

PROTEIN DIGESTIBILITY AND ACCEPTABILITY  
OF HEMP SEED MEAL IN HORSE DIETS

A Capstone Project  
Presented to the Faculty of the Graduate School  
of Cornell University  
in Partial Fulfillment of the Requirements for the Degree of  
Master of Professional Studies in Animal Science  
Concentration in Animal Nutrition

by  
Taylor Walker  
August 2025



## TABLE OF CONTENTS

ABSTRACT.....	1
INTRODUCTION.....	2-7
METHODS.....	8-11
RESULTS.....	11
DISCUSSION.....	12-13
CONCLUSION.....	13
APPENDIX.....	14-20
REFERENCES.....	21-23

## **LIST OF ABBREVIATIONS**

ADF – Acid detergent fiber

AIA – Acid insoluble ash

BW – Body weight

CF – Crude fat

CP – Crude protein

HSM – Hemp seed meal

NDF – Neutral detergent fiber

NSC – Non-structural carbohydrates

PUFA – Polyunsaturated fatty acids

THC – Tetrahydrocannabinol

WSC – Water soluble carbohydrates

## ABSTRACT

Hemp seed meal (HSM) has the potential to serve as a replacement protein feed for horses. The goal of this project was to assess the protein digestibility and acceptability of HSM in equine diets. Four feed concentrates containing 0% (control), 10%, 20%, and 40% HSM were tested. Horses were randomly assigned to the four feed concentrates over four 7-day periods in a 4 × 4 Latin square design. Horses were offered a first-cutting, mixed orchardgrass-timothy hay at 1% of body weight (BW; as-fed) and the feed concentrate at 0.4% BW (as-fed) in the morning and evening and were turned out to a winter pasture for approximately 7.5 hours per day. Horses were adapted to their respective feed concentrate from days 1 to 5 followed by fecal sample collection on days 6 and 7 of each period. Protein digestibility was measured using both lignin and acid-insoluble ash (AIA) as internal, indigestible markers. Whole-diet (hay + concentrate) protein digestibility, feed concentrate intake, hay intake, fecal consistency, and weight change were assessed. No refusals of feed concentrates occurred across treatments. No differences were observed for any of the measured variables between the HSM treatments and the control. Digestibility values measured using AIA appeared overestimated, potentially due to soil contamination, whereas digestibility values measured using lignin fell within reported ranges for horses consuming grass hay and feed concentrates. The results demonstrate that HSM inclusion up to 40% does not affect feed concentrate intake, fecal score, and whole-diet protein digestibility, indicating that HSM is an acceptable feed ingredient for horses and may replace soybean meal as the primary protein source.

## INTRODUCTION

Hemp (*Cannabis sativa L.*) is a highly versatile crop grown for food, textiles, building materials, biofuel production, and more. Hemp fabrics are made from fibers of the stalks of the plant. These fabrics were popular during the era of the World Wars due to their fiber content. Before cotton became the principal fiber plant, hemp was critical in the textile industry (Yano and Fu, 2023). Hempcrete, a variation of concrete, is made from hemp hurds and is primarily used for thermal insulation and non-structural building components.

With a short cropping period and fewer requirements for water and pesticides, hemp can be classified as a sustainable crop. Cotton has a cropping period of 140 to 160 days, and soybeans have a cropping period of 100 to 130 days. In comparison, hemp has a cropping period of 70 to 120 days (Consentino et al., 2012). Hemp can also grow in a wide variety of climatic conditions and uses around 12 to 15 inches of water per growing season per crop, compared to the 20 to 30 inches of water needed to grow one cotton crop per season (Consentino et al., 2012). Soybean meal is the long-established protein ingredient in monogastric diets. Demand for alternative protein ingredients has increased due to growing concern over the environmental impact of soybean meal production, and hemp seed meal (HSM) has been proposed as a potential alternative protein ingredient (Yano and Fu, 2023).

