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Effects of Combining Feed Grade Urea and a Slow-release Urea Product on Performance, Dietary Energetics and Carcass Characteristics of Feedlot Lambs Fed Finishing Diets with Different Starch to Acid Detergent Fiber Ratios

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ABSTRACT: Recent findings have shown that microbial nitrogen flow and digestible energy of diets are increased when urea is combined with a slow-release urea (SRU) in diets with a starch to acid detergent fibre ratio (S:F) 4:1. This affect is attributable to enhanced synchrony between ruminal N availability for microbial growth and carbohydrate degradation. To verify the magnitude of this effects on lamb performance, an experiment was conducted to evaluate the effects of combining urea and a SRU in diets containing S:F ratios of 3:1, 4:1, or 5:1 on performance, dietary energetics and carcass characteristics of finishing lambs. For that, 40 Pelibuey×Katahdin lambs (36.65±3 kg) were assigned to one of five weight groupings in 20 pens (5 repetition/treatments). The S:F ratio in the diet was manipulated by partially replacing the corn grain and dried distiller's grain with solubles by forage (wheat straw) and soybean meal to reach S:F ratios of 3:1, 4:1 or 5:1. An additional treatment of 4:1 S:F ratio with 0.8% urea as the sole source of non-protein nitrogen was used as a reference for comparing the effect of urea combination *vs.* conventional urea at the same S:F ratio. There were no treatment effects on dry matter intake (DMI). Compared the urea combination vs urea at the same S:F ratio, urea combination increased ($p<0.01$) average daily gain (ADG, 18.3%), gain for feed (G:F, 9.5%), and apparent energy retention per unit DMI (8.2%). Irrespective of the S:F ratio, the urea combination improved the observed-to-expected dietary ratio and apparent retention per unit DMI was maximal (quadratic effect, $p\leq 0.03$) at an S:F ratio of 4:1, while the conventional urea treatment did not modify the observed-to-expected net energy ratio nor the apparent retention per unit DMI at 4:1 S:F ratio. Urea combination group tended (3.8%, $p = 0.08$) to have heavier carcasses with no effects on the rest of carcass characteristics. As S:F ratio increased, ADG, G:F, dietary net energy, carcass weight, dressing percentage and *longissimus thoracis* (LM) area increased linearly ($p\leq 0.02$). Combining urea and a slow-release urea product results in positive effects on growth performance and dietary energetics, but the best responses are apparently observed when there is a certain proportion (S:F ratio = 4:1) of starch to acid detergent fibre in the diet. (**Key Words:** Slow-release Urea, Finishing Lambs, Growth Performance, Dietary Energetics, Carcass)

INTRODUCTION

A topic of interest in recent years in feedlots has been the search for strategies that optimise nutrient synchrony between N and carbohydrate compounds in the rumen in order to promote better nutrient utilisation and energy efficiency, and as a strategy for reducing the risk of environmental pollution (Hristov et al., 2011). The N retention in the rumen is mainly mediated by the rate of degradation of N compounds and carbohydrates, and by the energy available for the process of protein synthesis (Tedeschi et al., 2002). It has been observed that in high-grain diets (ratio of starch vs acid detergent fibre (ADF) greater than 5 to 1), urea can be supplemented at 50% higher than

