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Effects of feeding varying levels of hempseed meal on dry matter intake, rumen fermentation, in vitro digestibility, blood metabolites, and growth performance of growing meat goats

Frank W. Abrahamsen,[1] Nar K. Gurung,[2]* PAS, Woubit Abebe,[1] Gopal P. Reddy,[1] Kim Mullenix,[3] and Sushil Adhikari[4]

[1]Department of Pathobiology, College of Veterinary Medicine, Tuskegee University, Tuskegee, AL 36088; [2]Department of Agricultural and Environmental Sciences, College of Agriculture, Environment, and Nutrition Sciences, Tuskegee University, Tuskegee, AL 36088; [3]Department of Animal Science, College of Agriculture, Auburn University, Auburn, AL 36849; and [4]Department of BioSystems Engineering, Auburn University, Auburn, AL 36849

ABSTRACT

Objective: The objective of this study was to evaluate the effect hempseed meal (HSM; a by-product of hemp oil production) supplementation has on DMI, rumen fermentation, in vitro true digestibility, blood metabolites, and growth performance of growing meat goats over a 60-d feeding trial.

Materials and Methods: Forty castrated Boer cross goats 4 to 5 mo of age with an average BW of 25.63 ± 0.33 kg were randomly assigned to 1 of 4 treatments (n = 10/treatment): control (0), 11%, 22%, and 33% HSM of the total diet on a DM basis. The forage to concentrate ratio was maintained at 50.2:49.8 on a DM basis, and timothy hay was used as a forage source. Diets were pelleted as TMR. Data were collected for DMI, rumen fermentation, blood metabolites, and growth performance for the 60-d feeding trial. Data were analyzed utilizing the GLM procedures of SAS (SAS Institute Inc.). Orthogonal contrasts for increasing HSM inclusion rates were used to determine linear and quadratic effects within the data.

Results and Discussion: The DMI was similar among treatments ($P > 0.05$). Total live weight gain (kg) decreased linearly ($P < 0.05$) with increasing inclusion rate of HSM (10.75, 9.53, 8.48, and 7.80 kg for 0, 11, 22, and 33%, respectively). The ADG values followed the same trend ($P < 0.05$; 0.179, 0.159, 0.141, and 0.130 kg for 0, 11, 22, and 33%, respectively). Similarly, G:F decreased linearly ($P < 0.05$) with increasing HSM inclusion rates (0.116, 0.101, 0.090, and 0.085). Acetic, propionic, butyric, valeric, iso-valeric, iso-butyric acid, and total VFA concentrations decreased linearly ($P < 0.05$) with the increasing inclusion rate of HSM. Serum albumin and total protein showed quadratic responses ($P < 0.05$) with increasing levels of HSM, whereas BUN and creatine kinase levels increased linearly ($P < 0.05$).

Implications and Applications: These findings provide new insights into the feeding value of HSM for meat goats; however, further research needs to be conducted to determine the optimal level of HSM supplementation.

Key words: goats, hempseed meal, in vitro true digestibility, rumen fermentation, growth performance

INTRODUCTION

Hemp (*Cannabis sativa* L.) production has been illegal in most of the United States for years for fear of the level of tetrahydrocannabinol (**THC**) potentially being stored, which is the psychoactive component of marijuana that causes mind-altering effects. It was long believed that if producers were to grow industrial hemp, marijuana could easily be established within the industrial hemp (Cherney and Small, 2016). Recent legislative changes to the 2014 and 2018 Farm Bills have resulted in a newfound interest in hemp production (Congressional Research Service, 2019). Historically, hemp has been produced worldwide for centuries as it can be grown in most climatic conditions and provides several products: fiber and oilseeds (Johnson, 2018). Fiber is often of high quality with a high strength

The authors declare no potential conflict of interest other than the fact that Kentucky Hemp Works (Crofton, KY) provided needed hempseed meal for the experiment.
*Corresponding author: ngurung@tuskegee.edu

to weight ratio, and seeds and oils are used to supply niche markets worldwide.