Hemp seed meal (HSM) is a byproduct of oil extraction from the whole hemp seed followed by milling of the remaining content into a meal. Botanically, hemp and marijuana are both classified as *Cannabis sativa L.* but represent two different varieties (or cultivars) bred for different purposes. The psychoactive cannabinoid compound in *Cannabis sativa L.* is called tetrahydrocannabinol (THC), and its presence occurs in varying concentrations depending on the parts of the plant, with the flowers containing the highest levels, as well as cultivation practices. Selective breeding has led to large differences in cannabinoid profiles and plant architecture.

Industrial hemp has been bred for low THC content ( $\leq 0.3\%$  in flowers), tall stalks for fiber, and seeds for oil, while marijuana has been bred for high THC content in the flowers to produce psychoactive effects. By legal definition, industrial hemp contains 0.3% or less THC in the flowering tops on a dry weight basis, and other parts of the plant, such as seeds used to produce HSM, typically contain nondetectable levels. On the other hand, marijuana has a THC concentration over 0.3% in the flowers, with some strains exceeding 30% (Hesami et al., 2023).

Hemp seed meal contains negligible amounts of cannabinoids, less than 0.005%, including THC and CBD, which is far below the 0.3% threshold for THC alone (Kasula et al., 2021). Despite this negligible amount, HSM has yet to be legally approved as a feed ingredient for poultry meat, livestock and companion animals, including horses. Consequently, there have been few studies evaluating the digestibility of HSM as an alternative protein ingredient for monogastric animals. As of August 2024, HSM has only been approved as a feed ingredient for laying hens, and additional studies are needed to determine the feasibility and nutritional benefits in the diets of livestock and companion animals (Hemp Feed Coalition, 2024). The composition of hemp seed (Table 1) consists of a generous fat profile, with approximately 31% fat, high protein (28 - 32%), and neutral detergent fiber (NDF) (32 - 40%) (Bailoni et al, 2021; USDA, 2019). That of HSM consists of approximately 9 - 12% crude fat, 25 - 30% NDF, and 28 - 32% crude protein (Kasula et al., 2021; USDA, 2019), with negligible amount of starch. This nutritional profile offers a significant opportunity as a potential feed ingredient in equine diets.

Table 1. Nutrient composition of whole hemp seed and hemp seed meal, %<sup>1</sup>

Item	Whole hemp seed	Hemp seed meal
Crude protein	20 - 25	28 - 32
NDF	27 - 36	32 - 40
Ether extract	30	10
Starch	<2	0.5

<sup>1</sup>USDA Food Data Central

Studies related to hemp involving horses have been limited to evaluating hemp seed oil (Ely et al., 2023). Hemp seed oil is characterized by a favorable omega-6-to-omega-3 fatty acid ratio (3:1) (Ely, 2023) and therefore can be used as a source of essential fatty acids (Klir et al., 2019). Additionally, hemp seed oil is rich in gamma-linolenic acid and stearidonic acid, which offer promising therapeutic applications in horses (Ely et al., 2023). Products containing CBD or full spectrum cannabinoids from hemp extract are often seen in the market promoting alternative treatments for arthritis, pain, or anxiety (Leise et al., 2023). The pharmaceutical application of hemp extracts or cannabinoids in equine medicine has only recently been explored. Currently, there is only one documented case involving their use in the management of cribbing behavior in horses. More long-term studies involving oral administration are needed before drawing any conclusions regarding the effect of hemp extract or cannabinoids in equine medicine (Cunha et al., 2023).

Digestibility of nutrients and safe levels of HSM dietary inclusion have not been reported for horses. The only study available in the literature so far has assessed the palatability of HSM for horses (Springer et al., 2023). The number of horses was limited, but the study found that there was a clear preference and greater consumption of HSM pellets over soybean meal and

sugar beet pulp pellets, with a similar palatability to rice bran pellets. The horses showed increased consumption of HSM pellets over time, which was not impacted by hay consumption, demonstrating the potential for HSM to be an acceptable replacement for other common feedstuffs in horse diets.

