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Research Article

Effects of Roughage Feeding Strategies on Growth Performance Carcass Quality and Fatty Acid Composition in Meat Goats

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ABSTRACT

This study aimed to compare the effects of three different roughage sources—Leucaena (*Leucaena leucocephala*), Pakchong 1 Napier grass (*Pennisetum purpureum × Pennisetum americanum*), and Pangola grass (*Digitaria eriantha*) in combination with concentrate supplementation on production performance, carcass quality, and fatty acid composition in meat goat. The experiment was conducted using a completely randomized design (CRD) involving nine male goats (50% Thai Native × Boer crossbred), approximately four months old, with an average initial body weight of 17.94 ± 1.5 kg. The animals were randomly allocated into three treatment groups (n = 3 per group), each receiving one type of freshly cut roughage *ad libitum* (Leucaena, Pakchong 1 Napier grass or Pangola grass) and supplemented with a 14% crude protein concentrate at 1.5% of body weight. The results indicated that goats fed *Leucaena leucocephala* combined with concentrate exhibited the highest dry matter digestibility, body weight gain, and omega-3 fatty acid accumulation, indicating that Leucaena is the most effective roughage source under the present experimental conditions. Nevertheless, both Pakchong 1 Napier grass and Pangola grass proved to be suitable and sufficient alternatives for goat feeding, particularly in areas where these grasses are readily available. Additionally, these forages contributed to the accumulation of omega-6 (C18:2) fatty acids, which are known to help maintain normal cell function, support immune responses, and reduce the risk of cardiovascular disease when consumed in balanced proportions.

1. Introduction

Meat goat production in Thailand has continued to develop, particularly in rural areas where farmers commonly utilize naturally available roughages such as Leucaena (*Leucaena leucocephala*) and native grasses as primary feed sources. In addition, some farmers cultivate specific forage crops such as Napier grass and Pangola grass to feed their goats. However, the quantity and quality of these forages vary cross season, especially during the rainy season, which spans from June to October and is considered a period of forage abundance. This season offers an opportunity for effective and economical goat feeding management. The information regarding the seasonal variation in forage availability and the types of roughages commonly used by farmers was derived from the authors' long-term field experience and on-farm observations in goat production areas, particularly in central and western Thailand, where seasonal patterns of rainfall strongly influence forage growth. Such practical experience reflects real conditions on smallholder farms and provides useful context for developing

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feeding strategies suitable for local production systems. The selection of suitable forage types combined with protein-rich concentrates or feed ingredients such as soybean meal or pelleted legume hulls plays an essential role in improving growth performance, reducing production costs, and enhancing meat and carcass quality, especially the nutritional composition of goat meat.

One important aspect of nutritional quality is the composition of beneficial fatty acids, particularly conjugated linoleic acid (CLA). CLA is an unsaturated fatty acid with antioxidant functions and has been linked to reduced risks of cardiovascular disease, cancer, and inflammatory disorders (Tricon *et al*., 2004). Its formation in meat is associated with the availability of fatty acid precursors in the diet, such as linoleic acid (C18:2n6) and alpha-linolenic acid (C18:3n3).

Different roughage sources, including leucaena, Napier grass, and Pangola grass, contain varying levels of these fatty acids. Leucaena, a leguminous forage, offers high protein content and good nutritional value, making it suitable during the rainy season. Napier grass, although highly productive, generally contains lower protein and higher fiber levels, which can reduce digestibility, therefore supplementation with protein-rich concentrate is often required to maintain a balanced diet.

Previous studies have highlighted the important interaction between forage type and CLA content in meat. Jaturasitha *et al*. (2009) demonstrated that purple guinea grass (*Panicum maximum* TD58) and Hamata stylo (*Stylosanthes hamata*) are rich in alpha-linolenic acid, contributes to increased CLA levels in beef. Furthermore, Saichuer *et al*. (2012) reported that goats fed only fresh purple guinea grass produced meat with higher CLA concentrations than goats receiving concentrate supplementation, despite the latter showing better growth performance.

