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Influence of protein level on growth performance, dietary energetics and carcass characteristics of Pelibuey × Katahdin lambs finished with isocaloric diets

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ABSTRACT

Forty Pelibuey × Katahdin intact male lambs (23.0 ± 1.8 kg initial shrunk weight) were used in an 84-day feeding trial (5 pens per treatment, randomized complete block design) to evaluate crude protein level (110, 140, 170, and 200 g/kg diet DM) in isocaloric diets (2.03 Mcal NE_m/kg) on finishing-phase growth performance, dietary energetics and carcass traits. Increases in protein levels were accomplished by increasing levels of canola and meat meal. Tallow was used to equilibrate energy levels among diets. Increasing dietary protein level increased (linear effect, $P = 0.01$) 84-d average daily gain, dry matter intake (linear effect, $P = 0.03$), and gain efficiency (linear effect, $P < 0.01$). The ratio of observed:expected dietary net energy increased (linear effect, $P \leq 0.02$) with increasing protein level during initial 56 days. However, overall the 84-d effect was not appreciable ($P = 0.17$). Hot carcass weight, kidney-pelvic-heart fat, and fat thickness increased (linear effect, $P \leq 0.03$) with dietary protein level. However, treatments effects on *longissimus thoracis* area, wall thickness, estimated yield grade, and carcass composition were not appreciable. It is concluded that during the initial growing phase (first 56 days) increasing dietary CP level up to 170 g CP/diet DM will enhance growth performance and efficiency of energy utilization. Thereafter (final 28 days), the effect of dietary CP levels greater than 110 g CP/kg diet DM on growth-performance and dietary energy utilization are not appreciable.

1. Introduction

Dorper, Katahdin and Saint Croix sheep breeds were introduced into México in recent years. However, due to their prolific nature and adaptability to a wide variety of climatic conditions, the Pelibuey breed (Cubano Rojo) and their crosses continue to be the most representative genotype (Partida and Martínez, 2010). In Mexico, usually, Pelibuey lambs and their crosses are placed on growing-finishing diets at initial body weights (BW) of 20–25 kg, and harvested at final BW of 30–35 kg. The growing-finishing diets fed typically contained between 1.78 and 1.95 Mcal/kg of net energy for maintenance (NE_m), and 16% to 18% of crude protein (Pineda et al., 1998; Ríos et al., 2011). During the relatively brief growing-finishing period (35–45 days) these high dietary CP levels were needed to support of optimal growth performance (Manso et al., 1998; Haddad et al., 2001; Zundt et al., 2002). However, present market demands have pushed for a heavier target harvest weights (45–50 kg), resulting in a greater degree of finish and extending the growing-finishing period to > 70 days (Muñoz-Osorio et al., 2016). In feedlot cattle, the extra-caloric effect of increased metabolizable protein (MP) intake is more likely to be manifest during the initial part of the growing-finishing period (Zinn et al., 2007; Carrasco et al., 2013). Very little information is available in the literature regarding to the influence of the protein level on overall growth performance of lambs over the more extended growing finishing phase. The objective of this experiment was to evaluate the growth performance, dietary energetics, carcass characteristics, and visceral mass in lambs fed isocaloric diets with different protein level during an 84-d growing-finishing period.

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2. Materials and methods

2.1. Diets, animals and experimental design

This experiment was conducted at the Universidad Autónoma de Sinaloa Feedlot Lamb Research Unit, located in the Culiacán, México (24° 46′ 13″ N and 107° 21′ 14″ W). Culiacán is about 55 m above sea level, and has a tropical climate. All animal management procedures were conducted within the guidelines of locally-approved techniques for animal use and care: NOM-051-ZOO-1995: Humanitarian care of animals during mobilization of animals; NOM-062-ZOO-1995: Technical specifications for the care and use of laboratory animals. Livestock farms, farms, centers of production, reproduction and breeding, zoos and exhibition halls, must meet the basic principles of animal welfare; NOM-024-ZOO-1995: Animal health stipulations and characteristics during transportation of animals, and NOM-033-ZOO-1995: Humanitarian care and animal protection during slaughter process.