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that recommended with positive effects on growth performance or in dietary energy utilisation (Milton et al., 1997; Zinn et al., 2003). The latter can be partially explained by the possible synchrony of ruminal degradation rates between feed-grade urea and starch. On the other hand, in cattle that were fed a high-forage diet (>10% ADF, i.e. rations for dairy and growing cattle), the use of slow-release urea products improved nutrient synchrony (Inostroza et al., 2010; Alvarez-Almora et al., 2011). Currently, as a result of the cost of corn grain, the replacement of corn grain by dried distillers grain with solubles (DDGS) in feedlot diets is a common practice (Klopfenstein et al., 2008). Although the energy value of DDGS is similar to corn grain (NRC, 2007; Estrada-Angulo et al., 2013), DDGS are lower in starch content (<6%) and higher in their content (>30%) of digestible fibre (Rosentrater, 2011; Carrasco et al., 2013). Therefore, depending on the replacement level, the starch:fibre ratio in finishing diets can be decreased (i.e. from 5.0 to 3.0). In growing–finishing diets, the few studies conducted in this field have been focused on evaluating the effect of SRU in direct substitution of high-protein ingredients (Pinos-Rodríguez et al., 2010; Bourg et al., 2012; Lascano et al., 2012) rather than as a strategy to promote synchrony, and no research has examined the role of the starch:fibre ratio of the finishing diets on the effects of the combination of both sources of urea on lambs growth performance and dietary energetics. Recent findings in a digestion trial showed that when conventional urea was combined with a SRU in diets with a ratio of starch-to-acid detergent fibre (S:F) of 4:1, the digestible energy (DE) was improved by 2% over the expected (p = 0.04) level; while, according to the expected DE values, the predicted DE was 1.00 time to the expected values with urea plus SRU in diets with lower (3:1) or greater (6:1) S:F ratios, and for those that were fed with only urea in diets with a similar ratio of 4:1 (López-Soto et al., 2014). Similarly, increases of 6% on net energy (NE) of diet was observed in feedlot cattle when were fed with a diet with a S:F ratio of 4.5 supplemented with a urea combination, while diets with conventional urea did not modify the observed-to-expected NE ratio when was included in diets with an identical S:F ratio (López-Soto et al., 2015). This is surprising, if is considers that different responses of animals can be caused not only by different sources of urea supplementation but also by dietary variations (i.e. rumen undegradable intake protein level); however, the differences on observed-to-expected DE and dietary NE obtained by Lopez-Soto et al. (2014; 2015) between SRU and for those that were fed with only urea in diets with a similar ratio of S:F justifies the need to confirm these results in a lamb performance trial. To test the findings of Lopez-Soto et al. (2014; 2015) on the impact on the dietary energetics, the objectives of this experiment was to examine, in feedlot lambs, the magnitude of the responses on dietary energetics with combining urea and a SRU in diets containing different (3:1, 4:1, or 5:1) S:F ratios.

MATERIALS AND METHODS

This experiment was conducted at the Universidad Autónoma de Sinaloa Feedlot Lamb Research Unit, located in Culiacán, Mexico (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 mobilisation of animals; NOM-062-ZOO-1995: technical specifications for the care and use of laboratory animals. Livestock farms, farms, centres 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).

Animals, diet, and experimental design

Fifty Pelibuey×Katahdin lambs were received at the research facility before initiation of the experiment. Upon arrival, the lambs were treated for parasites (Tasasel 5%, Fort Dodge, Animal Health, Mexico) and injected with 1×10^6 IU vitamin A (Synt-ADE, Fort Dodge Animal Health). For 2 weeks before the initiation of the experiment, lambs were fed the reference diet (without slow-release urea). Following a 2-week evaluation period, lambs were weighed individually before the morning meal (electronic scale; TORREY TIL/S: 107 2691, TORREY electronics Inc., Houston TX, USA) and 40 lambs (36.65±3 kg) were selected from the original group of 50 lambs for use in the study, based on the uniformity of weight and general condition and were assigned to one of five weight groupings in 20 pens, with two lambs per pen. Pens were 6 m^2 with overhead shade, automatic waterers and 1-m fence-line feed bunks. Dietary treatments were randomly assigned to pens within blocks. Four treatments were tested using urea and urea and slow-release urea combination in diets with different S:F ratios. The S:F ratio in the diet was manipulated by partially replacing the corn grain and DDGS by forage (wheat straw) and soybean meal to reach S:F ratios of 3:1, 4:1, or 5:1. The slow-release urea product used was a polymer-coated urea that contains 41% N (SRU, Optigen II; Alltech Mexico, Guadalajara, Jalisco, Mexico). Based on the hypothesis that a combination of feed-grade urea with slow-release urea in finishing diets promotes synchrony between ruminal N availability and carbohydrate digestion, the combination of urea and SRU (as a percentage of dry matter [DM] in the diet) was performed based on S:F ratios as follows: i) 0.80 U and 1.00% SRU for 3:1 S:F ratio