Silversides and Lefrançois (2005) reported that in poultry diets, HSM used as the primary protein source complementing the energy provided by cereal grains resulted in lower concentrations of palmitic acid and increased linoleic and alpha-linolenic acids in the yolk, without affecting hen performance. At an inclusion rate of 4% HSM, laying hens showed increased feed efficiency and egg production, with no mortality or difference in BW. Furthermore, at an inclusion rate of 12% HSM, yolk color score was greater compared to the 4% inclusion rate and the control group, without affecting egg quality and eggshell weight. Overall, laying hen performance was not negatively impacted by the dietary HSM inclusion. Egg production and feed efficiency increased, while the omega-6 to omega-3 ratio decreased in the yolk. Laying hens provide a model for the potential of HSM to be included in animal diets (Ozturk et al., 2022).

In growing sheep fed diets with HSM replacing canola meal, no detrimental nutrient utilization or feed intake were observed at a dietary inclusion rate of 20% (Mustafa et al. 1999). In yearling steers fed diets containing 14% hemp seed for 166 days, no negative effects on gain, gain to feed ratio, and carcass traits were found. Additionally, tissue concentration of conjugated linoleic acid and omega-3 fatty acids were greater (Gibb et al., 2005). In a ten-week study feeding juvenile sunshine bass, a mixture of 30% fish meal, 30% soybean meal, and 25% corn was replaced with a mixture of 27% of soybean meal, 27% meat and bone meal, and 20% HSM without negative effects on growth, survival, body composition, and performance. Similar to

soybean meal, fish meal creates a strain on the environment due to its extensive production, which demands substantial quantities of food-grade fish for rendering. The demand for fish meal causes disruption in marine food webs, and the approval of HSM as a feed ingredient for aquaculture systems has the potential to increase sustainability in an environmentally taxing industry (Webster et al., 2000; Sample, 2022).

Hemp seed meal contains antinutritional factors including phytic acid, tannins, and protease inhibitors at low concentrations than other oil seeds, which may affect the bioavailability of proteins (Rizzo et al., 2023). However, in two studies using rats and pigs, HSM nutrient digestibility was reported superior to other feeds commonly fed. Using a rat bioassay, hemp proteins were reported to have a protein digestibility-corrected amino acid score (PDCAAS) similar to certain grains, nuts, and some pulses (House et al., 2010). Protein digestibility was measured from 84.1-86.2% for whole hemp seed, 90.8-97.5% for HSM, and 83.5-92.1% for dehulled hemp seed.

Horses have a simple stomach with a highly developed large intestine, which takes up 65% of the total digestive system. Horses rely on structural fiber-heavy diets due to their hindgut fermentation and complete dependence on microbial fermentation of plant cell wall carbohydrates, requiring between 45 and 60% NDF in their diet. This greater NDF intake reduces the risk of large intestinal dysfunctions associated with intake of non-structural carbohydrates (NSC; or non-cell wall carbohydrates), such as starch and fructans. Non-cell wall carbohydrates are rapidly fermentable in the large intestine and therefore must be carefully monitored to avoid large intestinal dysfunction and laminitis. Laminitis and colic are leading causes of death in horses; therefore, careful monitoring of this dietary component substantially enhances overall health and welfare. The nutrient profile of HSM demonstrates its potential as

an ideal ingredient for horse diets with low concentrations of non-fiber carbohydrates (NFC), NSC, water-soluble carbohydrates (WSC), simple sugars (ethanol-soluble carbohydrates; ESC) relative to soybean meal (Table 2) or cereal grains.

Table 2. Non-cell wall carbohydrate composition of hemp seed meal and soybean meal<sup>1</sup>

Item, %	Soybean meal <sup>1</sup>	Hemp seed meal <sup>2</sup>
NFC (Non-fiber carbohydrates)	25.9	5.4
NSC (Non-structural carbohydrates)	17.6	4.9
WSC (Water-soluble carbohydrates)	16.2	4.7
ESC (Simple sugars)	13.5	3.4
Starch	1.5	0.2

<sup>1</sup>Dairy One - Feed Composition Library.

<sup>2</sup>Dairy One Lab, Ithaca, NY.

The combination of high NDF, protein, and fat with low starch (Table 1) and NFC (Table 2) makes HSM a promising and multifunctional ingredient for horse feed concentrates. While rat and pig studies have provided potential for HSM to be an efficient alternative feed ingredient for horses, protein digestibility trials in horses are needed to determine the nutritional value of HSM for horses.

