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VALORIZATION OF BY–PRODUCTS RESULTING FROM HEMP PROCESSING IN ORDER TO FORMULATE FEED FOR THE LIVESTOCK SECTOR

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Abstract: The recovery of waste resulting along the agri–food chain into by–products is a viable method for obtaining alternative and organic feed ingredients. Traditionally, hemp (*Cannabis sativa* L.), is used for textile fibers, but in recent years it has enjoyed increased attention as animal feed due to its special nutritional properties. Being a culture in continuous development, it generates significant amounts of waste. A number of studies indicate that the inclusion of hemp co–products in the diet of animals provides unconventional sources of superior nutrients, with amounts varying depending on the species and the purpose pursued. The results of the analysis of the nutritional components of industrial hemp by–products (husks (HS); hemp seed cakes; industrial hemp seed flour, IHSM; flower and leaf mixture (MFL); industrial hemp ethanol extraction by–product, IHEEB; filter residue for industrial hemp oil, IHOFR;) encourage further research to obtain new potential applications in the livestock sector.
Keywords: hemp waste, circular economy, animal nutrition, sustainability

1. INTRODUCTION

The current trend of global population growth involves an expansion of animal production to meet the growing demand for complete proteins. In general, the cost of animal feed constitutes more than 70% of the total expenditure related to animal production, which is why a number of researches have focused on the analysis of plant materials and by-products known for nutritional values as possible supplements in animal husbandry. Feed companies face a shortage of basic proteins and energy ingredients, but also the absence of synthetic metabolites, caused by a number of factors, including high ingredient prices and climate change [1,2]. Protein is essential macronutrients for humans, animals, and fish [3].

The analysis of new and less used feed resources for animal feed and shelf life optimization is vital for the sustainability of the livestock and meat industries. Innovative alternatives to regular food include hemp by-products (*Cannabis sativa* L.) (e.g., seeds, oil, oilseed cakes, peels, and leaves). Hemp is part of the category of crops with a real potential in obtaining feed with a high content of nutrients. However, many of the by-products resulting from the further processing of hemp are discarded as waste [4, 5].

Significant amounts of industrial hemp by-products are generated from the most well-known uses of this plant: fiber, cannabinoids, and oil extraction.) Hemp seed flour (hemp seed cake), obtained from the process of extracting oil from the seeds, and hemp biomass that remains after cannabinoids are obtained, especially cannabidiol (used hemp biomass or SHB) are the main by-products used as animal feed [6,7]. Hemp contains various bioactive compounds that may provide health benefits, according to research conducted on monogastric animals [8]. Also, by-products made from hemp are high in cellulose and could be used as animal feed, which could improve economic viability and environmental sustainability in terms of both hemp cultivation and food production [9,10]. Dry matter (HS) products have been shown to be an effective option to reduce the environmental impact of cattle and pigs [11]. However, regulatory agencies around the world are mainly concerned about the possible presence of THC and cannabidiol (CBD) residues in animal products intended for human consumption [12,5].

This paper explores emerging solutions for optimizing the process of including hemp co-products that are safe for both animal nutrition and the food sector.

2. MATERIALS AND METHODS

The efficient use of these residues can have a considerable impact in promoting bioeconomy concepts and in the shift from linear to circular production systems [13]. In this regard, numerous researchers have analyzed the nutritional characteristics of hemp co-products, in order to adapt them for a safe feed for the livestock sector. Among the by-products of hemp use, hemp seed cake or flour (HSB) resulting from seed processing, hemp stems and peels resulting from fiber processing, and used hemp biomass (SHB) can be used as animal feed [12]. Hemp by-products, although underutilized, are used as novel food for ruminants. Of these by-products, hemp seed cake is most often included in animal feed due to its high biological protein value, with an amino acid profile comparable to that of soy [15,16]. The analysis of the nutritional composition of hemp seed cake (HSC) and feed formulated with HSC is presented in Table 1. Overall, the data on nutritional structure were consistent with other results presented in the literature [17]. Hermp seed cake and feed nutritional analysis (% as is basis) Table 1.