(U+SRU3); ii) 0.80 U and 0.80% SRU for 4:1 S:F ratio (U+SRU4); and iii) 1.00 U and 0.80% SRU for 5:1 S:F ratio (U+SRU5). An additional treatment of 4:1 S:F ratio with 0.8% urea (U4) as the sole source of non-protein nitrogen (NPN) was used as a reference for comparing urea combination vs conventional urea at the same S:F ratio.

The relative differences in protein concentration between the U4 diet and the U+SRU4 diet was 0.90% (14.01% vs 15.40% crude protein). Although, it is well recognized that when the diet contains more than 1.95 Mcal of net energy of maintenance (NE_m)/kg, increasing protein level above of 14% has no additional beneficial effects on the productive performance of finishing lambs (Ríos et al., 2014), it is important to consider that different responses of animals can be caused not only by different sources of urea supplementation but also by dietary variations (i.e. UIP level). Ingredients and chemical composition of dietary treatments are shown in Table 1. The experiment lasted 56 days and lambs were weighed at the beginning of the trial, at day 28 and in the end of the experiment. The initial body weight (BW) was converted to shrunk body weight (SBW) by reduction of 4% of BW to adjust for the gastrointestinal fill (Cannas et al., 2004), and all lambs were fasted (food but not drinking water was withdrawing) for 18 h before recording the final BW. Lambs were allowed *ad libitum* access to dietary treatments. Daily feed allotments to each pen were adjusted to allow minimal (<5%) feed refusals in the feed bunk. The amount of feed offered and of feed refused was weighed daily. Lambs were provided fresh feed twice daily at 0800 and 1400 hours. Feed bunks were visually assessed between 0740 and 0750 hours each morning, refusals were collected and weighed, and feed intake was determined. Adjustments to either increase or decrease daily feed delivery was provided at the afternoon feeding. Feed and refusal samples were collected daily for DM analysis, which involved oven drying the samples at 105°C until no further weight loss occurred (method 930.15; AOAC, 2000).

Feed analyses

Feed was subjected to the following analysis: DM (oven drying at 105°C until no further weight loss; method 930.15; AOAC, 2000); ash (method 942.05; AOAC, 2000), Kjeldahl N (method 984.13; AOAC, 2000); ADF (Van Soest et al., 1991); starch (Zinn, 1990); calcium (method 927.02; AOAC,

Table 1. Ingredients and composition of experimental diets

Item	Treatments[1]			
	U4	U+SRU3	U+SRU4	U+SRU5
Ingredient composition (% DMB)				
Steam flaked corn	60.00	55.00	60.00	65.00
DDGS	8.00	6.00	8.00	13.00
Soybean meal	5.00	5.00	4.00	0.00
Wheat straw	12.00	18.00	12.00	6.00
Urea	0.80	0.80	0.80	1.00
Optigen 1200[2]	-	1.00	0.80	0.80
Cane molasses	9.70	9.50	9.60	9.40
Yellow grease	2.20	2.50	2.50	2.50
Trace mineral salt[3]	0.50	0.50	0.50	0.50
Limestone	1.80	1.70	1.80	1.80
NE concentration[4] (Mcal/kg of DM basis)				
Maintenance	2.00	1.89	1.99	2.10
Gain	1.34	1.26	1.34	1.43
Nutrient composition (% of DM)[5]				
Crude protein	14.01	15.70	15.40	15.84
Starch	42.62	38.77	42.10	45.12
ADF	10.71	13.07	10.52	8.53
Calcium	0.78	0.76	0.80	0.79
Phosphorus	0.35	0.32	0.35	0.41

U, urea; SRU, slow-release urea; DMB, dry matter basis; DDGS, dried distillers grain with solubles; NE, net energy; DM, dry matter; ADF, acid detergent fibre; NE_m, net energy of maintenance; NE_g, net energy of gain.

