Effects of different methionine to lysine ratios in starter feed on growth, blood, digestive traits, and carcass traits in goat kids

Hsin-Tai Hong, Chun-Yun Wu, Tsung-Hsien Hsu, and Chean-Ping Wu

ABSTRACT
The purpose of this study was to assess the effects of the methionine-to-lysine ratio (MLR) in a low-protein (17%) starter on the growth, blood, digestive traits, and carcass traits of goat kids. Forty-five goat kids were assigned to one of three different starter groups (MLR): A (0.29), B (0.31), or C (0.33). During the six-week trial, growth and blood parameters were evaluated every 2 weeks, and digestive traits were evaluated from 0 to 14 days during the treatment. At the end of the treatment period, five goat kids from each group were slaughtered to measure their carcass traits. Results showed no significant growth differences among the groups. Blood parameters were in a normal range and without significant differences. There were no significant differences in digestive traits among the three groups. For carcass traits, group C had significantly higher carcass and heart weights ($P < 0.05$). In conclusion, adjusting the MLR from 0.29–0.33 in 17% crude protein starter had no negative effect on goat kids. This approach may not only decrease feed costs and reduce nitrogen emission to achieve environmental benefits, but also increase feeding efficiency.

Introduction

Goats are an important source of food and economic resource in developed and developing countries and are particularly important in undeveloped countries. Apart from the protein demands of goats, the design of a diet formulation for goats should include consideration of the protein level and microbial proteins synthesized in the rumen. According to a previous study, providing a high-protein diet may not improve growth but instead may reduce the utilization rate of nitrogen and contribute to environmental pollution (Morse 1995), whereas a lower protein diet reduces nitrogen emission and improves nitrogen utilization.

Mammals that consume high levels of dietary protein exhibit growth dysplasia due to hypogenesis in their intestinal systems (Opapeju et al. 2009). Additionally, negative effects such as aplasia of the gut and poor stomach development can occur when an animal is weaned from a high-protein diet. In dairy cattle, excessive nitrogen can decrease productive performance, which negatively affects nutritional utilization in milk production, reproductive performance, and economic benefits and contributes to environment pollution (Klopfenstein et al. 2002). In beef cattle, excess protein may increase costs and decrease profits and the utilization of nitrogen.

Several studies have investigated nutrient composition in livestock diets. For example, Sinclair et al. (2014) found a significantly positive correlation of 14% to 22% between crude protein (CP) and dry matter (DM) intake in ruminants. Hristov (2009) found that lowering the level of dietary protein in dairy cattle effectively improves protein utilization. In goat kids, Negesse et al. (2001) considered feed intake and found that body weight gain increased with high CP in the range 8.7%–17.6%. Atti et al. (2004) suggested that the optimum CP level in concentrate for growing goats was approximately 130 g/kg DM (13%), and levels lower (10%) or higher (16%) than that did not improve meat production. Furthermore, Hwangbo et al. (2009) suggested that an adequate CP level in the total mixed ration for achieving optimal growth performance and meat quality of growing Korean black goats might be 18% of DM. Furthermore, the utilization of nitrogen in goat kids is optimal when the CP proportion is 12%.

Bahrami-Yekdangi et al. (2014) suggested that optimizing the utilization of nitrogen should be the first goal in dietary protein application. The National Research Council (2007) suggests that 18%–20% of CP, which can increase the body weight of weaned goat kids by 100–200 g/day, should be used. Further, the Council states that the nitrogen content in commercial starter, which typically has 22% of CP, is above the required amount. By meeting the animal’s amino acids requirements without overfeeding, the efficiency of protein utilization can be maximized (Klemesrud et al. 2000). Consequently, recent efforts have focused on lowering the protein level to adjust the balance of amino acids and improve protein utilization in goat kids.

According to the Cannikin Law, an imbalance of amino acid quantities in ruminants could decrease growth performance or
increase nitrogen emissions. Kerr et al. (2003) found that various amino acids, particularly essential amino acids, are lacking when protein levels are decreased. Therefore, supplying essential amino acids is a feasible approach for lowering dietary protein levels (Tuitoek et al. 1997). Adding essential amino acids to the feed can also increase the feed conversion rate (FCR), decrease feed costs, and beneficially affect the environment. Tuitoek et al. (1997) suggested that adding crystalline amino acids can confer the same benefits. For goats fed a corn grain/soybean meal/maize stover diet, methionine is likely the most limited amino acid, followed by lysine and leucine (Shan et al. 2007).