Forty Pelibuey × Katahdin [23.04 ± 1.80 kg (average shrunk body weight)] crossbred intact male lambs were used in a growth-performance experiment from February to May to evaluate the effects of protein level on growth performance, dietary energetics, carcass traits, and visceral organ mass. The average ambient temperature and relative humidity during the course of the experiment were 24.9 °C, and 41%, respectively. Four weeks before the experiment started, lambs were treated for endoparasites (Albendaphorte 10%, Animal Health and Welfare, México City, México), and injected with 1×10^6 IU vitamin A (Synt-ADE®, Fort Dodge, Animal Health, México). Upon initiation of the experiment, lambs were weighed individually before the morning meal (electronic scale; TORREY TIL/S: 107 2691, TOR REY electronics Inc, Houston TX, USA) and randomly assigned within five weight blocks of four pens each (2 lambs/pen). In this way, the experiment consisted of 4 treatments (10 lambs in each treatment) with 5 pen replication per treatment. The 20 pens used in the experiment were 6 m^2 with overhead shade, automatic waterers and 1 m fence-line feed bunks. Lambs were adapted to the assigned treatment 14-d before the start of experiment (Table 1). Dietary treatments consisted of a cracked corn-based diets which were formulated to be isocaloric (2.07 Mcal NE_m/kg). The energy concentration of diet was manipulated by addition of tallow while protein level was mainly adjusted replacing cracked corn grain with combinations of urea, canola meal and rendered pork meat meal to reach CP concentrations of 110 (CP11), 140 (CP14), 170 (CP17), and 200 g CP/kg of diet DM (CP20), respectively. In the case of the CP11 treatment, urea was the sole source of supplemental N. Urea was added in all diets to ensure that degradable intake protein (DIP) in diet not limit microbial efficiency, and hence optimal ruminal fermentation (Zinn and Shen, 1998). The average of estimated ruminal undegradable intake protein (UIP) in experimental diets averaged 38 ± 0.46%. Corn was prepared by passing whole regional white corn through rollers (46 × 61 cm rolls, 5.5 corrugations/cm; Memco, Mills Rolls, Mill Engineering & Machinery Co., Oklahoma, CA). Roll pressure was adjusted so that the kernels were broken to produce a bulk density of approximately 0.50 kg/L. The canola meal used was a standard quality US canola meal obtained by solvent extraction (Industrial de Oleaginosas, Guadalajara, Jalisco, México). The rendered strictly pork meat meal was obtained from El Kowi Enterprise (Hermosillo, Sonora, México). The forage source (wheat straw) was ground in a hammer mill (Bear Cat #1A-S, Westerns Land and Roller Co., Hastings, NE) with a 3.81 cm screen, before incorporation into complete mixed diets. Dietary treatments were randomly assigned to pens within blocks, resulting in 5 pens replicates per treatment. The experiment lasted 84 days. Lambs were allowed *ad libitum* access to dietary treatments. Daily feed allotments to each pen were adjusted to allow minimal (< 5% of total offered) residual feed remaining in feed bunk just prior to the morning feeding. The amount of feed offered and residuals were weighed daily. Lambs were provided fresh feed twice daily at 0800 and 1400 h in a 40:60 proportion (as feed basis). Feed bunks were visually assessed between 0740 and 0750 h each morning, refusals were collected and weighed and feed intake was determined. Adjustments, to either increase or decrease daily feed delivery, were provided at the afternoon feeding. Lambs were individually weighed at the beginning of the trial and 28-d intervals thereafter. The initial and interim shrunk body weight (SBW) was determined as full BW × 0.96 (adjustment for gastrointestinal fill; Cannas et al., 2004). Upon completion of the study, all lambs were weighed following an 18 h fast (food but not drinking water was withdrawn) to obtain final SBW.

Table 1
Composition of experimental diets (DM basis).

Item	Protein level, % of DM			
	11	14	17	20
White corn, dry rolled	75.00	68.50	63.15	57.40
Canola meal	–	6.25	9.50	16.00
Meat meal[a]	–	2.50	5.50	7.25
Wheat Straw	10.00	9.50	9.00	7.00
Molasses	8.65	7.00	6.50	5.50
Tallow	3.00	3.50	4.00	4.50
Urea	1.10	1.00	1.10	1.10
Limestone	0.50	0.50	–	–
Phosphate deflourinated	0.50	–	–	–
Zeolite	0.75	0.75	0.75	0.75
Trace mineral salt [b]	0.50	0.50	0.50	0.50
Chemical composition, g/kg DM basis [c]				
CP	111	141	169	198
NDF	154	165	169	171
EE	63.8	71.1	78	84.2
Ash	37	42.7	49.1	53.7
Rumen degradable intake protein, %	61.0	60.4	60.5	61.1
Rumen undegradable intake protein, %	39.0	39.6	39.5	38.9
Estimated NE, Mcal/kg[d]				
NE_m	2.06	2.06	2.06	2.06
NE_g	1.41	1.41	1. 41	1.41
E:P ratio[e]	0.183	0.144	0.120	0.102

[a] Pure pork meat meal (El Kowi Enterprice, Hermosillo, Sonora, México).
[b] Trace mineral salt contained: $CoSO_4$, 6.8 g/kg; $CuSO_4$, 10.4 g/kg; $FeSO_4$, 35.7 g/kg; ZnO, 12.4 g/kg; $MnSO_4$, 10.7 g/kg; KI, 0.52 g/kg; and NaCl, 923.5 g/kg.
[c] Degradable intake protein (DIP) was calculated based on tabular DIP values for individual ingredients (NRC, 2007). Dietary chemical composition for CP, NDF, EE, ash, and neutral detergent fiber (assayed with amylase and expressed exclusive of residual ash) were determined by analyzing subsamples collected and composited throughout the experiment.
[d] Net energy was calculated based on tabular net energy (NE) values for individual feed ingredients (NRC, 2007).
[e] Estimated kcal net energy of maintenance/g protein.

2.2. Sample analysis

Corn, canola meal, pork meat meal, and urea were subjected to the following analyses: DM (oven drying at 105 °C until no further weight loss; method 930.15; AOAC, 2000), and CP (N × 6.25, method 984.13; AOAC, 2000). While the complete diets were subjected to the following analyses: DM (oven drying at 105 °C until no further weight loss; method 930.15; AOAC, 2000); CP (N × 6.25, method 984.13; AOAC, 2000); ash (method 942.05; AOAC, 2000); NDF (Van Soest et al., 1991, corrected for NDF-ash, incorporating heat stable α-amylase (Ankom Technology, Macedon, NY) at 1 mL per 100 mL of NDF solution (Midland Scientific, Omaha, NE)), and ether extract (method 920.39; AOAC, 2000). Feed and refusal samples were collected daily for DM analysis (oven-drying at 105 °C until constant weight, method 930.15; AOAC, 2000).