There are 2 different methods for extracting oil from ripe seeds: mechanical or solvent based. After the oil is extracted, a residual meal is left behind that is high in CP and fiber while low in fat compared with the whole seed (Mustafa et al., 1998). With the possibility of increased production of industrial hemp in the Southeastern United States, it is essential to find a use for the by-product of oil production. It has consistently been shown that this by-product has the potential to be an suitable feedstuff for ruminants because it is high in CP and fiber (Mustafa et al., 1998; Hessle et al., 2008; European Food Safety Authority, 2011). On average, hempseed meal (**HSM**) contains 30 to 35% CP (DM basis; Mustafa et al., 1998; Hessle et al., 2008). Additionally, 80% of the fat found in whole seeds is PUFA, which could potentially serve as an energy source while improving the animal health of nonruminant animals (Mustafa et al., 1998). Karlsson and Martinsson (2011) used HSM as a protein supplement, and when being compared with other protein sources (pea protein and rapeseed meal), it was determined that HSM resulted in the lowest level of animal performance. Karlsson et al. (2010) supplemented dairy cattle and determined that there was no decrease in DMI, but a decrease was observed in nitrogen efficiency as HSM used in that study was relatively high in RDP. Mustafa et al. (1998) supplemented 20 sheep for a digestibility trial and determined that DMI was not affected by the level of HSM supplementation up to 100%, which agrees with the study completed by Karlsson et al. (2010).

The objective of this study was to evaluate the effect of varying levels of HSM on rumen fermentation, in vitro true digestibility (**IVTD**), blood metabolites, and growth performance of growing meat goats.

MATERIALS AND METHODS

Animal Care and Use

This experiment was conducted at the Caprine Research and Education Unit at Tuskegee University, George Washington Carver Agricultural Experiment Station, Tuskegee, Alabama. The Institutional Animal Care and Use Committee of Tuskegee University approved all animal care and experimental procedures performed in this experiment (TUACUC Protocol Request Number: R07–2019–5). Goats were purchased from a vendor in Texas. Upon arrival, goats were dewormed with Cydectin (moxidectin @1 mg/kg BW; Fort Dodge Animal Health) and vaccinated with *Clostridium perfringens* type C and D-Tetani Bacterin-Toxoid (Bayer Corp.). Goats were quarantined for 30 d, during which they were adapted to the control complete TMR diet. Upon completion of the quarantine period, goats were moved to an indoor barn and were individually housed in 1.1 m × 1.2 m pens with plastic-coated, expanded metal floors.

Diet and Chemical Composition

Goats were supplemented with varying rates of HSM: 0 (control), 10, 20, and 30% of the total diets on an as-fed basis (Table 1). Diets consisted of timothy grass hay (Stampede Premium), cracked corn, soybean meal, HSM, molasses, and a 16:8 mineral supplement (Meat Maker, Ridley USA Inc.). The forage:concentrate ratio was maintained at 50.2:49.8 containing 0, 11, 22, and 33% HSM on a DM basis. The HSM used in the experiment was prepared by using the cold press method to extract hemp seed oil. All treatment diets were formulated to be iso-nitrogenous and to meet the NASEM requirements for growing meat goats (NASEM, 2007). Each diet was pelleted as a complete pellet to minimize differences in physical forms and appearances as well as to prevent sorting by goats. A 230-g sample was collected from every fifth bag and composited by treatment during the bagging process. Composite samples of the respective treatment diets, were then shipped to Holmes Laboratory (Millersburg, OH) for analysis of DM, CP, ADF, acid hydrolysis fat, ash, phosphorus, magnesium, potassium, sulfur, manganese, zinc, and iron according to the methods described by AOAC (1990). The NDF concentration was determined utilizing the Ankom 2000 fiber analyzer (Ankom Technology) according to the manufacture's recommendations. Lignin concentration was determined according to the USDA (1970) Forage Fiber Analysis Handbook Procedure 397. Values for NE_g were calculated according to the equation described by NASEM (1989).

In Vitro True Digestibility

Pelleted feed samples were ground utilizing Wiley Mill grinder, equipped with a 1-mm sieve (Thomas Scientific). Sixty Ankom F-57 filter bags (Ankom Technology) were then filled with ~0.3 g of ground sample per treatment. In vitro true digestibility was determined according to the method described by Tilley and Terry (1963) with modifications utilizing a rotating jar incubating system according to the manufacturer's recommendations (Daisy II;

Table 1. Composition of experimental diets used in the 60-d feeding period (on an as-fed basis)

	Hempseed meal supplementation, %			
Ingredient, % of diet	**0**	**10**	**20**	**30**
Timothy hay pellet	50	50	50	50
Cracked corn	27	22.5	17.5	11.5
Soybean meal	19.5	14	9	5
Hempseed meal	0	10	20	30
Molasses	2.5	2.5	2.5	2.5
Goat premix	1	1	1	1

Ankom Technology). Rumen fluid inoculum was obtained from 2 fistulated steers maintained on a 16% CP diet at 1% BW to ensure that rumen fluid would potentially be similar to experimental animals. These steers had *ad libitum* access to clean water, hay, and minerals. According to the manufacturer's recommendations, a buffer solution was prepared and added to the jars at a 1:5 ratio with rumen fluid to aid in maintaining a stable pH. After a 48-h incubation period, all samples were washed with NDF solution to clean the microbial debris and any remaining soluble fractions utilizing the Ankom 2000 fiber analyzer according to the manufacturer's recommendations (Ankom Technology). After the NDF treatment, samples were dried for 4 h at 102°C. Bags were then weighed, and percent IVTD was calculated.