In recent years, consumer demand for safe, high-quality, and health-promoting foods has increased significantly. Enhancing CLA content in goat meat presents an opportunity to create value-added products and expand access to niche markets such as the halal meat sector. Tailoring feeding strategies to seasonal forage availability may not only improve production efficiency and reduce feed costs but also support the sustainability of goat production systems in Thailand.

These three forages were selected because they are among the most commonly used roughage sources in tropical goat production systems. Leucaena represents a high-protein legume, while Pakchong 1 Napier grass and Pangola grass are widely cultivated grasses differing in digestibility and fiber content. Their comparison provides practical implications for selecting appropriate roughage sources for meat goat production in Thailand.

2. Materials and Methods

2.1 Animals and Experimental Design

The experiment was conducted using a completely randomized design (CRD). A total of nine male crossbred goats (50% Thai Native × Boer), with an average age of approximately 4 months (post-weaning stage) with an average body weight of 17.94 ± 1.54 kg, were used. The goats were randomly allocated into three treatment groups with three replicates per group (one goat per replicate). All goats were fed a concentrate diet containing at least 14% crude protein (commercial concentrate feed) at 1.5% of their body weight. The experimental treatments were as follows: Group 1: goats fed with freshly cut *Leucaena leucocephala*, Group 2: goats fed with freshly cut Pakchong 1 Napier grass, and Group 3: goats fed with freshly cut Pangola grass. The forages used in the experiment were obtained from typical farm-based sources to reflect practical feeding practices. *Leucaena leucocephala* (leucaena) was harvested from naturally growing stands in public areas commonly utilized by local farmers. The upper 1–2 meters of the plants, mainly consisting of tender leaves and branches, were cut and chopped before feeding. Pakchong 1 Napier grass (*Pennisetum purpureum × P. americanum*) and Pangola grass (*Digitaria eriantha*) were harvested from farmer-owned pastures at approximately 60 days of regrowth, which represents the stage most commonly used for ruminant feeding due to optimal balance between yield and nutritive quality. Clean drinking water and mineral blocks were provided *ad libitum*. Prior to the experimental period, all goats underwent a 14-day adaptation phase, during which they were dewormed using a commercial ivermectin-based anthelmintic Ivermec-F® by subcutaneous injection at the recommended dosage. The feeding trial lasted for 90 days. The experiment was conducted in a well-ventilated, raised-floor housing facility with a tiled roof. Each goat was housed individually in a pen measuring 1.5 × 1.5 meters. The environmental conditions inside the housing were monitored throughout the experimental period, with an average temperature of approximately 32°C and relative humidity of around 60%. Ventilation was maintained using natural airflow and supplemental fans to ensure adequate air exchange and minimize heat stress. All pens were cleaned daily, and manure was removed to maintain hygiene and prevent the buildup of harmful gases such as ammonia, which may negatively affect feed intake and growth performance.

2.2 Data Collection and Chemical Analysis

Feed intake was recorded daily by weighing the feed offered and the feed refused in order to calculate the individual daily feed intake. Individual body weights of the experimental goats were recorded at the beginning and at the end of the feeding trial to determine body weight change, average daily gain (ADG), and feed conversion ratio (FCR). Representative samples of each feed were randomly collected for chemical composition analysis. The proximate composition was determined using the standard procedures of the Association of Official Analytical Chemists (AOAC, 2000). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed following the method described by Van Soest *et al*. (1991).

Fecal and Feed Sampling for Dry matter digestibility. Determination representative samples of the feed consumed and feces were collected to determine the acid-insoluble ash (AIA), which was used as an internal marker to estimate the apparent dry matter digestibility (DMD). No other nutrient digestibility measurements were performed in this study. The analysis followed the method of Schnieder and Flatt (1975). Fecal samples were collected during the last week of the experimental period for five consecutive days. After each daily collection, samples were stored in a refrigerator. At the end of the 5-day period, the fecal samples from each individual goat were pooled together, and a composite subsample was taken for analysis. This subsample was dried at 105 °C overnight, ground, and passed through a 1 mm sieve before analysis for AIA content.