Hill et al. (2008) found that a methionine-to-lysine ratio (MLR) of 0.31 in milk replacer has the most favourable effect on growth performance in 5-week-old calves; for calves fed milk replacer, starter, and hay, the optimal MLR is 0.30 (Wang et al. 2012). Feed with 16.8% protein and a 3.0 MLR increases meat redness in reared Friesian steers, and a 3.4 MLR improves the carcass rate (Prado et al. 2014). It has been predicted that an MLR of 3.4 in the diet is suitable for balancing animal growth. In weaned piglets, the maximum growth performance was observed at a dietary MLR of 0.275 from days 0–21 post-weaning (3.5–12 kg body weight; Owen et al. 1995). However, few studies have examined the balance of amino acids in goat kid starters; thus, the aim of this study was to estimate the effect of the MLR in low-protein starter on the growth, blood, digestive traits, and carcass traits of goat kids.

Materials and methods

We used 45 male eight-week-old goat kids obtained from the Animal Research Farm, National Chiayi University, Taiwan. The experiment was approved by the ethics committee of the Institutional Animal Care and Use Committee of National Chiayi University. The experiments complied with the Guide for the Care and Use of Laboratory Animals. The treatments were conducted according to the Affidavit of Approval of Animal Use Protocol.

Animal management

All goat kids were housed in individual pens (65 × 60 × 50 cm³/pen), which were 95 cm from the ground. Milk replacer (Victoria Whole Milk Powder, Victoria, Australia) was mixed with warm water (1:7; approximately 40°C), and kids were fed 800 mL/day milk replacer at 8:00 and 17:00 for 6 weeks.

The goat kids were randomly allocated to one of three different starter groups: A (0.29 MLR), B (0.31), or C (0.33). The levels of protein and MLR in the basal starter were 17% and 0.33, respectively. To adjust the MLR, an MLR of 0.31 was added to 0.053% synthetic lysine (L-lysine, CJ Corporation, Seoul, Korea), and a 0.29 MLR was added to 0.115% synthetic lysine. The starter composition is shown in Table 1. Starter and water were available ad libitum. We recorded the starter intake of each kid every day, and each kid was weighed once every two weeks. Two trial periods (H block and L block) were included because of the birth timings of the goat kids. We consolidated the data from the two birthing periods.

| Table 1. Ingredients in the treatment starter. |
|-----------------------------------------------|
| Ingredients (% fresh basis) | A⁰ | B¹ | C¹ |
| Corn grain | 64 | 64 | 64 |
| Wheat bran | 4 | 4 | 4 |
| Molasses, cane | 4 | 4 | 4 |
| Soybeans, full-fat | 19.2 | 19.2 | 19.2 |
| Soybean meal | 2 | 2 | 2 |
| S + M+F² | 2.5 | 2.5 | 2.5 |
| Dicalcium phosphate | 0.5 | 0.5 | 0.5 |
| Calcium carbonate | 2.0 | 2.0 | 2.0 |
| Salt | 0.5 | 0.5 | 0.5 |
| Mineral and vitamin premix | 1.1 | 1.1 | 1.1 |
| Antioxidants | 0.2 | 0.2 | 0.2 |
| Synthetic lysine³ | 0.115 | 0.053 | 0 |
| Chemical composition (NRC) | | | |
| Crude protein⁴ | 17 | 17 | 17 |
| Metabolizable energy (Kcal/kg) | 3037.18 | 3037.18 | 3037.18 |
| Calcium⁵ | 1.006 | 1.006 | 1.006 |
| Phosphorus⁴ | 0.523 | 0.523 | 0.523 |
| Lysine⁴ | 0.885 | 0.823 | 0.770 |
| Methionine⁶ | 0.257 | 0.257 | 0.257 |
| Met/Lys ratio | 0.29 | 0.31 | 0.33 |

⁰Starter groups (Met-to-Lys ratios): A (0.29), B (0.31), and C (0.33). ¹Probiotic fermentation product. ²L-lysine crystalline powder, CJ Corporation. ³S + on dry matter basis.