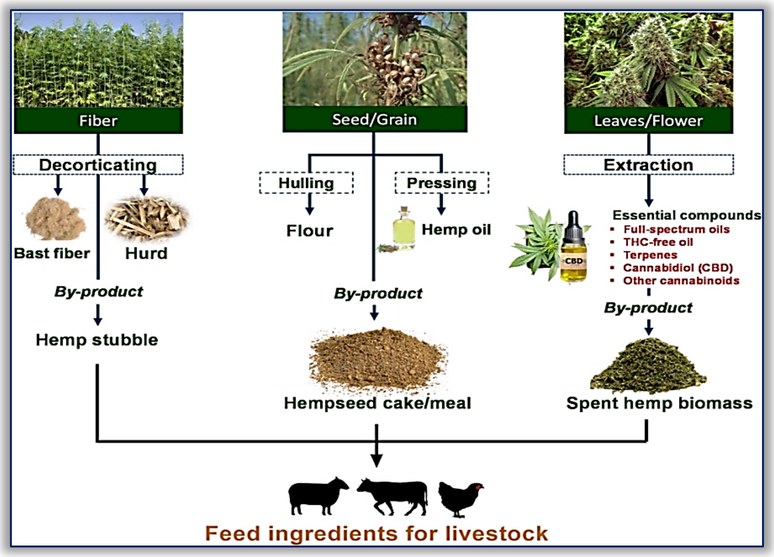

Figure 1 – Schematic representation of the different purposes of hemp cultivation and potential by–products as animal feed [14]

Table 1 [17]

Nutrients	Hemp seed cake (HSC) and treatments									
	HSC	SD	C0	SD	H10	SD	H20	SD	H30	SD
Moisture	7.53	0.31	12.12	0.01	11.21	0.38	10.03	0.47	8.40	0.20
Protein (Raw)	32.06	0.30	14.81	0.51	16.31	0.19	16.75	0.06	16.57	0.25
Fat (Raw)	9.02	0.03	2.70	0.00	5.57	0.05	8.78	0.26	11.47	0.16
Fiber (Raw)	32.21	0.44	1.79	0.11	4.92	0.87	7.07	0.18	9.82	0.11
Ash	5.38	0.05	11.27	0.21	11.48	0.28	12.71	0.04	12.21	0.55
Minerals (%)										
As	0.17	0.01	3.38	0.03	3.18	0.08	3.61	0.24	3.45	0.14
P	0.71	0.47	0.50	0.06	0.50	0.01	0.56	0.04	0.57	0.01
Yes	0.01	0.00	0.14	0.01	0.14	0.01	0.16	0.01	0.15	0.01
mg	0.48	0.01	0.17	0.01	0.21	0.00	0.26	0.01	0.28	0.00
Mn (ppm)	133.00	0.58	78.50	3.54	93.55	1.77	135.00	9.90	145.00	7.07
Fe (ppm)	133.67	2.01	283.50	38.89	260.00	7.07	261.50	13.44	244.00	12.21
Zn (ppm)	77.83	0.56	86.15	7.85	89.60	4.53	123.50	10.61	128.00	2.83
Cu (ppm)	18.83	0.46	19.40	0.28	17.55	0.35	17.95	0.07	19.20	3.54
K	0.95	0.02	0.73	0.05	0.72	0.01	0.73	0.04	0.62	0.00
Amino acids (%)										
Methionine	0.51	0.12	0.42	0.10	0.42	0.01	0.44	0.10	0.52	0.01
Cysteine	0.34	0.05	0.24	0.04	0.23	0.00	0.22	0.02	0.24	0.01
Lysine	1.13	0.02	0.86	0.05	1.04	0.05	1.00	0.05	0.97	0.16
Phenylalanine	1.24	0.01	0.72	0.02	0.81	0.01	0.71	0.00	0.75	0.00
Leucine	1.93	0.02	1.34	0.03	1.45	0.03	1.25	0.01	1.29	0.00
Isoleucine	0.91	0.01	0.52	0.02	0.69	0.02	0.52	0.01	0.61	0.01
Threonine	1.18	0.03	0.59	0.07	0.72	0.01	0.67	0.02	0.66	0.06
Valine	1.13	0.02	0.57	0.03	0.77	0.01	0.61	0.02	0.76	0.01
Histidine	0.73	0.02	0.41	0.02	0.50	0.01	0.41	0.00	0.48	0.00
Arginine	4.00	0.05	0.93	0.06	1.26	0.01	1.39	0.02	1.82	0.04
Aspartic acid	1.37	0.03	1.60	0.13	1.63	0.02	1.76	0.00	1.56	0.11
Serine	3.55	0.03	0.82	0.07	0.87	0.05	0.82	0.02	0.77	0.05
Glutamic acid	1.45	0.02	2.73	0.23	2.70	0.01	2.75	0.03	2.46	0.23
Proline	4.94	0.03	1.07	0.06	1.03	0.02	0.99	0.01	0.98	0.06
Hydroxyproline	1.35	0.04	0.13	0.01	0.08	0.01	0.17	0.01	0.14	0.00
Alanine	1.16	0.01	0.78	0.05	0.84	0.01	0.70	0.04	0.78	0.01
Tyrosine	0.89	0.01	0.51	0.01	0.54	0.01	0.50	0.01	0.51	0.01
Tryptophan	0.27	0.00	0.10	0.01	0.11	0.01	0.19	0.01	0.13	0.01