[1] Please describe the treatments.

[2] Optigen-II. Alltech de México, Guadalajara Jalisco, Mexico.

[3] Trace mineral salt contained: $CoSO_4$, 0.068%; $CuSO_4$, 1.04%; $FeSO_4$, 3.57%; ZnO, 1.24%; $MnSO_4$, 1.07%; KI, 0.052%; NaCl, 92.96%.

[4] Based on tabular NE values for individual feed ingredients (NRC, 2007) with the exception of supplemental fat, which was assigned NE_m and NE_g values of 6.03 and 4.79, respectively (Zinn, 1988).

[5] Dietary composition was determined by analyzing subsamples collected and composited throughout the experiment. Accuracy was ensured by adequate replication with acceptance of mean values that were within 5% of each other.

2000) and phosphorus (method 964.06; AOAC, 2000).

Calculations

The estimations of dietary energetic and expected dry matter intake (DMI) were performed based on the average obtained of estimated initial SBW and observed final SBW. Average daily gains (ADG) were computed by subtracting the initial BW from the final BW and dividing the result by the number of days on feed. The efficiency of BW gain was computed by dividing ADG by the daily DMI. The estimation of expected DMI was performed based on observed ADG and 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, 1985), EG (energy gain, Mcal/d) = $0.276\times ADG\times SBW^{0.75}$ (NRC, 1985), NE_m and net energy of gain (NE_g) are energy concentrations of experimental diets (derived from tabular values based on the ingredient composition of the experimental diet; NRC, 1985). The apparent retention per unit of DM was estimated by dividing the observed DM intake over expected DMI. The coefficient (0.276) was estimated assuming a mature weight of 113 kg for Pelibuey×Katahdin male lambs (Canton and Quintal, 2007). From the derived estimates of energy required for maintenance and gain, the NE_m and NE_g values of the diet were obtained using the quadratic formula: $x = (-b-\sqrt{b^2-4ac}\ /2c$, where $a = -0.41EM$, $b = 0.877EM+0.41DMI+EG$, and $c = -0.877DMI$, and $NE_g = 0.877\ NE_m-0.41$ (Zinn et al., 2008).

Carcass data

The hot carcass weights (HCW) were obtained from all lambs at time of harvest. 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: i) body wall thickness (distance between the 12th and 13th ribs beyond the ribeye, five inches from the midline of the carcass); ii) fat thickness perpendicular to the *m. longissimus thoracis* (LM), measured over the centre of the ribeye between the 12th and 13th ribs; iii) LM surface area, measured using a grid reading of the cross-sectional area of the ribeye between the 12th and 13th ribs; and iv) kidney, pelvic and heart fat (KPH). The KPH was removed manually from the carcass, and then weighed and is reported as a percentage of the cold carcass weight (USDA, 1982).

Statistical analyses

Performance (gain, gain efficiency, and dietary energetics) and carcass data were analysed as a randomised complete block design. The experimental unit was the pen. The MIXED procedure of SAS (SAS Institute, 2004) was used to analyse the variables. The fixed effect consisted of treatment, and pen as the random component. Three contrasts were defined to answer: i) the effect of urea combination vs reference diet (urea at same S:F ratio, 4:1), ii) linear response of the S:F ratio in urea combination treatments, iii) quadratic response of the S:F ratio in urea combination treatments. F-test (numerator = 1 df, denominator = error df) was utilized to test contrasts. The analysis was carried out using SAS (SAS Inst., Inc., Cary, NC, USA; Version 9.1). 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.