Blood parameters

Blood samples were collected during weight measurement for subsequent analysis. To determine the health status of the kids, we exsanguinated the jugular vein of the goat kids and analyzed glucose (Glu), γ-glutamyl transferase (γ-GT), total protein (TP), albumin (Alb), globulin (Glo), ratio of albumin to globulin (A/G), and blood urine nitrogen (BUN) using a blood chemistry analyzer (LST008AS, Hitachi, Tokyo, Japan).

Digestion traits

Digestibility measurements were conducted as described by Elamin et al. (2012), with slight modifications. Twenty-four goat kids (12 weeks old, 8 from each MLR group) were adapted to cages for 7 days, and a 7-day collection period followed. The starter and water were offered ad libitum. Feed was offered twice per day at 8:30 and 17:00, and refused feed was withdrawn. Feces were collected daily and weighed. At the end of the collection period, dried feces samples were combined, and a representative sample was taken for proximate chemical analysis according to AOAC methods. Moisture, DM, and CP were analyzed to evaluate the digestibility of the starter.

Carcass traits

Fifteen goat kids (5 from each MLR group) were weighed after fasting for 12 h with free access to water. The dressed carcass comprised the body after removing the skin, head (at the occipito–atlantal joint), fore feet (at the carpal–metacarpal joint), hind feet (at the tarsal–metatarsal joint), and viscera. The kidneys, including kidney and pelvic fat, were retained in the carcass, and the testes and scrotal fat were removed. The weight of the body (kg), skin (kg), carcass (kg), whole visceral organs (kg), heart (g), hepatobiliary organs (kg), lung (kg), kidney (g), spleen (g), total stomach (kg), reticulorum (kg), abdominal fat (kg), and gut (kg) and gut length (m) were measured and recorded.
Statistical analysis

Data for growth, blood parameters, digestive traits, and carcass traits were calculated using the Mixed Model Procedure of SAS (SAS Institute, Cary, NC, USA). The least squares method was used to detect significant differences between groups. \( P < 0.05 \) was considered to indicate a significant difference.

Results

Growth and blood parameters

The growth performance of kids fed the three MLR diets is shown in Table 2. The initial mean body weights of goat kids at 6 weeks of age were 8.09 ± 0.57, 8.19 ± 0.60, and 8.45 ± 0.57 kg in the A, B, and C groups, respectively. After the 6-week trial, the body weights of these goat kids were 15.24 ± 0.59, 14.48 ± 0.61, and 15.60 ± 0.59 kg, respectively. Differences in these growth parameters were not significant among the MLR groups. At 8–10 weeks of age, an interaction effect, by which intake increased with increasing MLR, was observed in the A and C groups. Moreover, the interaction was also observed in the FCR of the MLR groups, with FCR decreasing with an increase in MLR.

The effects of different MLRs on the blood traits of goat kids are shown in Table 3. Blood trait values were normal and agreed with the values reported by Kaneko (2008). No significant differences in these blood parameters were observed among MLR groups other than in the level of Alb. The level of Alb in the B group was 3.33 ± 0.06 g/dL, which was the lowest among the MLR groups (\( P = 0.02 \)).

Digestive traits

The digestive traits in the three MLR groups of goat kids are shown in Table 4. Data for goat kids with diarrhea were not included in our analyses. The apparent digestibility (AD) of the starter was calculated by assuming an 80% AD of milk replacer. The AD values of DM in groups A, B, and C were 86.5%, 83.4%, and 86.4%, respectively. The AD values of CP were 77.6%, 72.1%, and 79.9%, respectively. No significant differences were observed among the groups.