## METHODS

### Animals and experimental design

Four mixed breeds (Morgan cross, grade, and Thoroughbred) geldings from the Cornell University Equine Park were used, with an average age of 14.5 years. Horses were randomly assigned to four diets in a  $4 \times 4$  Latin square design with four periods. Each period lasted 7 days. Each horse's weight was estimated by measuring the horse's girth circumference and body length. Girth circumference (inches) was taken by placing a measuring tape beginning caudal to the withers and directing to the horse's elbow. Length (inches) was measured from the center of the sternum to the point of the buttock. Weight (lbs) was calculated using the following equation: Heart Girth  $\times$  Heart Girth  $\times$  Body Length/ 330 and converted to kg (Table 3).

### Diets

The daily feeding consisted in a concentrate feed and hay. The concentrate feeds were composed of graded concentration of hemp seed meal (HSM): 0% HSM, 10% HSM, 20% HSM, and 40% HSM and formulated to contain 20% CP. Nutrient concentration of the 4 experimental concentrates was calculated based on NRC (2012) values for corn, soybean meal, and corn oil, and NRC (1989) values for timothy pellets (i.e., timothy grass). Ingredient and nutrient composition of the feed concentrates are presented in Table 4. The HSM used for these concentrates consisted of 30.40% crude protein, 10.56% crude fat, 4.72% ash, 48.90% NDF, 37.30% ADF, 14.40% lignin, and 5.40% NFC (DM basis) (Table 5). Nutrient composition of the hay is presented in Table 5.

## **Feeding schedule and data collection**

Over the course of the study, the horses were fed hay (orchardgrass/timothy mix) at 7:30 and their respective feed concentrate at 8:05. This allowed the horses to consume hay for at least 30 minutes before consuming their respective concentrate. The horses were turned out to a winter pasture from 10:30 to 16:00. Consequently, horses had access to minimal grass pasture grazing during this time period. At 16:00, horses were brought into their respective stalls, and received hay followed by their concentrate as described for the morning feeding. Concentrate was fed at 0.25% BW on days 1 and 2, 0.30% BW on day 3, and 0.40% BW on days 4 to 7. Hay was fed at 1% BW (0.33% in the morning and 0.67% in the evening), with a hay to concentrate ratio of 71:29 for days 4 to 7.

Horses were adapted to their feed concentrate from days 1 to 5 followed by fecal collection on days 5 and 6 of each period. Fecal samples were collected using fecal bags for clean fecal collection to prevent contamination with bedding and urine (Figure 1). On days 6 and 7 of each collection period, fecal bags were fitted in the mornings at 8:00 and removed at 12:00. The fecal bags were emptied, the feces manually homogenized, and samples frozen at -20°C for later analyses of DM, N, AIA and lignin (Dairy One, Ithaca, NY). Fecal score was determined based on a scale from 1 to 9, with 1 indicating pure liquid, and 9 indicating dry with mucous, as shown in Table 7. Hay orts were collected after the morning and evening feeding to calculate daily hay intake.

## Nitrogen digestibility calculations

Daily hay intake on days 4, 5 and 6 of each collection period was used to calculate average daily hay intake for the N digestibility estimation. Whole diet daily AIA or lignin intake was calculated as the product of AIA and lignin concentration in the hay (DM basis) and the daily hay intake (DM basis) plus the product of AIA or lignin concentration in the concentrates (DM basis) and the daily concentrate intake (DM basis). The overall percentage of N in the diet was calculated as described above for AIA and lignin, using the analyzed N concentration in the hay and the concentrates (DM basis).