2.3. Calculations

Average daily gain (ADG) was determined as the difference in SBW divided by the corresponding days on feed. Gain efficiency was determined as the ADG divided by corresponding dry matter intake (DMI). The estimation of expected DMI was performed based on observed ADG and average SBW according to the following equation: expected DMI, kg/d = $(EM/NE_m) + (EG/EN_g)$, where EM (energy required for maintenance, Mcal/d) = $0.056 \times SBW^{0.75}$ (NRC, 1985a), EG (energy gain, Mcal/d) = $0.276 \times ADG \times SBW^{0.75}$ (NRC, 1985a), NE_m and NE_g are 2.07 and 1.40 Mcal/kg, respectively (derived from tabular values based on the ingredient composition of the experimental diet; NRC, 1985a). The coefficient (0.276) was estimated assuming a mature weight of 113 kg for Pelibuey × Kathdin male lambs (Canton and Quintal, 2007). Dietary NE was estimated by means of the quadratic formula: $x = (-b - \sqrt{b^2 - 4ac})/2c$, where $x = NE_m$, $a = -0.41EM$, $b = 0.877$ EM + 0.41 DMI + EG, and $c = -0.877$ DMI (Zinn et al., 2008).

2.4. Carcass and visceral mass data

All lambs were harvested on the same day. After humanitarian sacrifice, lambs were skinned, and the gastrointestinal organs were separated and weighed. After carcasses (with kidneys and internal fat included) were chilled in a cooler at −2 °C to 1 °C for 48 h, the following measurements were obtained: 1) body wall thickness (distance between the 12th and 13th ribs beyond the ribeye, five inches from the midline of the carcass); 2) fat thickness perpendicular to the *m. longissimus thoracis* (LM), measured over the center of the ribeye between the 12th and 13th rib; 3) LM surface area, measure using a grid reading of the cross sectional area of the ribeye between 12th and 13th rib, and 4) kidney, pelvic and heart fat (KPH). The KPH was removed manually from the carcass, and then weighed and reported as a percentage of the cold carcass weight (USDA, 1982). Each carcass was split along the vertebrae into two halves. The carcass composition was assessed using physical dissection by the procedure described by Luaces et al. (2008).

All tissue weights were reported on a fresh tissue basis. Previous data suggests that there is very little variation among fresh and dry weights for visceral organs (Neville et al., 2008). Organ mass was expressed as kg, and as g/kg final empty BW. Final EBW represents the final SBW minus the total digesta weight. Full visceral mass was calculated by the summation of all visceral components (stomach complex + small intestine + large intestine + liver + lungs + heart), including digesta. The stomach complex was calculated as the digesta-free sum of the weights of the rumen, reticulum, omasum and abomasum.

2.5. Statistical analysis

Performance (gain, gain efficiency, and dietary energetics) and carcass data were analyzed as a randomized complete block design, with pen as the experimental unit. The MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) was used to analyze the variables. Carcass composition and visceral organ mass data were analyzed as a randomized complete block design with subsampling (Hinkelmann and Kempthorne, 2008), with pen as the experimental unit and animal as the observational unit. The MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) was utilized to analyze the data. Treatment effects were tested for linear, quadratic and cubic components of the CP level. In addition, means separations by T-test multiple comparisons between protein levels were performed. Contrasts were considered significant when the P-value was ≤ 0.05, and tendencies were identified when the *P*-value was > 0.05 and ≤ 0.10.

3. Results

The crude protein concentration of corn, canola meal, meat pork meal, and urea used in diets, and crude protein concentration of diets used in the trial are shown in Table 2. The CP concentration values were within the expected range. The CP concentration of each diet was very close (< 0.6% variance) to targeted throughout the course of the study.

Quadratic and cubic effects were not significant (P ≥ 0.10). Thus, the P values for those components are not present in the tables.

Treatment effects on growth performance and dietary net energy are shown in Tables 3 and 4. As expected, with increases in dietary CP concentration, CP intake likewise increased (P < 0.01). During initial 56 days of feeding, average daily gain (ADG) increased (linear effect, *P* ≤ 0.04) with increasing CP level. However, during the final 28-d period (from day 56 to harvest), ADG was not affected (*P* > 0.49) by

Table 2
Variation on CP concentration of ingredients and diets used in the trial.

Item	CP (N × 6.25)
Ingredients[a]	
Corn	9.45 ± 0.10
Canola meal	41.80 ± 0.16
Meat meal [b]	58.71 ± 0.14
Urea	281.80 ± 0.06
Diets [c]	
T11	11.10 ± 0.09
T14	14.05 ± 0.11
T17	17.03 ± 0.07
T20	20.02 ± 0.13

[a] n = 8 samples of each ingredient.
[b] Pure pork meat meal (El Kowi Enterprise, Hermosillo, Sonora).
[c] n = 12 samples (one of each batch elaborated weekly during the trial).

Table 3
Treatment effects on growth performance in Pelibuey × Katahdin lambs fed different levels of protein.

Item	Protein level, % 11	14	17	20	SEM	Contrast *P*-value[a] Linear
Days on test	84	84	84	84		
Pen replicates	5	5	5	5		
Shrunk body weight, Kg [b]						
Initial	22.99	23.08	23.09	22.99	0.108	0.97
28-d	28.95a	30.08ab	31.43b	31.45b	0.516	< 0.01
56-d	35.82a	37.78ab	39.02bc	40.37c	0.786	< 0.01
Final	43.35a	45.42ab	46.27b	48.22b	0.936	< 0.01
Protein intake, g/d						
1 to 28 d	91.8a	128.3b	164.3c	194.2d	5.85	< 0.01
28 to 56 d	117.4a	160.7b	195.9c	253.6d	8.50	< 0.01
56 to 84 d	140.0a	191.8b	222.7c	286.5d	8.00	< 0.01
1 to 84 d	116.4a	160.2b	194.4c	243.5d	6.41	< 0.01
ADG, kg/d						
1 to 28 d	0.213a	0.250ab	0.298b	0.302b	0.018	< 0.01
28 to 56 d	0.246a	0.275ab	0.270ab	0.319b	0.020	0.04
56 to 84 d	0.268	0.273	0.260	0.280	0.016	0.75
1 to 84 d	0.242a	0.266b	0.276bc	0.300c	0.014	0.01
DMI, kg/d						
1 to 28 d	0.827a	0.910ab	0.972b	0.981b	0.037	< 0.01
28 to 56 d	1.058a	1.140ab	1.159ab	1.281b	0.058	0.03
56 to 84 d	1.261a	1.360ab	1.318ab	1.447b	0.061	0.08
1 to 84 d	1.049a	1.136ab	1.150a	1.230b	0.043	0.03
Gain to feed, kg/kg						
1 to 28 d	0.258a	0.275a	0.307ab	0.308b	0.010	< 0.01
28 to 56 d	0.232	0.241	0.233	0.249	0.008	0.17
56 to 84 d	0.213a	0.201ab	0.197ab	0.194b	0.009	0.03
1 to 84 d	0.231a	0.234ab	0.240ab	0.244b	0.004	0.01