Carcass traits

The carcass traits of the three MLR groups are shown in Table 5. The results indicate that the fastest live weight and carcass heart weight in group C were significantly higher than in the other groups (\( P < 0.05 \)), showing a linear tendency and quadratic relationship (\( P < 0.1 \)). The skin and lung weights tended to be higher in group C than in the other groups (\( P < 0.1 \)). Kidney weight increased with increasing MLR. The dressing percentage and organ weights (hepatobiliary organs, spleen, stomach, reticulorumen, abdominal fat, intestine, and viscera) as percentages of body weight were not influenced by differences in MLRs.

Discussion

Generally, the protein demand in young animals is higher than that in mature animals.

Negesse et al. (2001) showed that the dietary CP level (8.7%–17.6%) affects the growth of male Saanen kids; in the present study, only group C had an average daily gain (ADG; 199.6 g/d) higher than the ADG (181 g/d) in Negesse et al. (2001) obtained under 17.6% dietary protein. The results show that the CP (17%) in the present study could meet the growth requirements. No variations in body weight or body weight gain were observed in any group, revealing no effect of changes in dietary nutrients on the goat kids (Kim et al. 2012). In previous studies, the ADG was found to be 150–160 g for goat kids born in different seasons in Kentucky (Andries 2013) and 177 g for goat kids in New Zealand (Deeming et al. 2016). Goetsch et al. (2001) obtained values of 167–173 g, similar to those for the A and B groups in the present study; in addition, the results from group C were similar to those obtained by Andries (2013). Furthermore, Arguello et al. (2004) considered the best ADG in goat kids to be 200 g/day, which was obtained in their study by natural suckling rather than by ad libitum or restricted artificial feeding. The ADG in group C in the present study was close to this value despite the fact that the goat kids were artificially fed, and the amount of milk replacer was restricted. This result indicates that a lower level of CP in starter for goat kids is a feasible strategy for optimizing ADG without negatively impacting the health of kids.

The ADG obtained in this trial is similar to that obtained by male Saanen and Saanen × Angora kids (21–29 kg) in the study by Treacher et al. (1987). Moreover, the FCR values for all groups in this study (1.48–1.57) were better than those of male Saanen and Saanen × Angora kids (2.51 and 1.81, respectively; Treacher et al. 1987). ADG, feed intake, and final body weight of group B in our study were lower than those for the other groups, which led to a better FCR. The results of the B

Table 2. Effects of methionine-to-lysine ratio in the starter on growth performance of goat kids².

|          | A            | B            | C            | P-value² |
|----------|--------------|--------------|--------------|----------|
| Initial BW² (kg) | 8.09 ± 0.57  | 8.19 ± 0.60  | 8.45 ± 0.57  | 0.90     |
| Final BW (kg)    | 15.24 ± 0.59 | 14.48 ± 0.61 | 15.60 ± 0.59 | 0.41     |
| ADG (g/d)        | 178.3 ± 9.0  | 169.2 ± 9.1  | 199.6 ± 9.4  | 0.06     |
| Feed intake (g/d)| 245.7 ± 22.1 | 228.0 ± 22.7 | 273.0 ± 22.1 | 0.36     |
| FCR             | 1.57 ± 0.19  | 1.48 ± 0.20  | 1.56 ± 0.19  | 0.94     |

²Values represent mean ± standard deviation.

Table 3. Effects of methionine-to-lysine ratio in the starter on blood parameters¹ of goat kids.

|          | A            | B            | C            | P-value² |
|----------|--------------|--------------|--------------|----------|
| Glu³ (mg/dL) | 69.64 ± 1.26 | 70.57 ± 1.30 | 71.42 ± 1.26 | 0.61     |
| γ-GT (U/L)  | 54.20 ± 2.94 | 55.40 ± 3.04 | 60.56 ± 2.94 | 0.28     |
| TP (g/dL)   | 06.39 ± 0.12 | 06.26 ± 0.12 | 06.48 ± 0.12 | 0.44     |
| Alb (g/dL)  | 03.50 ± 0.06a| 03.33 ± 0.06b| 03.58 ± 0.06 | 0.02     |
| Glo (g/dL)  | 02.89 ± 0.13 | 02.93 ± 0.14 | 02.90 ± 0.13 | 0.97     |
| A/G         | 01.26 ± 0.05 | 01.15 ± 0.05 | 01.27 ± 0.05 | 0.28     |
| BUN (mg/dL) | 15.72 ± 0.76 | 17.16 ± 0.79 | 16.66 ± 0.76 | 0.42     |

¹Values represent mean ± standard deviation.