RESULTS

According to the determinations of starch and ADF obtained in the laboratory, the starch:ADF ratio reached 100%, 99%, 100% and 106% of that planned for each treatment (Table 1). Treatment effects on growth performance of feedlot lambs are shown in Table 2.

Across the entire 56-day period, the average observed-to-expected DMI of lambs fed the reference diet was 102% of the expected value, based on tabular (NRC, 2007) estimates of diet energy density and observed SBW and ADG values (Table 2), which supports the suitability of the prediction equations proposed by the NRC (1985) for the estimation of DMI in relation to SBW and ADG in feedlot lambs. We expect that dietary NE ratio (observed-to-expected) would be to 1 this mean that animals were performed as expected. Or stated differently, animals performance is consistent with DMI and dietary energy density (NRC). If ratio is greater than 1, the observed dietary NE represent a greater value (concentration) than expected according to NRC, therefore the energy was better utilized by the animal, thus, the efficiency was improved. In contrast, if ratio is less than 1, energetic efficiency was less than expected (contrary to the observed:expected DMI in which values greater than 1 represent lower efficiencies.

There were no effects of the urea combination or SF ratio on DM intake. Even when the diets that contain the same proportion of S:F ratio contained the same amount of available energy (Table 1), with urea combination the ADG, gain for feed, and apparent energy retention per unit DMI were increased (p<0.01) by 18.3%, 9.5%, and 8.2%, respectively.

Irrespective of the S:F ratio, the urea combination improved the observed-to-expected dietary ratio and apparent retention per unit DMI was maximal (quadratic effect, p≤0.03) at an S:F ratio of 4:1, while the urea treatment did not modify the observed-to-expected NE ratio nor the apparent retention per unit DMI at 4:1 S:F ratio. In contrast with lambs fed the reference diet (urea at 4 S:F ratio), lambs fed with dietary treatments containing combination of urea with SRU at the same S:F ratio (4 S:F), tended (3.8%, p = 0.08) to have heavier carcasses with no effects on carcass

Table 2. Influence of treatments on growth performance and dietary energy of lambs

Item	Treatments[1]				SEM	S:F ratio[2]		
	U4	U+SRU3	U+SRU4	U+SRU5		U4 vs U+USR4	Linear	Quadratic
Pen replicates	5	5	5	5				
Days on feed	56	56	56	56				
Weight (kg) [3]								
Initial	36.61	36.49	36.75	36.73	0.21	0.66	0.42	0.60
Final	49.89	49.30	52.34	52.42	0.64	0.02	<0.01	0.09
Average daily gain (kg)	0.235	0.229	0.278	0.280	0.013	0.04	0.02	0.15
Dry matter intake (kg)	1.237	1.257	1.335	1.295	0.046	0.16	0.57	0.31
Gain for feed (kg/kg)	0.190	0.180	0.208	0.216	0.006	<0.01	<0.01	0.03
Dietary net energy (Mcal/kg)[4]								
Maintenance	2.03	1.98	2.15	2.21	0.02	0.01	<0.01	0.03
Gain	1.37	1.33	1.48	1.53	0.02	0.01	<0.01	0.03
Observed to expected dietary ratio[5]								
Maintenance	1.02	1.04	1.08	1.05	0.01	<0.01	0.42	0.03
Gain	1.02	1.05	1.10	1.06	0.01	<0.01	0.60	0.02
Apparent energy retention per unit DMI[6]	0.98	0.94	0.90	0.94	0.01	<0.01	0.57	0.01

U, urea; SRU, slow-release urea; SEM, standard error of the mean; DMI, dry matter intake; BW, body weight; NE, net energy; ADG, average daily gain; DMI, dry matter intake; NE_m, net energy of maintenance; NE_g, net energy of gain.