[a,b,c] Means in the same row with different superscript letters differ.
[a] *P* = Observed significance level linear effect of protein level supplementation.
[b] Initial shrunk weight is the full live weight reduced 4% to adjustment for gastrointestinal fill. Final shrunk weight was obtained following an 18 h fast (food but not drinking water was withdrawn).

Table 4
Treatment effects on dietary energy in Pelibuey × Katahdin fed different levels of protein.

Item	Protein level, %				SEM	Contrast *P*-value[a]
	11	14	17	20		Linear
Days on test	84	84	84	84		
Pen replicates	5	5	5	5		
Dietary NE, Mcal/kg						
Maintenance						
1 to 28 d	1.98a	2.04a	2.15b	2.15b	0.038	< 0.01
28 to 56 d	2.00a	2.06ab	2.06ab	2.11b	0.028	0.03
56 to 84 d	2.05	2.01	2.04	2.01	0.026	0.28
1 to 84 d	2.01a	2. 04ab	2.08ab	2.09b	0.024	0.05
Gain						
1 to 28 d	1.33a	1.37a	1.47b	1.47b	0.034	< 0.01
28 to 56 d	1.35a	1.40ab	1.39ab	1.45b	0.028	0.03
56 to 84 d	1.39	1.35	1.39	1.36	0.023	0.28
1 to 84 d	1.35a	1.38ab	1.42ab	1.42b	0.021	0.05
Observed to expected dietary NE ratio[b]						
Maintenance						
1 to 28 d	0.96a	0.98a	1.04b	1.04b	0.018	< 0.01
28 to 56 d	0.97a	0.99ab	0.99ab	1.02b	0.016	0.02
56 to 84 d	0.99	0.97	0.98	0.98	0.017	0.44
1 to 84 d	0.97	0.98	1.00	1.01	0.021	0.17
Gain						
1 to 28 d	0.94a	0.97a	1.05b	1.05b	0.024	< 0.01
28 to 56 d	0.95	0.99	0.99	1.02	0.025	0.03
56 to 84 d	0.99	0.96	0.98	0.97	0.016	0.44
1 to 84 d	0.97	0.98	1.00	1.01	0.022	0.17
Observed to expected daily DM intake[c]						
1 to 28 d	1.06a	1.03a	0.95b	0.95b	0.022	< 0.01
28 to 56 d	1.04a	1.00ab	1.00ab	0.98b	0.017	0.03
56 to 84 d	1.00	1.03	1.01	1.03	0.023	0.31
1 to 84 d	1.02	1.01	0.99	0.98	0.014	0.17

[a,b,c] Means in the same row with different superscript letters differ.
[a] *P* = Observed significance level linear, quadratic and cubic effect of level of protein level supplementation.
[b] Expected diet NE based on tabular values for individual dietary ingredients (NRC, 2007).
[c] Expected DMI was computed as follows: DMI, kg/d = $(EM/NE_m) + (EG/NE_g)$, where EM = maintenance coeficient of 0.056 Mcal/BW$^{0.75}$ (NRC, 1985a) and EG is the daily energy deposited (Mcal/d) estimated by equation: EG = ((0.276 × ADG) × SBW$^{0.75}$, NRC, 1985a). The divisor NE_m and NE_g are the NE of diet (calculated from tables of composition of feed (NRC, 1985a)].

dietary CP level. Notwithstanding, the initial 56-d effect on ADG was sufficient so that overall ADG increased (linear effect, $P = 0.01$) with increasing CP level.

Likewise, DMI increased (linear effect, $P \leq 0.03$) during initial 56 days. There was also a numerical trend (linear effect, $P = 0.08$) for greater DMI during the final 28 d. Overall (d1 to d 84), DMI increased ($P = 0.03$) with increasing level of CP.

Gain efficiency increased ($P < 0.01$) with increasing CP level during initial 28-d period. From d 28–56 differences in gain efficiency were not appreciable ($P > 0.17$), and during the final 28-d period gain efficiency decreased (linear effect, $P = 0.03$) with increasing CP. Notwithstanding, overall 84-d gain efficiency increased (linear effect, $P < 0.01$) with increasing CP level.

Estimated dietary NE, observed-to-expected diet NE and apparent energy retention per unit DMI increased (linear effect, $P \leq 0.05$) during initial 56 days. During the final 28-d period, there were no treatments effect ($P > 0.28$) on estimated dietary NE energy nor observed-to-expected diet NE. Nevertheless, overall (84-d) dietary NE increased (P = 0.05) with increasing dietary protein level. Although, overall observed-to-expected dietary NE was not different ($P > 0.17$).

Treatment effects on carcass characteristics and chemical composition are shown in Tables 5 and 6. Hot carcass weight, KPH and backfat thickness increased (linear effect, $P \leq 0.03$) with increasing CP level. However, there were no treatment effects ($P \geq 0.67$) on LM area, wall thickness, and carcass composition.