Total daily dry matter fecal output and N digestibility were estimated using both acid insoluble ash (AIA) and lignin as an indigestibility marker. Daily dry matter fecal output was estimated as follows (Note: in the equations below, AIA is presented; the same equations were used for lignin):

$$1) \text{ AIA intake } \left( \frac{g}{day} \right) = \% \text{ AIA in total diet} \times \text{daily DM intake, } \frac{g}{day}$$

$$2) \text{ Fecal DM output } \left( \frac{g}{day} \right) = \frac{\text{AIA intake } \left( \frac{g}{day} \right)}{\text{Fecal AIA, \%}}$$

Apparent whole tract N digestibility (%) was estimated as follows:

100

$$\times \frac{\left[ \left( \text{Diet DM intake } \left( \frac{g}{day} \right) \times \% \text{ N in diet} \right) - \left( \text{Fecal DM output } \left( \frac{g}{day} \right) \times \% \text{ N in feces} \right) \right]}{\text{Diet DM intake } \left( \frac{g}{day} \right) \times \% \text{ N in diet}}$$

## Statistical analysis

An ANOVA was performed using RStudio to evaluate the experimental treatment effect on the response variables of digestibility, hay intake, and fecal score. The model included diet and week as fixed classification effects and horse as a random effect. A two-sample t-test was performed to determine the difference in BW at the beginning and end of the study for each horse.

## RESULTS

Whole tract N digestibility (%), fecal score, and BW are presented in Table 7. Nitrogen digestibility values of the whole diet (hay + concentrate) based on AIA as an indigestible marker were 88.10% for control, 87.00% for 10% HSM, 91.40 % for 20% HSM, and 89.00% for 40% HSM (Table 7), and did not differ from control. Nitrogen digestibility values based on lignin as an indigestible marker were 53.00% for control, 39.00% for 10% HSM, 61.50% for 20% HSM, and 44.70% for 40% HSM (Table 7). One of the values for the 20% HSM diet was unreliable and was omitted from the results. Daily hay intake did not differ between diets, with 3.14 kg for control, 3.41 kg for 10% HSM, 3.00 kg for 20% HSM, and 2.92 kg for 40% HSM. Daily concentrate intake was 2.17 kg across all diets (Table 7).

Fecal score did not differ between diets with 7.25 for control and 20% HSM, and 7.00 for 10% HSM and 40% HSM (Table 8). Body weight at the beginning and end of the study was  $544 \pm 54.5$  and  $512 \pm 32.5$  kg, respectively and did not differ.

## DISCUSSION

No feed concentrate refusals were observed, indicating full acceptability of HSM when included at levels up to 40% of the feed concentrate. Normal fecal scores across all diets demonstrated that HSM did not impact gastric function. Inclusion of HSM at 10, 20 or 40% of the feed concentrate did not impact N digestibility when measured using either AIA or lignin as indigestible markers. However, the use of AIA likely led to an overestimation of N digestibility in this study across all diets. Because horses were turned out from 10:30 to 16:00, soil contamination with exogenous silica may have led to an underestimation of fecal DM output, and therefore an overestimation of digestibility. Based on these findings, N digestibility values using lignin as an indigestible marker were considered most reliable. The N digestibility values based on lignin were similar to those reported in horses fed hay with a feed concentrate in a 75:25 ratio and using various n-alkanes as indigestible markers (Peiretti et al., 2006). The N digestibility values were 36.1%, 46.2%, and 49.0% based on C27, C29, and C31 n-alkanes as internal markers, respectively. In that study, horses were fed a commercial concentrate containing 12.0% CP and 28.7% NDF and composed of citrus pulp, corn, barley, soybean meal, wheat and carob pulp. The hay was Mediterranean meadow first-cutting hay containing 8.1% CP and a nutrient profile similar to the grass hay used in the present study. Woodward et al. (2011) reported N digestibility of timothy grass hay (first cutting) alone at 38.0% and timothy grass hay with oats supplemented in an 83:17 and 72:28 hay: oats ratio of 47.1 and 52.6%, respectively, aligning with the reported N digestibility values herein.

The variation in N digestibility across diets may have resulted from inconsistency in hay intake across horses. Horses were moved from the Cornell Equine Park facility where horses were housed on pasture, to the study site at the Teaching Equine Unit, with limited turnout time,

and a short adaptation period to the hay. A longer adaptation period to ensure more consistent hay intake across horses is recommended. In future studies, horses should not be turned out to prevent soil contamination when AIA is used as the indigestible marker. Additionally, serial blood chemistry and body condition scoring should be conducted over a longer period of time to monitor horse health and evaluate the safety of HSM as an ingredient.