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Data are the mean of three replicate (n=3) of HSC and two replicates (n=2) of each feed type, HSC=hemp seed cake, C0=Control no HSC, H10:10% HSC, H20:20% HSC, H30:30% HSC. SD-standard deviation.

In order to signal the antioxidant activity of hemp by-products, consisting of leaves, inflorescences, wrinkled seeds and stems, their nutritional characteristics were analyzed [18]. The quantitative macronutrient and cannabinoid content of MHF is presented in Table 2.

3. RESULTS

Cattle

Since hemp by-products are cellulose-containing plant materials, the target species for these feeds would be ruminants, especially cattle [9]. The objective of one experiment was to explore the nutritional components of industrial hemp by-products and to provide theoretical support for the application of industrial hemp by-products in dairy cattle production [19].

Crude protein and carbohydrate fractions in industrial hemp by-products and conventional feed, according to the Cornell Net Carbohydrate and Protein System (CNCPS), Table 2.

Table 2 [18]

Item	Micronized hemp fiber (MHF)
Nutrient composition (%)	
Dry matter	88.99
Moisture	11.11
Organic matter	76.51
Ash	23.49
Raw protein	17.56
Ether extract	7.05
Raw fiber	8.55
Dietary fiber	36.36
Soluble dietary fiber (SDF)	4.75
Insoluble dietary fiber (IDF)	31.61
SDF: IDF ratio	0.15
Gross energy (kcal/kg)	2,972.50
Cannabinoids (mg/g)	
Cannabidiol (CBD)	1.518
Cannabinol (CBN)	0.231
Cannabichromene (CBC)	0.209
Cannabidiolic Acid (CBDA)	0.370
Cannabigerolic acid (CBGA)	–
Cannabidivarin (CBDV)	0.251
D8–Tetrahydrocannabinol (D8–THC)	–
D9–Tetrahydrocannabinol (D9–THC)	–
D9–Tetrahydrocannabivarinic acid (THCA)	–
Tetrahydrocannabivarin (THCV)	–

Table 2 [19]