Weights of liver ($P < 0.01$), stomach complex ($P = 0.08$), intestines ($P = 0.07$) and visceral fat ($P < 0.01$) increased with increasing CP level. Although, when expressed as g/kg of EBW, CP level

Table 5
Treatment effects on carcass characteristics and chemical composition of Pelibuey × Katahdin fed different levels of protein.

Item	Protein level, %				SEM	Contrast *P*-value[a]
	11	14	17	20		Linear
Hot carcass weight, kg	24.30a	25.44ab	25.75ab	26.98b	0.700	0.02
Dressing percentage [b]	56.17	55.51	55.57	55.94	0.809	0.86
Cold carcass weight, kg	23.79a	25.10ab	25.49ab	26.57b	0.738	0.03
Drip loss, %	1.34	1.28	1.06	1.38	0.179	0.91
Longissimus muscle area, cm^2	15.35	15.23	15.68	15.36	0.593	0.87
Kidney-pelvic-heart fat, %	2.42a	2.43a	2.59ab	2.96b	0.153	0.03
Backfat thickness, mm[c]	0.32a	0.31a	0.37ab	0.41b	0.028	0.03
Wall thickness, mm	20.22	20.85	20.44	20.82	0.927	0.74
Carcass composition, %						
Lean	59.08	58.95	59.16	58.87	0.738	0.90
Fat	22.54	22.40	21.86	22.36	0.792	0.90
Bone	18.38	18.65	18.95	18.77	0.610	0.67
Muscle:fat ratio	2.62	2.63	2.71	2.64	0.121	0.96
Muscle:bone ratio	3.21	3.16	3.12	3.14	0.143	0.75
Estimated yield grade[d]	1.64a	1.62a	1.86ab	1.99b	0.114	0.02

[a,b,c] Means in the same row with different superscript letters differ.
[a] *P* = Observed significance level linear, quadratic and cubic effect of protein level supplementation.
[b] Computed as follows: Dressing percentage = (HCW/Final BW*0.96)*100.
[c] Fat thickness over the center of the LM beetween of 12th and 13th ribs.
[d] Yield grade was estimated as: YG = (Fat thickness, in × 10) + 0.4 (8), where: 1 = Most desirable, minimum fat and heavy muscled, and 5 = Least desirable, fat and light muscled.

Table 6
Treatment effects on organ mass of Pelibuey × Katahdin fed different levels of protein.

Item	Protein level, %				SEM	Contrast *P*-value[a]
	11	14	17	20		Linear
EBW, percentage of full weight	91.75	92.03	92.30	92.49	0.39	0.16
Organs						
Stomach complex[b], kg	1.100	1.170	1.158	1.216	0.42	0.08
Stomach complex, g/kg EBW	27.23	27.79	26.97	27.20	0.65	0.75
Intestines[c], kg	1.695a	1.803ab	1.784ab	1.858b	0.064	0.07
Intestines, g/kg EBW	42.07	42.71	41.80	41.65	1.122	0.69
Liver, kg	0.836a	0.880b	0.880b	0.935c	0.020	< 0.01
Liver, g/kg EBW	20.71	20.89	20.59	20.98	0.185	0.55
Visceral fat, kg	1.476a	1.616b	1.742b	1.918c	0.057	< 0.01
Visceral fat, g/kg EBW	36.77a	38.36ab	40.80bc	43.14c	1.201	< 0.01

EBW = empty body weight.
[a,b,c] Means in the same row with different superscript letters differ.
[a] *P* = Observed significance level for linear, quadratic and cubic effect of protein level supplementation.
[b] Stomach complex = (rumen + reticulum + omasum + abomasums), without digesta.
[c] Small and large intestine without digesta.

did not affect ($P \geq 0.55$) proportion of stomach complex, intestines, and liver. Increasing CP level increased (linear effect, $P < 0.01$) the proportion of visceral fat (Table 6).

4. Discussion

The CP concentration of white corn used in the present experiment was consistent with previous reports (Sánchez et al., 2007; Castro-Pérez et al., 2013). White corn grain generally contained slightly greater N than yellow corn (Cravero et al., 2003; Plascencia et al., 2011). The CP concentration of the canola meal used was very similar to the standard quality US canola meal obtained by solvent extraction specified by NRC (2007). The CP content of rendered pork meat meal was consistent with the analyses provide by the Company.

Net protein intake during the course of the experiment averaged 116, 160, 194, and 244 g/d, for CP11, CP14, CP16 and CP20 respectively. The linear increase in CP intake was anticipated due to differences in dietary CP concentration in diet as well as CP-level effects on DMI.