[1] U4 = 0.80% U for 4 S:F ratio; U+SRU3 = 0.80 U and 1.00% SRU for 3 S:F ratio; U+SRU4 = 0.80 U: 0.80% SRU for 4 S:F ratio; U+SRU5 = 1.00 U and 0.80% SRU for 5 S:F ratio.

[2] Proportion of starch to fibre acid detergent in diet.

[3] The initial BW was reduced by 4% to adjust for the gastrointestinal fill, and all lambs were fasted (food but not drinking water was withdrawing) for 18 h before recording the final BW.

[4] The estimation of dietary NE was performed based on observed ADG, DMI and average shrunk weight (SBW) and was estimated by means of the quadratic formula: $x = (-b\pm\sqrt{b^2-4ac})/2c$, where $x = NE_m$, $a = -0.41EM$, $b = 0.877$ EM+0.41 DMI+EG, and $c = -0.877$ DMI, where EM = maintenance coefficient of 0.056 Mcal/$BW^{0.75}$ (NRC, 1985), EG is the daily energy deposited (Mcal/d) estimated by equation: EG = ([0.276×ADG]×$SBW^{0.75}$; NRC, 1985), and DMI is the average daily dry matter intake (Zinn et al., 2008).

[5] Observed to expected dietary NE ratio was computed by dividing NE observed between expected diet NE, which was estimated based on tabular values for individual dietary ingredients (NRC, 2007).

[6] Expected DMI was performed based on observed ADG, average shrunk weight (SBW) and the calculated NE diet and was computed as follows: DMI, kg/d = (EM/NE_m)+(EG/EN_g), where EM = maintenance coefficient of 0.056 Mcal/$BW^{0.75}$ (NRC, 1985) and EG is the daily energy deposited (Mcal/d) estimated by equation: EG = ([0.276×ADG]×$SBW^{0.75}$, NRC, 1985). The divisors NE_m and NE_g are the NE of diet (Table 1, calculated from tables of composition of feed [NRC, 2007]).

characteristics.

As energy concentration (S:F ratio) increased in diet, ADG, G:F, dietary NE, carcass weight, dressing percentage and LM area increased linearly (p≤0.02).

DISCUSSION

Urea combination effects on growth performance and dietary energy of diet

The absence of the effects on feed intake as a consequence of the supplementation of combination of urea plus SRU have been observed previously in finishing lambs when lambs were fed with a 50:50 forage:concentrate diet (Moura et al., 2014) and in steers when they were fed a finishing diet (>70% concentrate; Tedeschi et al., 2002; Pinos-Rodríguez et al., 2010; Castañeda-Serrano et al., 2013). However, a tendency for a reduction in the DMI has been observed in some studies when feedlot cattle were supplemented with protected urea or with combinations of SRU plus urea (Huff et al., 2000; Taylor-Edwards et al., 2009). The basis for the inconsistencies in the DMI responses to SRU supplementation is not clear, but may be related to the taste of SRU products and/or diet composition (i.e. inclusion of high levels of corn silage).