Item	ZIHEEB	DIHEEB	IHS	AH	SEM	p	IHSM	IHOFR	SBM	SEM	p
Protein fractions (g/kg CP)											
PA	104 c	19.4 d	250 b	346 a	10.4	<0.01	35.7 b	76.3 a	13.2 c	5.29	<0.01
PB1	27.7 BC	41.0 b	14.4 c	80.2 a	6.01	<0.01	60.4 c	116 b	175 a	9.80	<0.01
PB2	365 a	250 b	323 a	328 a	17.1	<0.01	575 a	545 AB	526 b	14.4	<0.01
PB3	312 a	314 a	212 b	153 c	16.3	<0.01	226	240	272	14.1	0.09
PC	191 b	376 a	200 b	92.6 c	9.93	<0.01	103 a	23.0 b	12.9 c	1.62	<0.01
CHO (g/kg DM)	527 d	623 c	797 a	717 b	2.55	<0.01	541 a	214 c	459 b	3.75	<0.01
NSC (g/kg CHO)	305 b	452 a	258 c	314 b	12.5	<0.01	189 c	603 b	641 a	9.50	<0.01
Carbohydrate fractions (g/kg CHO)											
CA	299 b	375 a	234 c	290 b	12.3	<0.01	187 b	590 a	591 a	9.64	<0.01
CB1	5.92 c	77.1 a	23.6 b	23.4 b	0.64	<0.01	2.46 c	12.7 b	50.0 a	0.34	<0.01
CB2	156 b	66.9 c	392 a	343 a	18.3	<0.01	162 b	71.0 c	273 a	19.1	<0.01
CC	540 a	481 b	350 c	344 c	15.9	<0.01	649 a	326 b	86.2 c	12.1	<0.01

ZIHEEB, Zhaozhou industrial hemp ethanol extraction byproduct; DIHEEB, Daxing' anling industrial hemp ethanol extraction byproduct; IHS, industrial hemp stalk; AH, there is alfalfa; IHSM, industrial hemp seed meal; IHOFR, industrial hemp oil filter residue; SBM, soybean meal. PA, non–protein nitrogen; PB1, rapidly degraded protein; PB2, intermediately degraded protein; PB3, slowly degraded protein; PC, unavailable protein; CHO, carbohydrate; NSC, non–structural carbohydrate; CA, sugars and soluble fraction; CB1, starch and pectin; CB2, fraction available cell wall; CC, unavailable cell wall. a–d Values in the same line with different capital letter superscripts mean samples have significant differences. SEM, standard error of the mean.

According to the data presented above, the flour obtained from industrial hemp seeds had a higher BP value than soybean meal ($p < 0.05$), but in comparison, it was significantly lower than the residues of the industrial hemp oil filter ($p < 0.05$). On the other hand, the concentration of PA in the other by-products was lower than that of alfalfa hay ($p < 0.05$). By-products of industrial hemp may be considered for inclusion in feed formulations as unconventional feed sources for dairy cattle, but the purpose of use must be duly considered [19].

Cold-pressed hemp cake was analyzed as a protein source for growing cattle, compared to a mixture of soybean meal and barley, investigating the influences on feed intake, weight gain (GVV), fecal traits and carcass characteristics. The calf fed hemp cake showed a significantly lower number of long particles in the feces, and the dry matter content in the feces and their consistency were considerably higher. Thus, feeding growing cattle with hemp cake leads to similar production

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and better rumen function compared to using soybean meal as a protein source [20]. Dried hemp leaves constitute an adequate protein option for dairy cows because the integration of hemp into their diet has no negative effects on animal health and does not alter the apparent digestibility of dry matter (DS), energy and organic matter (OM) or chemical degradability (CP) [21].

Sheep

Sheep are known for adapting quite easily with a wide range of alternative feeds. Due to these characteristics, research on feeding sheep with hemp by-products has been increasing in recent years. The results claim that it is an excellent source of protein, having a positive impact not only on preventing decreased performance, but also on the antioxidant effect, optimizing the fatty acid profile, improving rumen metabolism, increasing meat quality and blood parameters, Figure 2 [22].