Consistent with our results, increased DMI, ADG, and gain efficiency has been a consistent response to increases in dietary CP level lightweight finishing lambs (Fluharty and McClure, 1997; Manso et al., 1998; Dabiri and Thonney, 2004; Javed et al., 2010). Protein supplementation may stimulate energy intake indirectly by improving diet acceptability, enhancing fermentation of organic matter, and modulation of gastric empty (Zinn and Shen, 1998). More directly, providing adequate metabolizable protein (MP) to meet requirements to sustain its genetic potential for growth at optimal energy intake promotes both increased growth rate and improved energetic efficiency. This effect is expected during the early growing phase where limitations in metabolizable protein supply are more particularly manifest. Based on equation proposed by NRC (2007) the metabolizable protein (MP) requirements (using ADG and average SBW) of lambs in CP11, CP14, CP17 and CP20 treatments during the first 28-d period, were 113, 123, 135 and 136 g/d, respectively. Based on expected intestinal flow of MP microbial protein [(NRC, 1985b, 6.25 × (0.809 × (23TDN-1.21)) × 0.80), where TDN is expressed as kg] plus metabolizable undegraded intake protein (0.80 × UIP × CP × DMI × 0.0001, Table 1 and 3) the MP supply for treatments CP11, CP14, CP17 and CP20 represented 0.88, 0.96, 0.99 and 1.04 of requirement, respectively. During the remaining two 28-d periods, MP supply exceeded requirements for all treatments. During the early feedlot growing phase, metabolizable methionine is expected to be the first limiting amino acid following by lysine in growing lambs fed a corn-based diets with urea as the sole source of supplemental N. The requirements of methionine and lysine of growing-finishing lambs are very similar than cattle (NRC, 2007). For efficient or optimal utilization, MP supply to the intestine should contain 5.6% lysine, and 1.7% methionine (NRC, 2007; Klemesrud et al., 2000; Zinn and Shen, 1998; Torrentera et al., 2017). Accordingly, the first limiting metabolizable amino acid during the first 28-d period was lysine, with diets providing 0.84, 0.95, 1.0, and 1.05, of requirements for CP11, CP14, CP17 and CP20, respectively. The lower dietary NE_g observed for CP11 and CP14 in this phase (0.94% and 97% of expected, respectively) is consistent with previous work evaluating metabolizable amino acid supplies in both crossbreed and Holstein steers (Zinn and Shen, 1998; Zinn et al., 2007; Torrentera et al., 2017). While the observed to expected dietary NE for lambs receiving CP17 and CP20 treatments was enhanced 4% during the first 28-d period. Observed-to-expected dietary net energy and DMI are an important and practical application of current standards for energetics in nutrition research (Zinn et al., 2008). The estimation of dietary energy and the ratio of observed-to-expected DMI (apparent energy retention per unit DMI) reveals differences in the efficiency of energy utilization of the diet itself, independent of confounding effects of ADG and DMI associated with gain-to-feed ratios.

Increases in gain efficiency of 10.7% was reported in Finnsheep × Dorset lambs when CP level was increased from 13 to 17% (Dabiri and Thonney, 2004). Increasing CP levels from 12 to 14% increased gain efficiency 15.8% in growing Talli lambs (Javed et al., 2010). Increasing protein level from 16.5 vs 20.7% CP increased gain efficiency 10.8% in Hampshire × Targhee crossbred lambs (starting finishing phase at 23 kg LW) in the first 41-d growing phase (Fluharty and McClure, 1997). During the subsequent finishing phase CP level did not affect growth performance. During a 50 d growing finishing period (initial weight, 31.4 kg), Kaya et al. (2009) observed a 17.2% increase in gain efficiency when CP was increased from 10 to 13% of diet, but not from 13 to 16% CP. Likewise, Dabiri and Thonney (2004) did not observe an improvement in 42-d gain efficiency of lambs (initial weight, 24.5 kg) when CP was increased from 15 to 17%. Generally (Beauchemin et al., 1995; Ruiz-Nuño et al., 2009), the magnitude of the positive effects on gain efficiency had been less appreciable when dietary CP level exceeded 14% in high-energy diets, such as that used in the present study. As duration of the feeding period increases, the great levels of dietary CP exceed requirements and hence, responses in gain efficiency diminish. This is observed both in feedlot lambs (Fluharty and McClure, 1997; Kaya et al., 2009; Ríos-Rincón et al., 2014) as well as in feedlot cattle (Zinn et al., 2007; Carrasco et al., 2013), and confirm our observation the absence of positive effects on observed-to-expected diet NE in the present experiment at higher levels dietary of CP beyond 56 days of finishing.

The optimal requirements for CP intake (based on the observed weight gain and energy efficiency) during first 28-d period was 13 g/kg $BW^{0.75}$ (diet NE_m energy:protein ratio of 13 cal/g of CP), this value is in reasonable agreement (0.94) with NRC (2007) for lambs growing from 20 to 30 kg (expected ADG = 0.300 kg/d). Thereafter, optimal CP intake was 11.5 g/kg $BW^{0.75}$ (diet NE_m energy:protein ratio of 14.5 cal/g of CP) for finishing Pelibuey × Katahdin lambs up to 50 kg LW.

Aside from the linear increase in carcass weight (Table 5), dietary CP level had minimal effects on carcass characteristics. The absence of effects of CP level on dressing percentage and LM area is consistent with previous reports (Beauchemin et al., 1995; Machado da Rocha et al., 2004; Ruiz-Nuño et al., 2009). Effects of CP levels on KPH and backfat thickness are consistent with treatment effects on ADG and final carcass weight (Ruiz-Nuño et al., 2009; Ríos-Rincón et al., 2014). In contrast, Ebrahimi et al. (2007) and Ríos-Rincón et al. (2014) observed that although increasing protein level increased carcass weight, it did not affect backfat thickness of finishing lambs. Consistent with previous studies (Hadjipanayotou, 1982; Searle et al., 1982; Ríos-Rincón et al., 2014), dietary CP level did not affect muscle-to-fat ratio, and muscle-to-bone ratio remained unchangeable by protein level.

It is generally recognized (Fluharty and McClure, 1997; Ludden et al., 2002), that the primary non-carcass components affected by CP level are liver, stomach, and intestines. The magnitude of the effect can be mediated by CP level, stage of growth, diet energy density and type of organ (Wang et al., 2009). Swanson et al. (1999) indicate that the influence of protein supplementation on visceral growth involves primarily the liver and not the intestines. In the present experiment, total liver weight linearly increased with increasing dietary CP level. Whereas, there were tendencies for increasing total weight of stomach complex and intestines. However, when expressed as a proportion of EBW (g/kg EBW) differences become less appreciable.

Effects of CP levels on visceral fat in lambs fed an isoenergetic diets has not been previously reported. The effects observed here could be attribute to protein-level effects on energy intake and rate of weight gain.