Rumen Fermentation, Blood Metabolites, and Animal Performance

Rumen Fermentation. Rumen fluid was collected from goats on d 60 of the feeding period via ororuminal intubation utilizing the Drench-Mate Calf RFE (Drench-Mate). Upon collection, samples were immediately stored −80°C. Before analysis, samples were thawed on ice and filtered through 4 layers of cheesecloth. Samples were then prepared according to the method described by Erwin et al. (1961) by using 25% metaphosphoric acid and ethyl butyrate as the internal control, and the concentrations of the previously described VFA were determined using an Agilent 7890 GC equipped with a flame ionization detector and a DB-WAXetr capillary column (30 m × 0.25 mm × 0.25 μm; Agilent). The flow rate of helium was 1 mL/min. The injector temperature was set at 185°C with injecting a volume of 1 μL and a split inlet ratio of 4:1. The temperature of the flame ionization detector was set at 250°C. The oven temperature was programmed from 80°C (held for 1 min) to 200°C (held for 15 min) at a rate of 10°C/min. Total VFA were calculated according to the method described by Hall et al. (2015).

Blood Chemistry Analysis. Blood was collected on d 60 of the feeding period via jugular venipuncture utilizing a Vacuette tube, 3.5-mL CAT Serum Separator/Clot Activator tube (Greiner Bio-One, North America Inc.). Samples were stored at room temperature until being centrifuged for 15 min at 2,500 × *g*. The serum was then placed into a 2-mL microcentrifuge tube and stored at −20°C for future analysis. Serum chemical analysis was conducted utilizing the IDEXX Catalyst DX system, which also provided reference ranges for each parameter (IDEXX Laboratories). Several serum chemical parameters were assessed to understand how HSM supplementation affected organ function and overall animal health.

Feeding and Animal Performance. Forty castrated male Boer cross goats were randomly assigned to 1 of 4 treatments (n = 10): 0, 11, 22, 33% HSM supplementation on a DM basis. Goats were approximately 4 to 5 mo of age with an average starting BW of 25.63 ± 0.33 kg; goat was the experimental unit. Goats were given *ad libitum* access to feed and water daily and were adjusted to their respective diets for 2 wk. Animals were fed twice daily at 0600 and 1800 h. Before each feeding, the refused feed was weighed using a stainless-steel Max food scale (Amiloe Inc.) to determine the feed intake for each animal over the 60-d feeding period. Animal BW was collected before feeding on d 0 and 60 of the feeding period utilizing a Sheep & Goat Digital Scale (Lakeland Farm and Ranch Direct) to calculate total BW gain, ADG, and G:F. At the conclusion of the 60-d feeding trial, the animals were humanely slaughtered according to USDA guidelines.

Statistical Analysis

Data were analyzed for linear and quadratic relationships utilizing an orthogonal contrast for equally spaced treatments to identify trends in the data. Significant treatment effects were declared at $P < 0.05$ (SAS 9.2, SAS Institute Inc.).

RESULTS AND DISCUSSION

Chemical Composition

The average CP concentration of TMR remained relatively constant at approximately 19%; however, the 33% treatment had a slightly elevated concentration CP (20.39%; Table 2). The HSM used to formulate the diets in this experiment had a CP concentration of 36.42%. Variable CP concentrations are reported for HSM in the literature ranging from 31.9 to 38.5% (Mustafa et al., 1998; Hessle et al., 2008; Karlsson et al., 2010). The CP concentration of HSM used in this study was greater when compared with values reported by other studies. The differences observed between these studies concerning CP concentration could probably be due to differences in growing conditions or the differences due to varieties being selected. Environmental factors can significantly affect the chemical composition of plant nutrients. Additionally, by-products tend to have a large amount of variability due to different processing methods.

Lignin levels increased in the diets with increasing levels of HSM (Table 2). This was expected because the lignin content of HSM used in the current study was 12.76%. Greater lignin content is reported to decrease digestibility as it makes cellulose and hemicellulose unavailable for microbial degradation (Van Soest, 1994).