Rumen Fluid Sampling and VFA Analysis. On the final day of the experiment, rumen fluid samples were collected from each goat at two time points: before feeding (0 h) and 4 hours after feeding. Sampling was conducted using a stomach tube connected to a vacuum pump. Approximately 100 mL of rumen fluid was collected from each animal. The pH of the rumen fluid was measured immediately after collection. The fluid was then filtered through four layers of cheesecloth. A subsample of 50 mL was transferred into a plastic bottle and acidified with 9 mL of 1 M sulfuric acid (H_2SO_4) to halt microbial activity. The acidified samples were centrifuged at 4,400 × g 12 min. The supernatant was collected and stored at -20°C for the subsequent analysis of total volatile fatty acids (VFAs).

Blood Sampling and Analysis. On the final day of the experiment, blood samples were collected at 0 and 4 h after feeding from the jugular vein using a 5 mL syringe. Each sample was divided into two portions. The first portion was placed in a fluoride-coated tube containing sodium fluoride to preserve plasma for the analysis of blood glucose concentrations. The second portion was placed in a plain tube i.e. without anticoagulant to obtain serum for the determination of blood urea nitrogen (BUN). Blood glucose concentione were analyzed using the method described by Henry *et al.* (1974), while BUN concentrations were determined according to the method of Tiffany *et al.* (1972).

Slaughtering Procedure and Carcass Evaluation. At the end of the 90-day feeding trial, two goats from each treatment group were randomly selected for slaughter. The selected animals were fasted for 12 hours prior to slaughter, with free access to clean drinking water. The live weight after fasting was recorded before slaughter. The animals were slaughtered and processed according to a modified procedure based on Kanthapanit (1986), with adjustments made to align with current standard slaughtering and carcass evaluation practices (FAO, 2020). The hot carcass weight was recorded immediately after evisceration, and the dressing percentage was calculated. The longissimus dorsi muscle area was measured at the cross-section of the longissimus dorsi muscle between the 12th and 13th ribs on the left side of each carcass. This was done by tracing the muscle area onto tracing paper twice, and the average area was calculated to determine the loin eye area.

Longissimus Dorsi Sampling and Meat Quality Analysis. Samples of the longissimus dorsi muscle, which is recognized as a high-quality and tender muscle, were collected for the analysis of physical meat quality parameters. These included pH, color values, shear force, drip loss (i.e., weight loss during refrigerated storage), and cooking loss (i.e., weight loss after standardized cooking). In addition, the fatty acid composition and the concentration of CLA in the longissimus dorsi were determined using gas chromatography.

2.3 Statistical Analysis

All collected data were subjected to analysis of variance (ANOVA) to evaluate the effects of different treatments. Differences among treatment means were compared using Duncan's New Multiple Range Test (DMRT) at a significance level of $p<0.05$.

3. Results and Discussion

3.1 Chemical Composition of diets

The chemical composition analysis of the roughages used in this study, Pakchong 1 Napier grass, Pangola grass, *Leucaena leucocephala* (leucaena), and concentrate-revealed that Pakchong 1 Napier grass had the highest moisture content compared to Pangola grass and leucaena. Regarding crude protein content, Pakchong 1 Napier grass and Pangola grass contained 6.51% and 5.82%, respectively, which were considerably lower than that of leucaena, (23.02%). As a leguminous forage, leucaena naturally possesses a high protein content.

Both Pakchong 1 Napier grass and Pangola grass used in this study were harvested as fresh forages at an average cutting age of approximately 60 days. This harvesting stage contributed to the reduced crude protein levels observed in both types of roughage. The fiber contents of the two grasses were relatively similar. The NDF contents of Pakchong 1 Napier and Pangola grasses were 64.71% and 64.30%, respectively, while the ADF contents were 44.50% and 40.29%, respectively. These values were considerably higher than those found in leucaena, which had NDF and ADF values of 37.80% and 32.58%, respectively, as shown in Table 1. The higher protein and lower fiber contents observed in leucaena are attributed to the appropriate cutting stage, which involved harvesting from the top portion down to approximately 1.5 meters-consisting largely of tender branches and leaves rich in nutrients. The results suggest that Pakchong 1 Napier grass and Pangola grass can be classified as moderate-quality roughages due to their crude protein levels