²Values in rows with different letters are significantly different (\( P < 0.05 \)).

³Glu: glucose; γ-GT: γ-glutamyl transferase; TP: total protein; Alb: albumin; Glo: globulin; A/G: albumin: globulin; BUN: blood urine nitrogen.
group indicated that regulating the MLR by adding synthetic lysine in the low protein starter could improve the nitrogen utilization rate in goat kids and growth performance, in addition to reducing nitrogen emissions.

Low feed intake decreases the growth performance of animals (Peng and Harper 1970). In a low-protein diet, additional supplementation of amino acids, such as with L-lysine crystalline powder, could improve amino acid balance and protein synthesis in the liver (Rogers 1976) and increase feed intake (Gietzen 1993). Although the feed intake and ADG did not increase in the groups that received amino acid supplementation, the FCR of B group was the optimal FCR among all the treatments.

Blood glucose levels can reflect the health and dietary nutrient intake of goat kids. Glucose is supplied by intestinal absorption of dietary glucose or by hepatic glucose production (Kaneko 2008). In the present study, the blood glucose levels were 69.64–71.42 mg/dL, which were within normal range (50–75 mg/dL; Kaneko 2008), suggesting that the diet of treatment 1 had a similar blood glucose level compared to the other treatments. Glucose is associated with energy metabolism and may help in fine-tuning diets or identifying problems with a feeding programme (Kohn et al. 2005). According to Kohn et al. (2005), a lower level of BUN may represent a lower BUN status in animals and may help in fine-tuning diets or identifying problems with a feeding programme (Kohn et al. 2005).

γ-glutamyl transferase is a hepatobiliary enzyme and is measured to detect liver diseases in livestock such as cattle, horses, sheep, and goats. In this study, the values of γ-glutamyl transferase levels in A and B groups were consistent with the reference value (20–56 U/L, Kaneko 2008), which indicated no glucose circulatory or hepatobiliary concerns stemming from the feeding goat kids with low-protein starter, which was used to regulate MLR. TP, Alb, Glo, and A/G were measured to evaluate protein utilization. In this study, TP values, which reflect protein synthesis, were not significantly different among the groups (P > 0.1). The TP concentrations (6.39 ± 0.12, 6.26 ± 0.12, and 6.48 ± 0.12 g/dL in groups A, B, and C, respectively) were slightly lower than the reference values (6.4–7 g/dL; Kaneko 2008). The lower values in the present study may be because the dietary starter contained lower levels (17%) of TP than the commercial starter did (18%–22%).

Alb is synthesized in the liver and accounts for 50%–60% of the blood protein level. The concentration of Alb is decreased when its synthesis in the liver is too low or its levels are too low in the gut. Although the concentration of Alb in group B was significantly lower than in the other groups (P < 0.05), it was within normal range (Kaneko 2008) and did not influence the health or blood biochemical values of the goat kids.

Glo is associated with immune function, while A/G reflects protein synthesis ability in the liver. Different MLRs did not affect the concentration of Glo in the goat kids in the present study (P > 0.1). Generally, the Alb value should be higher than that of Glo in the normal blood of animals, and thus the Alb-to-Glo ratio should be more than 1 (Kaneko 2008). There were no significant differences in the A/G values among the groups in the present study, and the ratios were all above 1. This indicates that the three different MLRs did not influence protein relative abundance in blood in goat kids.