When HSM was incorporated into these experimental diets, there was an increase in both NDF and ADF contents (Table 2). The HSM utilized in this experiment had an NDF concentration of 49.47%, whereas Karlsson et al. (2012) reported concentrations of 39.3% and 38.2%, respectively. Mustafa et al. (1998) reported the NDF concentration of HSM in their study to be 50.79%, which was similar to the value found in the current study. Both NDF and ADF concentrations followed a similar trend, increasing with the increasing level of supplementation (Table 2).

Table 2. Chemical composition of experimental diets and hempseed meal (HSM) used in the experimental diets fed over the 60-d feeding period to growing meat goats

	HSM supplementation				
Nutrient analysis[1]	**0%**	**11%**	**22%**	**33%**	**HSM**
DM, %	89.06	88.66	89.1	89.86	89.61
CP, %	19.18	19.91	19.25	20.39	36.42
Lignin, %	3.34	4.77	6.21	7.02	12.26
ADF, %	21.06	24.67	28.96	30.97	36.47
NDF, %	33.29	35.18	39.63	42.80	49.47
NFC,[2] %	40.64	37.8	35.38	31.90	10.47
Acid hydrolysis fat, %	3.19	3.32	4.22	4.50	11.53
TDN, %	71.20	69.20	64.7	62.79	63.22
NE_g,[3] Mcal/kg	1.06	1.00	0.87	0.82	0.377
Ash, %	7.02	7.01	7.09	6.79	5.82
Calcium, %	0.95	0.92	0.88	0.82	0.23
Phosphorus, %	0.39	0.41	0.48	0.52	1.03
Magnesium, %	0.23	0.24	0.26	0.28	0.49
Potassium, %	1.43	1.29	1.29	1.24	1.03
Sulfur, %	0.22	0.22	0.22	0.22	0.16
Sodium, %	0.09	0.08	0.09	0.09	0.03
Copper, mg/kg	20	15	16	22	37
Manganese, mg/kg	64	75	82	91	88
Zinc, mg/kg	71	67	74	80	76
Iron, mg/kg	144	154	154	137	120

[1]All values are presented on a DM basis, except DM.

[2]NFC: nonfiber carbohydrates.

[3]NE_g: NASEM (1989).

The pure HSM used in making the experimental diets had an ADF concentration of 36.47%. This ADF value was greater than the values reported by Karlsson et al. (2010), which was 32.1% on a DM basis, and 33.6% reported by Karlsson and Martinsson (2011). Similarly, Mustafa et al. (1998) reported a lower ADF concentration (30.04%) from their study. There is a large amount of variation between the values obtained in this study and other reported values, which could be a result of plant maturity at the time of harvest, variety selected, environmental conditions, or the method of analysis.

The amount of oil that HSM contains varies according to the extraction process. The oil contained in the HSM can provide the animal with another source of energy. In the present study, acid hydrolysis fat concentration increased with the increasing levels of HSM supplementation (Table 2). The HSM used in the current study had an acid hydrolysis fat concentration of 11.53%. Karlsson and Martinsson (2011) and Karlsson et al. (2010) reported crude fat concentrations of 12.7% and 12.4%, respectively. However, Mustafa et al. (1998) reported an ether extract concentration of 5.24%.

The nonfiber carbohydrate (**NFC**) concentrations decreased with the increasing level of HSM supplementation. Average TDN values were calculated according to the formula outlined by Weiss et al. (1992) and decreased with the increasing rate of HSM inclusion. Net energy values were also calculated and followed a similar trend to that of TDN, decreasing with the increasing level of HSM inclusion (Table2).

The molar concentration of acetic acid (**A**) decreased linearly ($P < 0.05$) with the increasing inclusion rate of HSM (Table 3.). Additionally, a linear decrease was observed for propionic (**P**), butyric, iso-butyric, valeric, isovaleric acids, A:P ratio, and total VFA concentrations in the rumen fluid with the increasing inclusion rate of HSM (Table 3). The results for propionic acid were expected to decrease as with the increase in HSM there was a decrease in NFC (Table 2) and propionic favoring substrate. The A:P ratios were greater than the values reported by Urge et al. (2004) for the similar genotype and similar age goats fed 50:50 forage and concentrate diets. Their reported values for total VFA were 67.8 and 44.4 mmol/L for phase 1 (first 12 weeks) and the second 12 wk of the growing period after 4 to 5 mo of age (Urge et al., 2004). Similarly, A:P ratios were 3.79 and 2.58 for phase 1 and phase 2, respectively. The phase 1 value was similar, whereas the phase 2 was lower compared with the current study.