### **CONCLUSION AND IMPLICATION**

The findings of this study demonstrate that HSM is a viable protein feed alternative with respect to acceptability and protein digestibility. At an inclusion rate of 40% HSM, the feed concentrate was accepted by the horses, and there were no negative effects on hay intake, or fecal consistency. The study indicates that HSM inclusion up to 40% of the feed concentrate is safe, and nutritionally adequate for horses at maintenance. The nutritional composition and sustainability of HSM make it an ideal candidate as an alternative protein feed ingredient in horse diets. With additional research, an appropriate inclusion rate for safety and the long-term effects of HSM in horse diets could be determined. This study was constrained by the number of animals and the trial duration. Nonetheless, it adds to the limited body of research on the potential for HSM as a protein feed ingredient for horses.

Table 3. Age, weight, and breed of horses<sup>1</sup>

Horse	Age (years) <sup>1</sup>	Weight (kg)	Breed <sup>1</sup>
Echo	26	450.4	Morgan Cross
Canada	4	457.3	Grade
Maxx	10	593.8	Thoroughbred
Kit Kat	18	673.6	Thoroughbred

<sup>1</sup>Provided by the Cornell University Equine Park.

Table 4. Nutrient composition of hemp seed meal, %<sup>1</sup>

Item	As fed	DM
Dry matter	91.8	100
Crude protein	27.9	30.4
Crude fat	9.69	10.56
Ash	4.33	4.72
NDF	44.8	48.9
ADF	34.2	37.3
Lignin	13.2	14.4
NFC	5.0	5.4

<sup>1</sup>Dairy One Lab, Ithaca, NY.

Table 5. Nutrient composition of orchard/timothy grass hay, %<sup>1</sup>

Item	As fed	DM
Dry matter	92.9	100
Crude protein	7.2	7.8
AIA	0.9	1.0
NDF	63.9	68.7
ADF	36.5	39.2
Lignin	4.7	5.1
NFC	13.3	14.3

<sup>1</sup>Dairy One Lab, Ithaca, NY.

Table 6. Ingredient and nutrient composition of experimental diets (as-fed)

Ingredient composition, %	Control	10% HSM	20% HSM	40% HSM
Oats	59.29	53.39	47.49	35.71
Soybean meal, 48 % CP	18.71	14.61	10.51	2.29
Hemp seed meal	0.00	10.00	20.00	40.00
Timothy pellets	10.00	10.00	10.00	10.00
Corn, yellow dent	10.00	10.00	10.00	10.00
Corn oil	2.00	2.00	2.00	2.00
Nutrient concentration, calculated, % <sup>1</sup>				
CP	20.00	20.00	20.00	20.00
NDF	28.22	30.89	33.55	38.89
WSC	5.62	4.89	4.16	2.71
NSC	38.84	38.60	38.36	37.89
Nutrient concentration, analyzed, % <sup>2</sup>				
CP	20.70	17.10	19.40	18.10
Starch	32.92	30.38	27.83	22.74
NDF	18.70	25.10	26.90	26.80
ADF	9.70	13.10	14.60	18.50
Total Ca	0.27	0.23	0.18	0.19
Total P	0.48	0.41	0.46	0.50

<sup>1</sup>Based on analyzed values for HSM, on NRC (2012) nutrient concentrations for corn, soybean meal, and corn oil, and on NRC (1989) for timothy grass (proxy for timothy pellets).

<sup>2</sup>Dairy One Lab, Ithaca, NY.

Table 7. Fecal score scale<sup>1</sup>

Score	Description
1	Pure liquid, like urine
2	Profuse watery diarrhea with some fecal matter
3	Very loose fecal matter with high water content (running off)
4	Loose (“dairy”) cow pie
5	Cow pie
6	Soft formed
7	Normal formed
8	Dry without mucous
9	Dry with mucous

<sup>1</sup>Nutrition Advisory Group to the Association of Zoos and Aquariums.