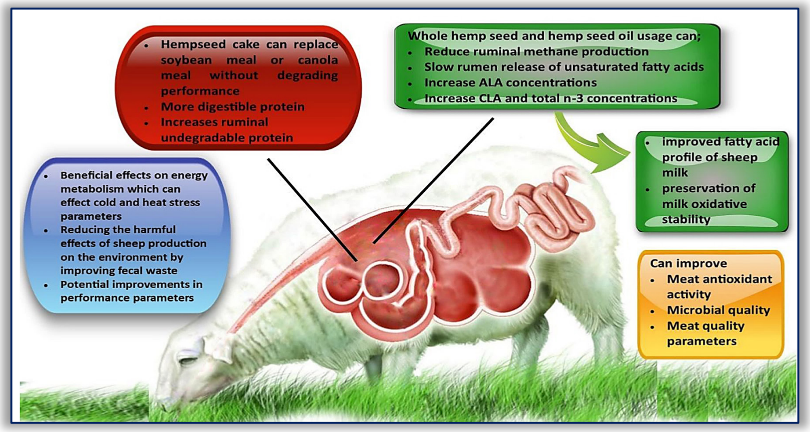

Figure 2 – Summarizing the effects of feeding hemp products in sheep [22]

The use of hemp seed cakes in sheep nutrition has shown benefits in terms of milk production, fatty acid profile (SFA) and oxidative stability. These indices have demonstrated that hemp by-products have real potential as a natural antioxidant and could help reduce lipid oxidation in raw milk [23]. The growth performance, carcass and physicochemical attributes of meat quality in ruminants fed with hemp by-products were analyzed. Lambs fed hempseed cake (HSC) had a high intake of meat protein (CP) with a low intake of Metabolizable Energy (ME), Table 3 [4]. Breeding performance of lambs and oxen fed hemp cakes or other protein feed, Table 3. It is suggested that hemp leaves can be included in goat diets without negative effects on performance, while the 4% content improves fiber intake and jejunal morphology [24]. Goats fed hemp hay showed significantly higher milk production with no changes in chemical composition [25].

Table 3 [24]

	Lambs			Steers		
Attributes	HSC	CM	SEM	HS	SBM	SEM
Total gain (kg)	6.4	9.5	0.52	192.6	193.3	0.95
Average daily gain (kg/d)	119	175	9.6	1.16	1.16	0.00
Body condition score (1–5)	2.9	3	0.04	–	–	
Feed conversion (DM/gain)	7.9	5	0.37	0.133	0.133	0.00

HSC, hempseed cake; CM, canola meal; S, hemp seed (full–fat); SBM, soybean meal; SEM, Standard error of mean. Inclusion levels: HSC—218 g/kg DM, CM—254 g/kg DM, and HS—140 g/kg DM.

Poultry

Hemp by-products have been shown to be excellent sources of yolk pigmentation, lutein enrichment, and egg fatty acids [17]. In one study, adding 5, 10, or 15% hemp seed cakes to the diet resulted in a linear increase in linoleic acid (LA) and α-linoleic acid (ALA) concentrations, with a decrease in saturated and monounsaturated fatty acids (SFA and MUFA) [26].

Table 4 [18]

Item	WITH	MHF	H–MHF	SEM	P–value
Carcass yield, %BW					
Dressing percentage	72.8	72.0	72.3	0.55	0.818
Breast	19.1b	18.8b	22.0a	0.50	0.011
Wings	9.1	8.8	8.6	0.12	0.232
Thighs+drumsticks	24.5	24.0	23.0	0.30	0.105
Visceral Edible Organs, %BW					
Liver	2.3	2.6	2.5	0.10	0.530
Proventriculus	0.5	0.5	0.5	0.03	0.602
Gizzard	1.4	1.5	1.1	0.07	0.061
Heart	0.7	0.7	0.6	0.04	0.391

Another analysis found higher concentrations of α-tocopherol, indicating better antioxidant capacity, in eggs from laying hens fed a hemp seed diet or hemp seed cakes [27]. The carcass characteristics of broilers fed a basic diet of micronized hemp fiber (MHF) over a period of 21 to 42 days are presented in Table 4. Although there were no significant differences in the percentage of clothing, chest, wings, thighs + legs ($p > 0.05$), the investigation reveals that feed supplementation with MHF at an inclusion rate of 1.5%, benefits overall productivity, improves the dynamics of in vitro cecal fermentation of the broiler microbiota [18].