According to Shen et al. (2018), who conducted similar work with growing lambs fed common protein sources

Table 3. Least squares means of fermentation profile parameters on d 60 of the feeding period for growing meat goats fed varying levels of hempseed meal (HSM)

	% HSM supplementation					*P*-value[2]	
VFA analysis[1]	0	11	22	33	SEM	Linear	Quadratic
Acetic acid (A), mmol/L	132.57	112.56	76.42	46.70	21.735	<0.01	0.75
Propionic acid (P), mmol/L	41.34	28.12	17.64	10.05	6.942	<0.01	0.57
Butyric acid, mmol/L	28.05	26.90	16.98	15.90	3.786	<0.01	0.99
Iso-butyric acid, mmol/L	5.56	4.61	3.24	2.62	0.742	<0.01	0.75
Valeric acid, mmol/L	4.82	3.51	2.15	1.60	0.907	<0.01	0.55
Iso-valeric acid, mmol/L	4.43	3.52	2.41	1.96	0.677	<0.01	0.63
A:P[3]	3.43	4.36	4.52	4.59	0.346	<0.01	0.09
Total VFA, mmol/L	206.78	171.09	113.19	74.25	32.599	<0.01	0.94
In vitro true digestibility, % of DM	65.2	62.3	57.0	54.1	1.220	<0.01	0.97

[1]Rumen fluid was collected via ororuminal intubation on d 60 of the feeding period. Molar concentrations were determined utilizing gas chromatography.

[2]Based on orthogonal contrast for equally spaced treatments (n = 10 per treatment).

[3]Acetic to propionic acid ratio.

(i.e., soybean meal and dried distillers grains; ~15% CP), VFA concentrations were similar to the levels observed for the 22 and 33% HSM treatments in the current study.

The IVTD values decreased linearly ($P < 0.01$) with the increasing inclusion rate of HSM (Table 3). The ADF concentrations is important as it relates to the ability of an animal to digest the forage; a greater ADF suggests a decrease in digestibility (Mertens, 1987; Oba and Allen, 1999; Ball et al., 2007). The observed increase in ADF resulted in a decrease in IVTD values for the respective treatments.

Serum Chemistry Analysis

The majority of the serum chemistry profile reported in the current study (Table 4) were similar ($P > 0.05$) among treatments except for BUN and creatine kinase, which increased linearly ($P < 0.05$) with increasing levels of HSM. Research with cattle has demonstrated that the contributing factors affecting BUN concentrations were found to be protein and energy levels of the diets (Hammond et al., 1994). The protein degradability and levels of intake can also affect BUN (Hammond, 1983, 1992). It is important to note that, in the present study, the protein levels were similar among the treatments. Although there were statistical differences, BUN values were within normal biological limits (Murray et al., 1990; Aiello, 2016).

Serum creatine kinase concentration increased linearly ($P < 0.05$) with the increasing inclusion rates of HSM supplementation. The greater levels are often indicative of a skeletal muscle injury or kidney function; however, there is no clear explanation for the increases observed. All values fell within the normal range except for the 33% treatment, which was much greater than normal, although no abnormal animal appearances were observed.

Serum albumin concentration decreased quadratically ($P < 0.01$). Albumin is synthesized in the liver and used to maintain homeostasis throughout the body. Values outside of the normal range would indicate that there was a deficit in protein supplied by the diet; however, this is not plausible as the protein levels in the diet were adequate for growing goats. Serum total protein concentration displayed a quadratic ($P < 0.05$) relationship. The control (0%) and 33% treatment serum total protein concentration was within the normal range, whereas the 11 and 22% were determined to be lower than the normal range. The low concentration observed for the 11 and 22% treatments cannot be explained as these animals consumed a large amount of feed but had a lower serum total protein concentration. Furthermore, Solaiman et al. (2009) supplemented goat kids with EasiFLo cottonseed as a protein source and found that as the level of supplementation increased from 0 to 32.7% supplementation, serum total protein increased in a linear fashion; however, their dietary proteins levels ranged from 14.0% to 16.8% for 0 and 32.7% EasiFlow inclusion diets. The contrasting results found in the current study could probably be attributed to differences in protein sources.

The total protein concentration showed a quadratic response ($P < 0.05$) among treatments with increasing levels of HSM in the diets. However, the values were within the biological limits of 6.4 to 7.0 g/dL (Aiello, 2016).