There is limited information concerning the effects of SRU on growth performance and dietary energetics in lambs; however, improvements in feed efficiency in finishing steers supplemented with SRU have been previously reported (Huff et al., 2000). Similarly, combining conventional urea with slow-release urea has been reported to promote milk production (Akay et al., 2004). Changes in productivity and/or energy efficiency can be partially explained by improvements in nutrient synchrony between N and carbohydrate compounds in the rumen and greater N retention (decreases in ruminal ammonia concentration and increases in the flow of microbial N to the duodenum). However this is not to be confused with the popular notion that rate of soluble feed N release to the rumen be in synchrony with carbohydrate fermentation. Numerous studies have proved the concept indefensible. Providing adequate ruminal available N, irregardless of the rate at which it is degraded or solubilized within the rumen, is the relevant factor affecting microbial protein synthesis. Irregardless of source (NPN or intact protein), microbial protein synthesis is maximal when degradable intake protein is roughly 10% of digestible organic matter intake (Zinn and Shen, 1998). This effect is due to N recycling to the rumen (Calsamiglia et al., 2010). Conversely, López-Soto et al. (2014) showed that steers fed a combination of urea and slow-release urea (using the same source of SRU) with an S:F ratio of 4:1 had higher (p = 0.04) flows of microbial N and DE of the diet than those fed urea at the same S:F ratio, or those fed urea plus SRU in diets with 3:1 and 6:1 S:F ratios. In studies conducted with steers (Tedeschi et al., 2002; Pinos-Rodríguez et al., 2010), the urea combination did not affect growth performance or digestibility of the diet. Based on the experimental diets of the study of Tedeschi et al. (2002), the estimated S:F ratio of their experimental diets was 14:1, while in the study conducted by Pinos-Rodríguez et al. (2010), the estimated S:F ratio of the diets was 5.4:1. Thus, the high S:F ratios of the diets used in the studies conducted by Tedeschi et al. (2002) and by Pinos-Rodriguez et al. (2010) could be a factor, as in the present experiment, in the lack or small effects on performance and feed efficiency of steers fed a urea combination.

Irrespective of the S:F ratio, the urea combination improved the observed-to-expected dietary ratio and apparent retention per unit DMI. According to the expected NE values (NRC, 2007), the observed dietary NE was 1.02 for lambs fed the reference diet, and 1.04, 1.08, and 1.05 times the expected values for the urea combinations at 3 S:F, 4 S:F, and 5 S:F ratios, respectively. At a 4 S:F ratio, the observed NE value in the urea combination treatment was improved on average by 4% compared to the rest of the urea combination treatments. It is important to consider that different responses of animals can be caused not only by different sources of urea supplementation but also by dietary variations (UIP level among others). However, in a growth-performance study conducted with feedlot steers, Lopez-Soto et al. (2015) with a similar urea combination as in the present experiment in a diet with a S:F ratio of 4.5 observed a 6% of increases on NE of diet and decreases of 6% on the apparent retention per unit DM, while diets with conventional urea did not modify neither the observed-to-expected NE ratio nor the apparent retention per unit DMI, when was included in diets with a S:F ratios of 3, 4.5, and 5.5. It has been observed that in high-grain diets (ratio of starch vs ADF greater than 5 to 1) urea can be supplemented at 50% higher than that recommended with positive effects on growth performance and in dietary energy utilisation (Milton et al., 1997; Zinn et al., 2003). Those researchers argued that those results can be partially explained by the possible synchrony of ruminal degradation rates between urea and starch. At lower S:F ratios it is expected a lower positive effects, therefore, absence of improves of observed NE ratio over expected in urea treatment at 4:1 S:F ratio is not aberrant (observed-to-expected DMI = 0.98), as mentioned above, absence of improvements of observed NE ratio over expected (averaging 0.98) with conventional urea supplementation in diets with S:F ratios of 3, 4.5, and 5.5 was previously reported (López-Soto et al., 2015). The observed-to-expected dietary energy and intake are an important and practical application of current standards for energetics in nutrition research (Zinn et al., 2008). Based on diet composition and growth performance, there is an expected energy intake and hence an expected of DMI (NRC, 1985). The estimation of dietary energy and the ratio of observed-to-expected DMI (apparent energy retention per unit DMI) revealed differences on the efficiency of energy utilisation of the diet itself. In the present experiment, the greatest improvement in the observed-to-expected DMI and dietary NE of the combination urea treatments was at 4:1 S:F ratio. Starch and fibre at these proportions provide an energetic advantage when they were supplemented with the urea combination. For example, if considering the same diet composition between the reference diet (U4) and U+SRU4 treatments (Table 1), then——compared with the reference diet—the energy improvement in the U+SRU4 treatment represents an equivalent increase of 5.3% ([2.15-2.03]/2.24) corn grain in the diet. This could support the theory that the S:F ratio is the most important factor that impacts on the synchrony when urea and SRU are combined, rather than the energy level *per se*.