Table 8. Feed intake, fecal score and whole nitrogen protein digestibility in horses fed hay with feed concentrates containing varying levels of hemp seed meal

Item	Control	10% HSM	20% HSM	40% HSM	SEM
n <sup>1</sup>	4	4	4	4	
Hay intake per day, kg	3.14	3.41	3.00	2.92	1.02
Concentrate intake per day, kg	2.17	2.17	2.17	2.17	-
Fecal score	7.25	7.00	7.25	7.00	0.18
Nitrogen digestibility (AIA), % <sup>2</sup>	88.10	87.00	91.40	89.00	0.93
Nitrogen digestibility (Lignin), % <sup>3</sup>	53.00	39.00	61.50	44.70	0.10

<sup>1</sup>Number of horses was 3 for the 20% HSM diet.

<sup>2</sup>N digestibility calculated using AIA as an indigestible marker.

<sup>3</sup>N digestibility calculated using lignin as an indigestible marker.

Figure 1. Horses fitted with fecal bags



## REFERENCES

- Bailoni, L., Bacchin, E., Trocino, A., & Arango, S. (2021). Hemp (*Cannabis sativa* L.) seed and co-products inclusion in diets for dairy ruminants: A review. *Animals*, *11*(3), 856. <https://doi.org/10.3390/ani11030856>
- Consentino, S. L., T., Giorgio, Scordia, D., & Copani, V. (2012). Sowing time and prediction of flowering of different hemp (*Cannabis sativa* L.) genotypes in southern Europe. *Industrial Crops and Products*, *37*(1), 20–33. <https://doi.org/10.1016/j.indcrop.2011.11.017>
- Cunha, R. Z., Felisardo, L. L., Salamanca, G., Marchioni, G. G., Neto, O. I., & Chiocchetti, R. (2023). The use of cannabidiol as a novel treatment for oral stereotypic behaviour (crib-biting) in a horse. *Veterinary and Animal Science*, *19*, 100289. <https://doi.org/10.1016/j.vas.2023.100289>
- Ely, K. (2023). *Hempseed oil as a novel source of polyunsaturated fatty acids and its effect on inflammation in sedentary horses* (Doctoral dissertation). Virginia Polytechnic Institute and State University.
- Ely, K., Suagee-Bedore, J. K., Shepherd, M., Lengi, A., Corl, B., & Fike, J. (2023). Hemp seed oil as a novel fatty acid supplement for horses. *Journal of Equine Veterinary Science*, *124*, 104355. <https://doi.org/10.1016/j.jevs.2023.104355>
- Gibb, D., Shah, M., Mir, P., & McAllister, T. (2005). Effect of full-fat hemp seed on performance and tissue fatty acids of feedlot cattle. *Canadian Journal of Animal Science*, *85*(2), 223–230. <https://doi.org/10.4141/A04-045>
- Hemp Feed Coalition. (2024). *Hemp seed meal for laying hens*. <https://hempfeedcoalition.org/applications/>
- Hesami, M., P., Marco, & Jones, A. M., Phineas. (2023). Morphological characterization of *Cannabis sativa* L. throughout its complete life cycle. *Plants*, *12*(20), 3675. <https://doi.org/10.3390/plants12203675>
- House, J. D., Neufeld, J., & Leson, G. (2010). Evaluating the quality of protein from hemp seed (*Cannabis sativa* L.) products through the use of the protein digestibility-corrected amino acid score method. *Journal of Agricultural and Food Chemistry*, *58*(23), 11801–11807. <https://doi.org/10.1021/jf102636b>
- Kasula, R. S., Shaffer, B., Connett, F., Barrett, C., Cocker, R., & Willingham, E. (2021). Characterization of the nutritional and safety properties of hemp seed cake as animal feed ingredient. *International Journal of Livestock Production*, *12*(2), 53–56. <https://doi.org/10.5897/IJLP2020.0750>
- Klir, Ž., Novoselec, J., & Antunović, Z. (2019). An overview on the use of hemp (*Cannabis sativa* L.) in animal nutrition. *Poljoprivreda*, *25*(2), 52–61. <https://doi.org/10.18047/poljo.25.2.8>