The following serum chemical constituents were not significantly different ($P > 0.05$) among treatments: aspartate aminotransferase, alkaline phosphatase, gamma-glutamyl transferase, lactate dehydrogenase, globulin, total bilirubin, and albumin:globulin ratio. Nonetheless, these values were similar to those of growing goats in other studies, indicating they are within the biological range for

Table 4. Least squares means of serum chemistry parameters on d 60 of the feeding period for meat goats fed varying levels of hempseed meal (HSM)

	% HSM supplementation					*P*-value[2]	
Serum chemistry[1]	0	11	22	33	SEM	Linear	Quadratic
Glucose, mg/dL	73.3	55.4	63.2	62.6	7.83	0.33	0.13
BUN, mg/dL	24.9	20.6	26.0	29.2	2.71	0.04	0.06
Creatinine (Crea), mg/dL	0.40	0.28	0.38	2.65	1.59	0.18	0.30
BUN:Crea	63.8	73.0	76.3	61.9	8.87	0.94	0.07
Albumin, g/dL	2.8	2.2	2.6	3.0	0.22	0.18	0.01
Globulin, g/dL	3.9	3.2	3.5	3.5	0.44	0.44	0.17
Albumin:globulin	0.7	0.7	0.7	0.7	0.037	0.16	0.28
Total protein, g/dL	6.7	5.4	5.9	6.3	0.57	0.70	0.03
Total bilirubin, mg/dL	0.5	0.3	0.4	0.4	0.08	0.19	0.31
Creatine kinase, mg/dL	82.6	111.9	138.8	225.2	65.43	0.03	0.54
AST, U/L	113.7	89.2	138.6	139.6	34.81	0.26	0.61
ALKP, U/L	375.7	186.1	322.9	310.7	111.21	0.87	0.27
GGT, U/L	64.9	54.3	65.2	70.4	10.03	0.39	0.27
LDH, U/L	949.2	733.4	911.2	851.2	129.83	0.78	0.40

[1]Serum chemical concentrations were determined using the IDEXX Catalyst DX system (IDEXX Laboratories) on d 60 of the feeding period. AST = aspartate aminotransferase; ALKP = alkaline phosphatase; GGT = gamma-glutamyl transferase; LDH = lactate dehydrogenase.

[2]Based on orthogonal contrast for equally spaced treatments (n = 10 per treatment).

growing goats (Solaiman et al., 2009; Al-Bulushi et al., 2017; Min et al., 2019).

Animal Performance

Final BW was similar among the different treatments. There were no differences ($P > 0.05$) in total DMI among treatments (Table 5). However, the NDF intake increased linearly ($P < 0.01$) with increasing levels of HSM, which was expected because of the diet formulation.

A linear increase ($P < 0.01$) was observed with respect to ADF intake, with increasing proportions of HSM. This was expected because the ADF content of HSM was high (36.47%). The greater ADF levels in diets are reported to lower digestibility levels, evident in the current study. This fraction of fiber (ADF) is composed of all the very slowly fermentable and indigestible feed components and thus is often associated with feed digestibility (Ball et al., 2007).

The ADG decreased linearly ($P < 0.01$) with the increasing inclusion rate of HSM supplementation (Table 5). As the HSM inclusion rate increased, NE_g, TDN, and NFC contents decreased (Table 1), resulting in lower ADG values. Karlsson and Martinsson (2011) reported lower live weight gains with HSM compared with other protein sources (i.e., peas at 44.4% and rapeseed cake 25.4% of the total diet). The ADG in the current study ranged from 179 to 130 g/d for the control treatment to the highest

Table 5. Least squares means of feed intakes and animal performance on d 60 of the feeding period for meat goats fed varying levels of hempseed meal (HSM)

	% HSM supplementation					*P*-value[1]	
Item	0	11	22	33	SEM	Linear	Quadratic
Initial BW, kg	24.8	26.5	25.8	25.4	0.66	0.35	0.29
Final BW, kg	35.6	36.0	34.3	33.2	0.86	0.11	0.38
DMI, g/d	1,384.2	1,393.0	1,402.3	1,357.3	127.17	0.69	0.51
ADF intake, g/d	291.2	343.7	406.0	420.3	35.33	<0.01	0.10
NDF intake, g/d	460.8	490.2	555.7	574.8	49.67	<0.01	0.90
ADG, g/d	179.2	158.8	141.3	130.0	16.00	0.01	0.70
G:F, g/g	0.129	0.113	0.100	0.95	0.003	0.01	0.49

[1]Based on orthogonal contrast for equally spaced treatments (n = 10 per treatment).