The BUN concentration is a useful indicator of protein status in animals and may help in fine-tuning diets or identifying problems with a feeding programme (Kohn et al. 2005). According to Kohn et al. (2005), a lower level of BUN may represent optimal nitrogen utilization and explain the balance of the

| Item                        | Treatment | P-value |
|-----------------------------|-----------|---------|
| Item                        | A         | B       | C       | Trt<sub>3</sub> | L<sub>3</sub> | Q<sub>3</sub> |
| Fasted live weight (kg)     | 16.73 ± 0.49<sup>ab</sup> | 16.10 ± 0.67<sup>ab</sup> | 18.30 ± 0.47<sup>a</sup> | 0.02 | 0.03 | 0.02 |
| Carcass weight (kg)         | 07.78 ± 0.29<sup>ab</sup> | 07.25 ± 0.51<sup>b</sup> | 08.63 ± 0.19<sup>b</sup> | 0.02 | 0.06 | 0.02 |
| Dressing percentage (%)     | 45.60 ± 0.80 | 45.02 ± 1.84 | 47.15 ± 0.89 | 0.30 | 0.62 | 0.15 |
| Total guts weight (kg)      | 04.16 ± 0.71 | 04.24 ± 0.47 | 04.71 ± 0.31 | 0.56 | 0.33 | 0.68 |
| Offal percentage (%)        | 24.90 ± 4.10 | 26.50 ± 3.70 | 25.70 ± 1.10 | 0.88 | 0.80 | 0.69 |
| Skin weight (kg)            | 01.39 ± 0.02 | 01.27 ± 0.08 | 01.60 ± 0.18 | 0.07 | 0.12 | 0.06 |
| Heart weight (g)            | 77.70 ± 4.50<sup>ab</sup> | 69.30 ± 5.70<sup>b</sup> | 88.30 ± 4.60<sup>b</sup> | 0.02 | 0.08 | 0.02 |
| Hepatobiliary weight (kg)   | 00.30 ± 0.02 | 00.34 ± 0.03 | 00.35 ± 0.04 | 0.24 | 0.12 | 0.55 |
| Lung weight (kg)            | 01.74 ± 0.009 | 01.76 ± 0.004 | 0.202 ± 0.014 | 0.06 | 0.03 | 0.21 |
| Kidney weight (g)           | 60.30 ± 1.70 | 65.70 ± 3.30 | 76.00 ± 10.40 | 0.12 | 0.05 | 0.67 |
| Spleen weight (g)           | 35.00 ± 7.50 | 28.70 ± 4.10 | 31.70 ± 4.30 | 0.56 | 0.57 | 0.37 |
| Stomach weight (g)          | 00.97 ± 0.61 | 00.39 ± 0.03 | 00.41 ± 0.07 | 0.26 | 0.17 | 0.38 |
| Reticularum weight (kg)      | 00.73 ± 0.45 | 00.29 ± 0.02 | 00.40 ± 0.08 | 0.30 | 0.25 | 0.29 |
| Abdominal fat weight (kg)   | 00.47 ± 0.08 | 00.43 ± 0.20 | 00.59 ± 0.08 | 0.50 | 0.41 | 0.41 |
| Intestinal weight (kg)      | 00.49 ± 0.04 | 00.47 ± 0.05 | 00.55 ± 0.09 | 0.50 | 0.38 | 0.45 |
| Intestinal length (m)       | 13.85 ± 4.25 | 15.45 ± 1.80 | 15.11 ± 1.24 | 0.83 | 0.66 | 0.70 |

<sup>1</sup>N = 5 goat kids per group.  
<sup>2</sup>Values represent mean ± standard deviation.  
<sup>3</sup>Trt = the effect of treatment; L = Linear relationship; Q = Quadratic relationship.  
<sup>4</sup>Values in rows with different letters are significantly different (P < 0.05).
first limiting amino acid. Although the concentration of BUN in group A was the lowest, indicating that nitrogen utilization in group A were better than that in the other two groups, the difference was not significant (P > 0.1). Additionally, the MLR of 0.29 in the starter was relatively balanced. According to the above blood parameters obtained in the present study, there were no health concerns regarding different MLRs in low-protein diets for goat kids. This implies that reducing the MLR improves feeding efficiency and reduces costs and potential negative environmental impacts, without negatively impacting goat kid health.

Waldo and Jorgensen (1981) suggest that feed nutrient quality determines intake, utilization efficiency, digested energy, and digestibility in animals. Nutrient digestibility is closely related to the development and capacity of the digestive tract (Thivend et al. 1980). The length of time starter resides in the digestive tract can affect digestibility. For example, high-value starter remains in the digestive tract longer than low-value starter does, which allows for increased microbial decomposition and results in improved digestibility.

