids and n-3 fatty acids. In their study, the effects of the Jubileu variety of hempseed on pig performance, nitrogen balance, and N_2O emissions were investigated. While growth and carcass quality were largely unchanged in the diet supplemented with 5% hempseed, urinary nitrogen levels and estimated N_2O emissions decreased. In conclusion, it was reported that hempseed can be added to pig diets and may provide beneficial effects on nitrogen metabolism and environmental impact.

Research is being conducted to diversify lipid sources rich in n-3 fatty acids for animal feed. In a study by Mourot and Guillevic (2015), three groups of 12 pigs each, with live weights ranging from 50 to 105 kg, were fed isolipidic diets; these diets contained palm oil (PO), rapeseed oil (CO), or hemp oil (HO), providing 0.6, 1.9, and 3.4 g of C18:3 n-3 (ALA) per kg of feed, respectively. The amount of ALA deposited in the meat was higher in the HO pigs ($p < 0.001$). They reported that hemp oil could be an interesting source of ALA to improve the nutritional quality of pork.

In their study, Mohamed and House (2024) stated that whole hemp seed, hemp oil, hemp cake/meal, and to a limited extent, hemp hulls are utilized in poultry, swine, ruminant, and aquaculture production. Research has shown that these products do not adversely affect animal health or performance; furthermore, they have been found to increase health promoting components such as omega-3 fatty acids, gamma-linolenic acid, and conjugated linoleic acid in animal products like eggs, meat, and milk. While most evidence in the literature focuses on whole hemp seed, hemp oil, and hemp cake/meal, the authors noted that other hemp derivatives such as hemp screenings not used for human consumption, protein concentrate (35–85% protein), and crude protein/meal (<35% protein) could also be valuable for animals. Consequently, it was reported that within established limits, hemp seed derivatives can be considered safe and effective feed ingredients, offering suitable alternatives to traditional feed components.

4. POULTRY

Jing et al. (2017) investigated the effects of hemp oil (HO) and its equivalent product Hemp Omega (HΩ) on the performance and tissue fatty acid profile of laying and broiler chickens. Nineteen-week-old Lohmann White layers were fed for 6 weeks, and 150-day-old Ross 308 chicks were fed for 21 days with diets supplemented with 3-8% HO or HΩ. The results showed no effect on performance. Chickens fed HO or HΩ had increased levels of total n-3 PUFAs, alpha-linolenic acid (ALA), EPA, DPA, and DHA in egg yolks, breast, and thigh meat, while MUFA levels decreased. Total n-6 PUFAs, linoleic acid (LA), and arachidonic acid (ARA) were generally unaffected, but gamma-linolenic acid (GLA) increased significantly. These findings indicate that hemp oil can enrich eggs and meat with n-3 PUFAs and GLA without negatively affecting chicken performance.

Vispute et al. (2021) investigated the effects of adding hemp and dill seeds to the diet on the physicochemical properties, oxidative stability, and sensory attributes of fresh and 15-30 day-stored broiler meat. A total of 192-day-old Cari-Vishal chicks were divided into six groups and fed either a basal diet supplemented with varying levels of hemp seed (HS) and dill seed (DS) or a control diet containing bacitracin methylene disalicylate (BMD). The results showed no differences in muscle cholesterol and fat content, while lipid peroxidation parameters (thiobarbituric acid reactive substances and free fatty acid content) were higher in the control groups and oxidative stability was improved in the seed-supplemented groups. As storage time increased, oxidative stability measured by ABTS and DPPH, as well as physicochemical properties such as pH, color, and odor, decreased, with groups receiving hemp seed alone or in higher-dose combinations showing higher ABTS activity.

Sensory attributes were unaffected across treatment groups. These findings indicate that supplementation with hemp and dill seeds reduces lipid peroxidation and improves lipid profile, oxidative stability, and sensory qualities of broiler meat.