HSM inclusion rates. Urge et al. (2004) reported ADG results for Boer wethers of similar age and BW fed 50:50 forage concentrate with 17.5% CP level diets were 0.09 and 0.100 kg for the first 12 wk and the second 12 wk of feeding, respectively. These values were much lower than the values found in the current experiment. Conversely, Cameron et al. (2001) found an ADG of 0.154 kg/d for Boer × Spanish crosses in a 16-wk period after weaning with individual housing and fed a commercial pelleted diet with an analyzed composition of 90% OM, 4.37 Mcal of GE/kg, 25% CP, 18% ADF, and 35% NDF on a DM basis. The diet used by Cameron et al. (2001) was of greater quality than used in the current study.

In the present study feed efficiency (G:F) decreased in a linear manner ($P < 0.01$) with the increasing level of HSM supplementation. In agreement with our study, Karlsson and Martinsson (2011) reported a decrease in G:F for a barley-based diet containing 21.8% HSM that was fed to the growing lambs (White Swedish Landrace × Texel). The G:F was the lowest when compared with the other protein sources utilized in their study: peas (44.4%) and rapeseed cake (25.4%). Feed offered to the lambs was based on the ME needed to gain 250 g/d. The lower ADG observed with the increasing HSM inclusion rate in the present study and in the Karlsson and Martinsson (2011) study resulted in the decrease in the F:G. In the current study, there were significant differences ($P < 0.05$) in ADF and NDF intakes among treatments that could affect energy intakes; however, protein levels in the diets were similar. The greater ADF and NDF levels were reflected by lower TDN levels and NE_g levels in diets with increasing inclusion rates of HSM. The NFC levels were also lower in diets with greater HSM inclusions.

Even with the highest level of HSM inclusion, the ADG was 0.130 kg in our study. These results demonstrate that the HSM can include up to 33% of the total diet without any problems.

APPLICATIONS

These findings provide new insights into the feeding quality of HSM for growing meat goats. The results showed that IVTD and animal performance decreased, whereas albumin, BUN, and creatine kinase increased with the increasing level of HSM supplementation. However, there were no differences in DMI between treatments. With the potential increase in HSM production, it is crucial that more work be completed to better understand the best feeding methods or ways to use it. The industrial hemp industry will rely on the success of this product because it could add a large value to the industrial hemp industry as long as it is priced competitively.

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LITERATURE CITED

Aiello, S. E. 2016. The Merck Veterinary Manual. 11th ed. Merck and Co. Inc.

Al-Bulushi, S., T. Shawaf, and A. Al-Hasani. 2017. Some hematological and biochemical parameters of different goat breeds in Sultanate of Oman "A preliminary study". Vet. World 10:461–466. https://doi.org/10.14202/vetworld.2017.461-466.

AOAC. 1990. Official Methods of Analysis. 15th ed. Association of Official Analytical Chemists.

Ball, D., C. S. Hoveland, and G. D. Lacefield. 2007. Southern Forages: Modern Concept for Forage Crop Management. Southern Forages International Plant Institute.

Cameron, M. R., J. Luo, T. Sahlu, S. P. Hart, S. W. Coleman, and A. L. Goetsch. 2001. Growth and slaughter traits of Boer x Spanish, Boer x Angora, and Spanish goats consuming a concentrate-based diet. J. Anim. Sci. 79:1423–1430. https://doi.org/10.2527/2001.7961423x.

Cherney, J., and E. Small. 2016. Industrial hemp in North America: Production, politics and potential. Agronomy (Basel) 6:58. https://doi.org/10.3390/agronomy6040058.

Congressional Research Service. 2019. Report R45525-The 2018 farm bill (P.L. 115–334): Summary and side-by-side comparison. Congressional Research Service.

Erwin, E. S., G. J. Marco, and E. M. Emery. 1961. Volatile fatty acid analyses of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44:1768–1771. https://doi.org/10.3168/jds.S0022-0302(61)89956-6.

European Food Safety Authority. 2011. Scientific opinion on the safety of hemp (*Cannabis genus)* for use in animal feed. EFSA J. 9:2011.

Hall, M. B., T. D. Nennich, P. H. Doane, and G. E. Brink. 2015. Total volatile fatty acid concentrations are unreliable estimators of treatment effects on ruminal fermentation *in vivo*. J. Dairy Sci. 98:3988–3999. https://doi.org/10.3168/jds.2014-8854.

Hammond, A. C. 1983. The use of blood urea nitrogen concentration as an indicator of protein status in cattle. Bov. Pract. 18:114–117.

Hammond, A. C. 1992. Use of blood urea nitrogen concentration to guide protein supplementation in cattle 3rd Annual Florida Ruminant Nitrogen Symposium. University of Florida, Institute of Food and Agricultural Sciences.