Although dietary NDF levels were low, it should be noted that the differences in NDF concentration between treatments observed here could have also contributed to dietary effects measured in the present experiment.

5. Conclusions

It is concluded that in growing-finishing Pelibuey × Katahdin lambs fed high-energy diets, increasing dietary CP level up to 170 g CP/kg diet DM can effectively enhance growth performance and dietary energy, particularly during the first 28 days of growing phase. Based on weight gain and energy efficiency, optimal requirements of protein intake during first 28 days is around of 13 g/kg $BW^{0.75}$ (diet energy:protein ratio of 13 cal/g of CP). Thereafter, 11.5 g/kg $BW^{0.75}$ (diet energy:protein ratio of 14.5 cal/g of CP) appears optimal for finishing Pelibuey × Katahdin lambs. Those CP quantity to metabolic weight ratio represent a concentration in diet of 170 g CP/kg diet DM for first 28 days of the growing-finishing period when lambs reach 30 kg live weight, and of 140 g CP/kg DM thereafter 28 days until harvest.

Conflict of interest statement

Author declare no conflict of interest.

References

AOAC, 2000. Official Methods of Analysis. Association of Official Analytical Chemists, Gaithersburg, MD.
Beauchemin, K.A., McClelland, L.A., Jones, S.D.M., Kozub, G.C., 1995. Effects of crude protein content, protein degradability and energy concentration of the diet on growth and carcass characteristics of market lambs fed high concentrate diets. Can. J. Anim. Sci. 75, 387–395.
Cannas, A., Tedeschi, L.O., Fox, D.G., Pell, A.N., Van Soest, P.J., 2004. A mechanistic model for predicting the nutrient requirements and feed biological values for sheep. J. Anim. Sci. 82, 149–169.
Canton, J.G., Quintal, J.A., 2007. Evaluation of growth and carcass characteristics of pure Pelibuey sheep and their cross with Dorper and Katahdin breeds. J. Anim. Sci. 85 (Suppl. 1), 581 (Abstr.).
Carrasco, R., Arrizon, A.A., Plascencia, A., Torrentera, N.G., Zinn, R.A., 2013. Comparative feeding value of distillers dried grains plus solubles as a partial replacement for steam-flaked corn in diets for calf-fed Holstein steers: characteristics of digestion, growth-performance, and dietary energetic. J. Anim. Sci. 91, 1801–1810.
Castro-Pérez, B.I., Garzón-Proaño, J.S., López-Soto, M.A., Barreras, A., González, V.M., Plascencia, A., Estrada-Angulo, A., Dávila-Ramos, H., Ríos-Rincón, F.G., Zinn, R.A., 2013. Effects of replacing dry-rolled corn with increasing levels of corn dried distillers grains with solubles on characteristics of digestion, microbial protein synthesis and digestible energy of diet in hair lambs fed high-concentrate diets. Asian-Australas. J. Anim. Sci. 26, 1152–1159.
Cravero, A.P., Morón-Jiménez, M.J., Ramón, A.N., 2003. Composición química y digestibilidad del mote. ALAN 53 (418), 424 (In Spanish).
Dabiri, N., Thonney, M.L., 2004. Source and level of supplemental protein for growing lambs. J. Anim. Sci. 82, 3237–3244.
Ebrahimi, R., Ahmadi, H.R., Zamiri, M.J., Rowghani, E., 2007. Effect of energy and protein levels on feedlot performance and carcass characteristics of Mehraban ram lambs, Pakistan. J. Biol. Sci. 15, 1679–1684.
Fluharty, F.L., McClure, K.E., 1997. Effects of dietary energy intake and protein concentration on performance and visceral organ mass in lambs. J. Anim. Sci. 75, 604–610.
Haddad, S.G., Nasr, R.E., Muwalla, M.M., 2001. Optimum dietary crude protein level for finishing Awassi lambs. Small Rum. Res. 39, 41–46.
Hadjipanayotou, M., 1982. Protein levels for *Chios* lambs given high concentrate diets. Ann. Zootech. 31, 269–278.
Hinkelmann, K., Kempthorne, O., 2008. Design and analysis of experiments, 2nd ed. Introduction to Experimental Design, vol. 1 John Wiley & Sons Hoboken, New Jersey.
Javed, S.I., Asif, J., Muhammad, A., 2010. Nutrient digestibility and feedlot performance of lambs fed diets variying protein and energy content. Trop. Anim. Health Prod. 42, 941–946.
Kaya, I., Unal, Y., Sahin, T., Elmali, D., 2009. Effect of different protein levels on fattening performance, digestibility and rumen parameters in finishing lambs. J. Anim. Vet. Adv. 8, 309–312.
Klemesrud, M.J., Klopfenstein, T.J., Lewis, J.A., 2000. Metabolizable methionine and lysine requirements of growing cattle. J. Anim. Sci. 78, 199–206.
Luaces, M.L., Calvo, C., Fernández, B., Fernández, A., Viana, J.L., Sánchez, L., 2008. Ecuaciones predictoras de la composición tisular de las canales de corderos de raza gallega. Arch. Zootec. 57, 3–14.
Ludden, P.A., Wechter, T.L., Hess, B.W., 2002. Effects of oscillating dietary protein on nutrient digestibility, nitrogen metabolism, and gastrointestinal organ mass in sheep. J. Anim. Sci. 80, 3021–3026.
Machado da Rocha, H.M., Susin, I., Pires, A.V., Fernández, J.S., Quirino, C.M., 2004. Performance of Santa Inés lambs fed diets of variable crude protein levels. Sci. Agric. 61, 141–145.