The AD of DM in goat kids was previously found to be 64.39%–81.66% (Mani and Chandra 2003; Kaneko 2008), which is lower than that found in the current study (83.4%–84.6%). Furthermore, the AD of CP was determined to be 59.37%–73.89% in the previous studies, which was lower than that found in the current study (72.1%–79.9%). The results of the present study support previous findings that the digestibility of nutrients improves with starter that has a limited amount of protein. Feeding a low-protein diet could decrease the amount of anti-nutritional factors in feedstuffs, which may induce diarrhea in young animals, worsen growth performance, and decrease the digestibility and utilization of nutrients. Furthermore, any protein remaining in the gastrointestinal tract can serve as a source of nutrients for pathogens that can then multiply, leading to disease. It is widely considered that designing a suitable low-protein diet that regulates the balance of amino acids benefits both animals and the environment.

In this study, the ratios of carcass weight and organ weight to total body weight were similar to those determined by Marichal et al. (2003). The dressing percentages of group A (46.5 ± 0.80%) and group C (47.15 ± 0.89%) were better than those found by Marichal et al. (2003; 40.77%–46.03%), and the percentage of intestinal weight was lower than that found by Marichal et al. (2003; 8.82%–12.06%). This may be because the goat kids were not weaned, and the reticulorumen had not fully developed. For the dressing percentage, organ weight as a percentage of body weight did not significantly differ among groups, and the carcass and organ weights, particularly those of the stomach and reticulorumen, were increased. This indicates that an MLR of 0.33 in starter can balance the amino acid composition, resulting in protein deposition and synthesis, increases in carcass weight and organs, and improvement in total carcass traits. In future studies, nitrogen digestion and emissions in goat kids should be evaluated to confirm the nitrogen utilization. Gastrointestinal traits, such as villi and papilla height in the intestine and rumen, respectively, could also be measured to understand their development and nutrient absorption under low CP starter administration in goat kids.

**Conclusion**

In this study, the dietary CP content was 17%, and synthetic lysine was added to regulate the methionine-to-lysine ratio. The growth performance and nitrogen utilization of goat kids were the best under an MLR of 0.29. Excellent carcass traits were observed with the MLR of 0.33, and no ratios (0.29–0.33) caused an imbalance in amino acids or had negative effects on the growth, blood, digestive, and carcass traits of goat kids. This indicates that decreasing the dietary protein level and regulating the amino acid balance can increase nitrogen utilization without adversely affecting growth performance, in addition to decreasing the costs of feeding goat kids.

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**Data availability statement**

The data that support the findings of this study are available on request from the corresponding author, C. P. Wu. The data are not publicly available because they contain information that could compromise the privacy of research participants.

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**References**

Andries KM. 2013. Growth and performance of meat goat kids from two seasons of birth in Kentucky. Sheep Goat Res J. 28:16–20.

Argüello A, Castro N, Capote J. 2004. Growth of milk replacer kids fed under three different managements. J Appl Anim Res. 25:37–40. doi:10.1080/09712119.2004.9706470

Atti N, Rouissi H, Mahouachi M. 2004. The effect of dietary crude protein level on growth, carcass and meat composition of male goat kids in Tunisia. Small Rumin Res. 54:89–97. doi:10.1016/j.smallrumres.2003.09.010

Bahrami-Yekdangi H, Khorvash M, Ghorbani GR, Alikhani M, Jahanian R, Kamalian E. 2014. Effects of decreasing metabolizable protein and rumen-undegradable protein on milk production and composition and blood metabolites of Holstein dairy cows in early lactation. J Dairy Sci. 97(6):3707–3714. doi:10.3168/jds.2013-6725

Deeming LE, Beausoleil NJ, Stafford KJ, Webster JR, Zobel G. 2016. Variability in growth rates of goat kids on 16 New Zealand dairy goat farms. Proc NZ Soc Anim Prod. 76:137–138.

Elamin KM, Tameem Eldar AA, Amin AE, Abdalla FS, Hassan HE. 2012. Digestibility and nitrogen balance of Sudan goat ecotypes fed...