Leise, J. M., Leatherwood, J. L., Paris, B. L., Walter, K. W., George, J. M., Martinez, R. E., Glass, K. P., Mays, T. P., & Wickersham, T. A. (2023). Evaluation of an oral supplemental cannabidiol product for acceptability and performance in mature horses. *Animals*, *13*(2), 245. <https://doi.org/10.3390/ani13020245>

Leizer, C., Ribnicky, D., Poulev, A., Dushenkov, S., & Raskin, I. (2000). The composition of hemp seed oil and its potential as an important source of nutrition. *Journal of Nutraceuticals, Functional & Medical Foods*, *2*(4), 35–53. [https://doi.org/10.1300/J133v02n04\\_04](https://doi.org/10.1300/J133v02n04_04)

Müller, C. E. (2012). Equine digestion of diets based on haylage harvested at different plant maturities. *Animal Feed Science and Technology*, *177*(1–2), 65–74. <https://doi.org/10.1016/j.anifeedsci.2012.06.002>

Mustafa, A. F., McKinnon, J. J., & Christensen, D. A. (1999). The nutritive value of hemp meal for ruminants. *Canadian Journal of Animal Science*, *79*(1), 91–95. <https://doi.org/10.4141/A98-080>

Nutrition Advisory Group to the Association of Zoos and Aquariums. (2025). *Fecal condition scoring resource center*.

Ozturk, E. D., Özlü, Ş., & Abacı, S. (2022). Evaluation of dietary hemp seed meal as soybean meal substitution on productive performance, egg quality, and yolk fatty acid composition of laying hens. *Research Square*. <https://doi.org/10.21203/rs.3.rs-2061877/v1>

Peiretti, P. G., Meineri, G., Miraglia, N., Mucciarelli, M., & Bergero, D. (2006). Intake and apparent digestibility of hay or hay plus concentrate diets determined in horses by total collection of feces and n-alkanes as internal markers. *Livestock Science*, *100*(2–3), 189–194. <https://doi.org/10.1016/j.livsci.2005.08.015>

Rizzo, G., Storz, M. A., & Calapai, G. (2023). The role of hemp (*Cannabis sativa* L.) as a functional food in vegetarian nutrition. *Foods*, *12*(18), 3505. <https://doi.org/10.3390/foods12183505>

Sample, A. (2022). Evaluation of hemp seed meal as a fish meal replacement through growth and digestibility trials in striped bass (*Morone saxatilis*) (Master's thesis). Georgia Southern University.

Silversides, F. G., & Lefrançois, M. R. (2005). The effect of feeding hemp seed meal to laying hens. *British Poultry Science*, *46*(2), 231–235. <https://doi.org/10.1080/00071660500066183>

Springer, R. W., Mason, A. C., Cross, T. D., Guay, K. A., Raub, R. H., Wellmann, K. B., & Jones, T. N. (2023). Assessment of the palatability and acceptability of hempseed meal pellets in horses compared to mainstream feedstuffs. *Journal of Equine Veterinary Science*, *131*, 104929. <https://doi.org/10.1016/j.jevs.2023.104929>

USDA. (2019). *Seeds, hemp seed, hulled food details*. U.S. Department of Agriculture. <https://fdc.nal.usda.gov/food-details/170148/nutrients>

Webster, C. D., Thompson, K. R., Morgan, A. M., Grisby, E. J., & Gannam, A. L. (2000). Use of hempseed meal, poultry by-product meal, and canola meal in practical diets without fish meal for sunshine bass (*Morone chrysops* × *M. saxatilis*). *Aquaculture*, 188(3), 299–309. [https://doi.org/10.1016/S0044-8486\(00\)00338-0](https://doi.org/10.1016/S0044-8486(00)00338-0)

Woodward, A. D., Nielsen, B. D., Liesman, J., Lavin, T., & Trottier, N. L. (2011). Protein quality and utilization of timothy, oat-supplemented timothy, and alfalfa at differing harvest maturities in exercised Arabian horses. *Journal of Animal Science*, 89(12), 4081–4092. <https://doi.org/10.2527/jas.2010-3825>

Yano, H. F., & Wei, F. (2023). Hemp: A sustainable plant with high industrial value in food processing. *Foods*, 12(3), 651. <https://doi.org/10.3390/foods12030651>