Manso, T., Mantecòn, A.R., Giraldez, F.J., Lavin, P., Castro, T., 1998. Animal performance and chemical body composition of lambs fed diets with different protein supplements. Small Rum. Res. 29, 185–191.
Muñoz-Osorio, G., Aguilar-Caballero, A.J., Sarmiento-Franco, L.A., Wurzinger, M., Camara-Sarmiento, R., 2016. Technologies and strategies for improving hair lamb fattening systems in tropical regions: a review. Ecosys. Agrop. Res. 3, 267–277.
NRC, 1985a. Nutrient Requirement of Sheep, 6th ed. National Academy Press, Washington, DC.
Ruminant Nitrogen Usage. National Academy Press, Washington, DC.
NRC, 2007. Nutrient Requirement of Small Ruminant. Sheep, Goats, Cervids, and New World Camelids. National Academy Press, Washington, DC.
Neville, T.L., Ward, M.A., Reed, J.J., Soto-Navarro, S.A., Julius, S.L., Borowicz, P.P., Taylor, J.B., Redmer, D.A., Reynolds, L.P., Caton, J.S., 2008. Effects of level and source of dietary selenium on maternal and fetal body weight, visceral organ mass, cellularity estimates, and jejunal vascularity in pregnant ewe lambs. J. Anim. Sci. 86, 890–901.
Partida, P.J.A., Martínez, L.R., 2010. Body composition in Pelibuey lambs in terms of feed energy concentration and slaughter weight. Rev. Vet. Mex. 41, 177–190.
Pineda, J., Palma, J.M., Haenlein, G.F.W., Galina, M.A., 1998. Fattening of Pelibuey hair sheep and crossbreds (Rambouillet-Dorset × Pelibuey) in the Mexican tropics. Small Rumin. Res. 27, 263–266.
Plascencia, A., Bermudez, R., Cervantes, M., Corona, L., Davila-Ramos, H., López-Soto, M.A., May, D., Torrentera, N., Zinn, R.A., 2011. Influence of processing method on comparative digestion of white corn *vs*. conventional steam-flaked yellow dent corn in finishing diets for feedlot steers. J. Anim. Sci. 89, 136–141.
Ríos, F.G., Gómez-Vázquez, A., Pinos-Rodríguez, J.M., García-López, J.C., Estrada-Angulo, A., Hernández-Bautista, J., Portillo, J.J., 2011. Effect of breed on performance and carcass characteristics of Mexican hair sheep. S. Afr. J. Anim. Sci. 41, 275–279.
Ríos-Rincón, F.G., Dávila-Ramos, H., Estrada-Angulo, A., Plascencia, A., López-Soto, M.A., Castro-Pérez, B.I., Calderón-Cortes, J.F., Portillo-Loera, J.J., Robles-Estrada, J.C., 2014. Influence of protein and energy level on growth performance: dietary energetics and carcass characteristics of feedlot hair lambs. Asian-Australas. J. Anim. Sci. 27, 55–60.
Ruiz-Nuño, A., Uribe-Gomez, J.J., Orozco-Hernandez, J.R., Fuentes-Hernandez, V.O., 2009. The effect of protein level concentrations in the diet of fattening Dorper and Pelibuey lambs. J. Anim. Vet. Adv. 8, 1049–1051.
Sánchez, F.C., Salinas, M.Y., Vázquez, G.M.C., Velázquez, G.G.A., Aguilar, G.N., 2007. Efecto de las prolaminas del grano de maíz (*Zea mays* L.) sobre la textura de la tortilla. ALAN 57, 295–301 (In Spanish).
SAS, 2007. User's Guide: Statistics Version 9, 6th ed. SAS Inst., Inc., Cary, NC.
Searle, T.W., Graham, N. McC., Donelly, J.B., 1982. The effect of plane of nutrition on the body composition of two breeds of wearier sheep fed a high protein diet. J. Agric. Sci. Camb. 98, 241–245.
Swanson, K.C., Redmer, D.A., Reynolds, L.P., Caton, J.S., 1999. Ruminally undegraded intake protein in sheep fed low-quality forage: effect on weight, growth, cell proliferation, and morphology of visceral organs. J. Anim. Sci. 77, 198–205.
Torrentera, N., Carrasco, R., Salinas-Chavira, J., Plascencia, A., Zinn, R.A., 2017. Influence of methionine supplementation of growing diets enriched with lysine on feedlot performance and characteristics of digestion in Holstein steer calves. Asian-Australas. J. Anim. Sci. 30, 42–50.
USDA, 1982. Official United States Standards for Grades of Carcass Lambs, Yearling Mutton and Mutton Carcasses. Agric. Marketing.
Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74, 3583–3597.
Wang, Y.J., Holligan, S., Salim, H., Fan, M.Z., McBride, B.W., Swanson, K.C., 2009. Effect of dietary crude protein level on visceral organ mass, cellularity, and the protein expression of ATP synthase Na^+/K^+-ATPase, proliferating cell nuclear antigen and ubiquitin in feedlot steers. Can. J. Anim. Sci. 89, 493–501.
Zinn, R.A., Shen, Y., 1998. An evaluation of ruminally degradable intake protein and metabolizable amino acid requirements of feedlot calves. J. Anim. Sci. 76, 1280–1289.
Zinn, R.A., Calderon, J.F., Corona, L., Plascencia, A., Montaño, F., Torrentera, N., 2007. Phase feeding strategies to meet metabolizable amino acid requeriments of calf-fed Holstein steers. Prof. Anim. Sci. 23, 333–339.
Zinn, R.A., Barreras, A., Owens, F.N., Plascencia, A., 2008. Performance by feedlot steers and heifers: ADG, mature weight, DMI and dietary energetics. J. Anim. Sci. 86, 1–10.
Zundt, M., Macedo, F.A.F., Martins, E.L., Mexia, A.A., Yamamnoto, S.M., 2002. Performance of lambs fed with different protein levels. Rev. Bras. Zoot. 31, 1307–1314.