Hammond, A. C., E. J. Bowers, W. E. Kunkle, P. C. Genho, S. A. Moore, C. E. Crosby, K. H. Ramsay, J. H. Harris, and H. W. Essig. 1994. Use of blood urea nitrogen concentration to determine time and level of protein supplementation in wintering cows. Prof. Anim. Sci. 10:24–31. https://doi.org/10.15232/S1080-7446(15)31923-9.

Hessle, A., M. Eriksson, E. Nadeau, T. Turner, and B. Johansson. 2008. Cold-pressed hempseed cake as a protein feed for growing cattle. Acta Agriculture Scandinavica 58:136–145.

Johnson, R. 2018. Hemp as an agricultural commodity. Congressional Research Service 7.

Karlsson, L., M. Finell, and K. Martinsson. 2010. Effects of increasing amounts of hempseed cake in the diet of dairy cows on the production and composition of milk. Animal 4:1854–1860. https://doi.org/10.1017/S1751731110001254.

Karlsson, L., and K. Martinsson. 2011. Growth performance of lambs fed different protein supplements in barley-based diets. Livest. Sci. 138:125–131. https://doi.org/10.1016/j.livsci.2010.12.010.

Karlsson, L., M. Ruiz-Moreno, M. D. Stern, and K. Martinsson. 2012. Effects of temperature during moist heat treatment on ruminal degradability and intestinal digestibility of protein and amino acids in hempseed cake. Asian-Australas. J. Anim. Sci. 25:1559–1567. https://doi.org/10.5713/ajas.2012.12213.

Mertens, D. R. 1987. Predicting intake and digestibility using mathematical models of ruminal function. J. Anim. Sci. 64:1548–1558. https://doi.org/10.2527/jas1987.6451548x.

Min, B. R., A. Frank, N. Gurung, J. H. Lee, J. W. Joo, and W. Pacheco. 2019. Peanut skin in diet alters average daily gain, ruminal and blood metabolites, and carcass traits associated with *Haemonchus contortus* infection in meat goats. Anim. Nutr. 5:278–285. https://doi.org/10.1016/j.aninu.2019.05.006.

Murray, R. K., D. K. Granner, P. A. Mayes, and V. W. Rodwell. 1990. Harper's Biochemistry. 22nd ed. Appleton and Lange.

Mustafa, A. F., J. J. Mckinnon, and D. A. Christensen. 1998. The nutritive value of hemp meal for ruminants. Can. J. Anim. Sci. 79:91–95.

NASEM. 1989. Nutrient Requirements of Dairy Cattle. 6th rev. ed. Update. National Academy Press.

NASEM. 2007. Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World Camelids. National Academy Press.

Oba, M., and M. S. Allen. 1999. Evaluation of the importance of the digestibility of neutral detergent fiber from forage: Effects on dry matter intake and milk yield of dairy cows. J. Dairy Sci. 82:589–596. https://doi.org/10.3168/jds.S0022-0302(99)75271-9.

Shen, J., Y. Chen, L. E. Moraes, Z. Yu, and W. Zhu. 2018. Effects of dietary protein sources and nisin on rumen fermentation, nutrient digestion, plasma metabolites, nitrogen utilization, and growth performance in growing lambs. J. Anim. Sci. 96:1929–1938. https://doi.org/10.1093/jas/sky086.

Solaiman, S. G., N. K. Gurung, Q. McCrary, H. Goyal, and W. H. McElhenney. 2009. Feeding performance and blood parameters of male goat kids fed Easiflo cottonseed. Small Rumin. Res. 81:137–145. https://doi.org/10.1016/j.smallrumres.2008.12.013.

Tilley, J. M. A., and R. A. Terry. 1963. A two stage technique for the invitro digestion of forage crops. Grass Forage Sci. 18:104–111. https://doi.org/10.1111/j.1365-2494.1963.tb00335.x.

Urge, M., R. C. Merkel, T. Sahlu, G. Animut, and A. L. Goetsch. 2004. Growth performance by Alpine, Angora Boer and Spanish wether goats consuming 50 and 75% concentrate diets. Small Rumin. Res. 55:149–158. https://doi.org/10.1016/j.smallrumres.2004.02.004.

USDA. 1970. Forage fiber analyses (apparatus, reagents, procedures, and some applications) No. 379. United States Department of Agriculture.

Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant, 2nd ed. Comstock Publishing.

Weiss, W. P., H. R. Conrad, and N. R. St. Pierre. 1992. A theoretically-based model for predicting total digestible nutrient values of forages and concentrates. Anim. Feed Sci. Technol. 39:95–110. https://doi.org/10.1016/0377-8401(92)90034-4.