Konca et al. (2014) investigated the effects of hemp seed (HS) on performance, egg characteristics, serum lipid profile, and antioxidant activity in Japanese quail. A total of 120 eight-week-old laying quails were fed diets containing 0%, 5%, 10%, or 20% HS for 8-14 weeks. The results showed no significant differences in body weight, feed intake, feed efficiency, or egg production; however, the 10% HS diet increased egg weight and specific gravity. Carcass traits were unaffected, while LDL levels were lower in the HS groups compared to the control. Glutathione peroxidase (GSH-Px) activity increased in the 10% and 20% HS groups, whereas other antioxidant parameters remained unchanged. Egg omega-3 content increased linearly with HS supplementation. These findings suggest that HS may serve as a natural feed additive that lowers LDL and enhances antioxidant capacity in laying quail. Konca and Beyzi (2012) reported that adding 10% hempseed to the diet of broiler quails during the fattening period increased carcass and heart weight, while decreasing liver and intestinal weight, without affecting gizzard weight. Similarly, Khan et al. (2010) observed that including 10% and 20% hempseed in broiler diets did not influence carcass yield. In addition, Eriksson and Wall (2012) reported that under organic production conditions, using 10% and 20% hemp cake during the growing and finishing periods had no significant effect on broiler carcass yield.

Yalçın et al. (2018) investigated the effects of hemp seed (HS) on quail meat quality. A total of 192 seven-day-old quails were fed diets containing 0%, 5%, 10%, or 20% HS for 5 weeks, and at the end of the experiment, 64 quails were slaughtered and meat samples were analyzed. The results showed that cooking loss of breast meat was significantly lower in the 20% HS group, and HS inclusion increased the redness of thigh meat. In breast meat, palmitoleic and oleic fatty acids decreased with HS supplementation, while linoleic and linolenic acid contents increased linearly. These findings indicate that adding HS can improve quail meat quality in terms of color, fatty acid composition, and cooking loss.

Cufadar et al. (2021) investigated the effects of hemp seed meal (HSM) inclusion in the diet on laying performance, external egg quality, and egg yolk fatty acid profile of Japanese quails. A total of 150 ten-week-old laying quails were fed diets containing 0%, 5%, 10%, 15% and 20% HSM for 8 weeks. The results showed that dietary HSM levels did not affect laying performance, while eggshell thickness and albumen index were significantly influenced by HSM. Inclusion of HSM in the diet improved the fatty acid composition of egg yolks, increasing total monounsaturated and omega-3 fatty acid content. These findings indicate that HSM can enhance egg yolk fatty acid profile without negatively affecting laying performance or egg quality.

Juodka et al. (2018) investigated the effects of adding Camelina or hemp seed cake to the diet on the intramuscular fatty acid profile of ducks. A total of 99 male ducks were fed diets containing control (%15-20 rapeseed cake), 15-20% hemp seed cake (HEM), or 15–20% Camelina cake (CAM), and their breast and leg muscles were analyzed at 49 days of age. Ducks fed Camelina cake showed increased levels of n-3 α-linolenic acid (ALA) and total n-3 polyunsaturated fatty acids (PUFAs) in breast and leg muscles, while n-6/n-3 and linoleic/α-linolenic ratios decreased. Ducks fed hempseed cake showed higher levels of linoleic acid, total n-6 PUFAs, and n-6 γ-linolenic acid (GLA). These findings indicate that Camelina cake supplementation can produce duck meat with high n-3 PUFA content suitable for functional foods, whereas hempseed cake supplementation yields high quality meat enriched in n-6 GLA.

Juodka et al. (2022) investigated the effects of replacing rapeseed cake with hemp seed cake or camelina cake in duck diets on carcass characteristics and liver fatty acid profiles. The study found that hemp seed cake positively influenced growth performance and carcass yield but did not alter the proportion of n-3 polyunsaturated fatty acids (PUFAs) in the liver. In contrast, camelina cake reduced feed intake and carcass yield, but more than doubled the levels of n-3 and long chain n-3 PUFAs in the liver compared to the control group, lowering the n-6/n-3 ratio to 3.38, thereby creating a healthier liver profile for human consumption.

Kaić et al. (2024) investigated the effects of adding industrial hemp leaves at different levels (1%, 2% and 3%) to broiler diets on carcass traits and meat quality. The results showed that the 2% hemp leaf inclusion resulted in the highest wing proportion and the lightest breast meat color (highest L*), while the 2% and 3% additions significantly reduced abdominal fat compared to the control groups. Additionally, meat toughness (shear force), which was highest at the low 1% dose, decreased with higher inclusion levels, altering the textural properties of the meat. In conclusion, hemp leaves have the potential to improve broiler meat quality, but more comprehensive studies are needed to assess their effects on other health parameters.