S:F ratio effects on growth performance and dietary energy of diet

The energy level (S:F ratio) did not affect the DMI. In high-energy diets, ME intake, rather than physical fill, appeared to be the dominant factor influencing the DMI. Lu and Potchoiba (1990) observed a curvilinear response in goats when comparing three levels of energy (1.66, 1.86, and 2.06 Mcal NE_m/kg DM) in diets. However, consistent with our results, other studies (Mahgob et al., 2000; Sheridan et al., 2000; Loe et al., 2004) did not find any effect on DMI in finishing lambs when comparing diets from 1.90 up to 2.16 Mcal NE_m/kg, which is similar to the range of energy density for the three S:F ratio treatments used in the present study (Table 1).

Increases in feed efficiency have been a common response when comparing high-energy and low-energy diets (NRC, 2007; Kioumarzi et al., 2008; Adbel-Basset, 2009). However, the effects of increased dietary energy levels on the ADG have been less consistent. In some instances (Lu and Potchoiba, 1990; García et al., 2003), increasing the energy level had no effect on the ADG, whereas in others

Table 3. Treatment effects on carcass characteristics

Item	Treatments[1]				SEM[2]	S:F ratio[2]		
	U4	U+SRU3	U+SRU4	U+SRU5		U4 vs U+SRU4	Linear	Quadratic
Hot carcass weight (kg)	29.79	28.45	30.97	31.16	0.43	0.08	<0.01	0.05
Cold carcass weight (kg)	29.44	28.13	30.68	30.83	0.42	0.06	<0.01	0.04
Drip loss (%)	1.18	1.03	0.95	1.09	0.16	0.34	0.80	0.59
Dressing percent	59.66	57.66	59.17	59.44	0.45	0.46	0.02	0.28
Longissimus muscle area (cm^2)	15.21	14.63	14.88	16.82	0.51	0.65	0.02	0.20
Backfat thickness (mm)	2.52	2.53	2.66	2.61	0.25	0.69	0.82	0.78
Kidney-pelvic fat (%)	2.84	2.56	2.90	3.08	0.21	0.85	0.09	0.73
Body wall thickness (mm)	13.81	13.42	13.43	13.81	0.50	0.61	0.59	0.77

U, urea; SRU, slow-release urea; SEM, standard error of the mean.

[1] U4 = 0.80% U for 4 S:F ratio; U+SRU3 = 0.80 U and 1.00% SRU for 3 S:F ratio; U+SRU4 = 0.80 U: 0.80% SRU for 4 S:F ratio, and U+SRU5 = 1.00 U and 0.80% SRU for 5 S:F ratio.

[2] Proportion of starch to fibre acid detergent in diet.

(Kioumarzi et al., 2008; Adbel-Basset, 2009), an increase in energy level markedly increased the ADG. The latter could be explained by the strong relationship between DMI and the dietary energy density (Cannas et al., 2004).

Treatments effects on carcass characteristics

The treatments effects on the carcass characteristics are shown in Table 3. There is limited information concerning the effects of SRU on carcass characteristics in lambs, but, consistent with previous findings with steers (Duff et al., 2000; Pinos-Rodríguez et al., 2010), urea combinations that replace soybean meal did not affect carcass characteristics. The linear increases in HCW and dressing percentage as a result of an increased S:F ratio is likely to be due to a concomitant linear increase in the ADG (Block et al., 2001). In the same manner, increased LM area has been a consistent response to increased rate of ADG in steers (Zinn et al., 2007).

Combining urea and a slow-release urea product results in positive effects on growth performance and dietary energetics, but the best responses are apparently observed when there is a certain proportion (S:F ratio = 4:1) of starch to ADF in the diet. When the S:F ratio increases or decreases, the level of response decreases. Further studies are needed to determine the conditions of the finishing diet so that it is possible to get the best response from the use of slow-release urea.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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