Aquaculture

The aquaculture industry plays a key role in providing a source of high-quality dietary protein, essential amino acids, n-3 long-chain polyunsaturated fatty acids, vitamins and minerals to the global population [4,28]. To support the growing demand for nutritious foods, protein isolates (PIs) extracted from hemp husks were analyzed, which showed the strongest antioxidant properties and correlated with phenolic content. As expected, the values increased in the biomasses of skimmed hemp cake and hemp husks, accounting for 31.6% and 16.6%, respectively, Figure 3 [34]. The results indicated that hemp protein includes all ten essential AA amino acids needed for fish, and protein digestibility ranges from 84.1 to 97.5% [3].

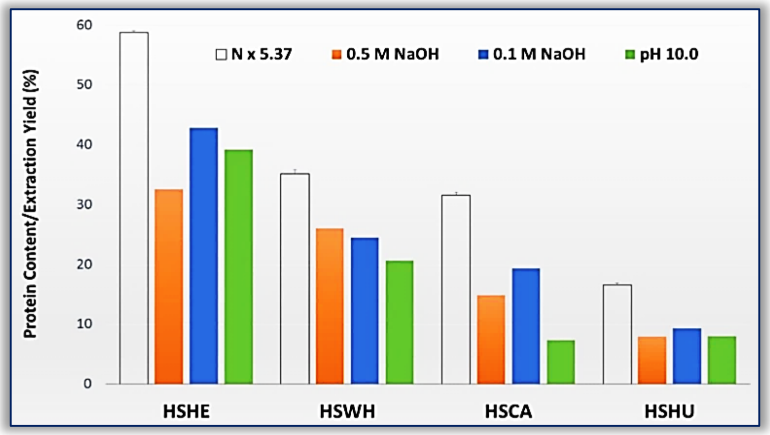

Figure 3 – Crude protein content and extraction yield of protein isolates from defatted hemp seeds and defatted by–products. HSHE—hemp hearts; HSWH—hemp whole seed; HSCA—hemp cake; HSHU—hemp seed hulls [3].

The growing demand for sustainable aquatic feed has led to the evaluation of the potential of using hemp meal as a functional ingredient in carp aquaculture diets. The results showed that replacing conventional protein sources (soybean and pea meal) with hemp seed meal at a rate of 20% resulted in 200 kg of hemp cake per tonne of feed, reduced conventional protein use by 33.3% and diverted up to 80% of waste to recycling [29].

Following the evaluation of the diet of European perch, which included 20% hemp flour, it can be stated that it provided the best overall growth and feed utilization. Fish that received hemp meal also showed favorable changes mainly in the intestinal mucosa, which supports digestion and nutrient absorption. The inclusion of hemp meal can lower feed costs, optimize sustainability, and reduce reliance on fishmeal in the aquaculture sector [30].

5. CONCLUSIONS

The results presented in the present study suggest that the nutritional value of hemp co-products offers an increased potential for obtaining selected feed in the animals' diet. Being vegetable materials containing cellulose, the species that are best suited for cattle. Hemp cake is the most common alternative protein source for growing cattle, it leads to growth similar to very expensive feed and better rumen function. In sheep feeding it showed benefits in terms of milk production, fatty acid profile (SFA) and oxidative stability. The lambs fed with hempseed cake (HSC) had a high intake of meat protein (CP) with a low intake of Metabolizable Energy (ME). For birds, they have been shown to be excellent sources of yolk pigmentation, enrichment with lutein and fatty acids of eggs. The carcass characteristics of broilers fed a basic diet of micronized hemp fiber (MHF) showed no significant differences. However, the investigation reveals that feed supplementation with MHF at an inclusion rate of 1.5%, benefits overall productivity, and improves the dynamics of in vitro cecal fermentation of the broiler microbiota. In aquaculture, the results showed that replacing conventional protein sources (soybean and pea meal) with hemp seed meal reduced conventional protein use by 33.3% and diverted up to 80% of waste to recycling. Following the evaluation of the diet of European perch, which included 20% hemp flour, it can be stated that it provided the best overall growth and feed utilization. In conclusion, industrial hemp by-products can be considered for inclusion in food formulations as unconventional food sources in the livestock sector, but the purpose of use must be duly considered.

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