In the study conducted by Sopian et al. (2025), the effects of adding *Cannabis sativa* residues at levels of 0.5%, 1%, and 2% to broiler diets on growth performance and meat characteristics were investigated. In terms of meat quality, the inclusion of *Cannabis sativa* residues had no significant effect on basic quality traits such as meat pH, color, drip loss, thawing loss, cooking loss, and shear force. However, reductions in some fatty acids, increases in free amino acids, higher moisture content, and lower fat content contributed to improvements in the nutritional value and flavor characteristics of the meat.

Darmawan and Öztürk (2025) reported that hemp seed is a potential candidate to replace soybean meal dependency due to its rich protein content and balanced amino acid profile, despite containing anti-nutritional factors. This study aimed to evaluate the effects of adding heat treated hemp seed cake (HSC) and phytase to broiler diets as a substitute for soybean meal on production performance, carcass characteristics, visceral organ weight, serum biochemistry, and intestinal health. The results showed that diets containing hemp seed cake had no statistically significant negative effects on carcass weight, liver weight, or abdominal fat. However, in all hemp-fed groups, the weight or length of organs such as the heart, jejunum, ileum, and cecum were higher compared to the control group (soybean-based diet). Particularly in the unprocessed or oven-heated hemp groups, the increased spleen and gizzard weights indicate that the digestive system may be adapting to the fibrous structure and composition of hemp. In summary, hemp use did not impair carcass yield but led to greater development of digestive tract organs.

5. CONCLUSION

As a general evaluation of the conducted studies, it has been observed that industrial hemp by-products, used as alternatives to traditional protein and energy sources in animal production, can be safely included in animal diets. Industrial hemp and its derivatives stand out as promising alternative feed resources in animal nutrition due to their rich nutrient composition, favorable fatty acid profile, and potential advantages in terms of sustainability. The studies reviewed in this paper indicate that the inclusion of hemp seed, hemp seed cake or meal, hemp oil, hemp leaves, and other processing by-products in animal diets generally does not have negative effects on carcass characteristics in ruminants, monogastrics, or poultry. In most studies, parameters such as carcass weight, dressing percentage, and overall growth performance were found to be similar to those obtained with conventional feed ingredients such as soybean meal or rapeseed products.

In terms of carcass characteristics, it has been concluded that hemp derivatives added to rations at certain levels generally have neutral or positive effects on parameters such as dressing percentage and hot and cold carcass weight. In poultry, the reduction in abdominal fat and the preservation of carcass quality in ruminants demonstrate the balanced effect of hemp on muscle development and body composition. In some species, the increase in the weight of digestive system organs (such as the gizzard and intestines) due to the fibrous structure of hemp is considered an indication that animals successfully adapt to this new feed resource.

The most remarkable finding regarding meat quality is that hemp can modify the fatty acid profile of animal products in favor of human health. Meat obtained from animals fed hemp supplemented diets has been found to be enriched with polyunsaturated fatty acids (PUFAs) such as n-3 (omega-3), n-6 (omega-6), and conjugated linoleic acid (CLA). In particular, the increase in alpha-linolenic acid (ALA) and gamma-linolenic acid (GLA) levels in meat allows these products

to be considered within the category of functional foods. However, the magnitude of these effects may vary depending on the type of hemp product used, the inclusion level in the diet, and the animal species. Moderate inclusion levels generally produce positive or neutral outcomes, whereas very high inclusion levels may cause minor changes in some meat quality parameters (such as cooking loss, aroma characteristics, or the development of digestive organs). Nevertheless, these effects are generally limited and do not negatively affect carcass yield or the overall acceptability of the meat. In addition, hemp has the potential to improve the physical and sensory quality of meat. Due to the natural antioxidant compounds it contains, hemp by-products increase the oxidative stability of meat, slow down lipid oxidation, extend shelf life, and help preserve meat color. Reduced cooking loss and improvements in textural properties of meat (such as tenderness and juiciness) support the production of high quality meat preferred by consumers.

In conclusion, the use of industrial hemp by-products in livestock diets has strategic importance in terms of both environmental sustainability and the production of high-quality animal protein. It is clear that hemp contributes to a healthier supply of red and white meat by increasing the nutritional value and antioxidant capacity of animal products. Future studies should examine the effects of different hemp varieties and inclusion levels on specific tissues in greater detail, which will further expand the potential applications of this resource.

AUTHORS' CONTRIBUTION

HT: Have equal contributions in the review article. **İCT:** Have equal contributions in the review article.

CONFLICTS OF INTEREST

The authors have no conflicts of interests.

RESEARCH AND PUBLICATION ETHICS

The authors declare that this study complies with Research and Publication Ethics.

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