Table 1 Chemical composition of Leucaena, Napier Pakchong 1 grass, Pangola grass and concentrate feed

Chemical composition (%)	Leucaena	Napier Pakchong 1 grass	Pangola grass	Concentrate feed
DM[1]	33.73±0.96	22.96±0.69	38.46±0.82	87.26±0.74
Moisture	66.27±0.69	77.04±0.69	61.54±0.82	12.74±0.74
Ash	8.42±0.12	13.10±0.34	10.91±0.14	15.84±0.29
EE[2]	3.70±0.15	2.12±0.14	1.38±0.01	6.31±0.17
CP[3]	23.02±1.15	6.51±0.83	5.82±0.12	14.44±1.03
NDF[4]	37.80±0.34	64.71±.73	64.03±0.57	-
ADF[5]	32.58±0.43	44.50±0.82	40.29±2.32	-
Gross Energy (cal/gDM)	4,582.50±18.19	3,904.89±17.09	3,89.03±12.28	3,927.96±0.30

[1] Dry matter, [2] Ether extract, [3] Crude protein, [4] Neutral detergent fiber, [5] Acid detergent fiber

being lower than 7%. Such levels are insufficient to meet the protein requirements of rumen microbes, particularly cellulolytic bacteria, which require a minimum of 7% dietary crude protein to maintain optimal metabolic activity (Hennessy, 1980; NRC, 2007; Wanapat, 2014). These nutritional limitations are expected to affect rumen fermentation, dry matter intake, and growth performance, which are further discussed in Section 3.2.

3.2 Feed Intake of goats

The results revealed a statistically significant difference in roughage intake among the treatment groups. Goats fed with leucaena and Pangola grass had higher roughage intake compared to those fed with Pakchong 1 Napier grass (Table 2). All goats were supplemented with a concentrate at 1.5% of their body weight, with an average intake of 261.78 g/head/day on dry matter basis, which accounted for approximately 1.25% of body weight. When considering total dry matter intake, goats in Groups 1, 2, and 3 consumed 1,067.93, 772.93, and 1,109.18 g/head/day, respectively. The total dry matter intake of goats fed with leucaena and Pangola grass was significantly higher (*P<0.05*) than that of goats fed Pakchong 1 Napier grass. This difference may be attributed to the higher moisture content and greater stem proportion in Pakchong 1 Napier grass, which likely led to a reduced palatability and voluntary feed intake.

Goats fed with leucaena supplemented with concentrate exhibited the highest total feed intake. This result corresponds with the high crude protein content of leucaena, which provided an adequate daily protein intake to support optimal growth. Consequently, goats in this group showed superior growth performance compared to the other groups. Moreover, the higher dry matter digestibility observed in goats fed with Leucaena was associated with improved feed utilization efficiency, as reflected by a lower feed conversion ratio (FCR) compared to the other treatments. The enhanced digestibility of Leucaena likely facilitated greater nutrient absorption and energy availability, which translated into higher growth performance per unit of feed consumed. Conversely, goats fed with Pakchong 1 Napier grass and Pangola grass, which contained higher fiber and lower protein levels, exhibited higher FCR values, indicating less efficient conversion of feed into body weight gain. This finding aligns with previous reports that roughages with lower digestibility result in poorer feed efficiency (Atti *et al*., 2004; NRC, 2007). However, when leucaena is used as the primary roughage, concentrate supplementation may not be necessary due to its sufficient nutritional value, especially its high protein content. In contrast, both Pakchong 1 Napier grass and Pangola grass, which contain lower protein levels, require supplementation with concentrate at 1.5% of body weight, in accordance with NRC (2006) recommendations. According to NRC guidelines, growing kids weighing approximately 20 kg require about 95 g of crude protein per day to achieve an average daily gain (ADG) of 100 g/day. Regarding dry matter digestibility, goats in Group 1 (fed with leucaena) had significantly higher digestibility coefficients than those in Groups 2 and 3, which received Pakchong 1 Napier and Pangola grass, respectively (*P<0.05*). This finding is consistent with the lower fiber content of leucaena, which likely enhanced ruminal fermentation and digestion efficiency.

3.3 Body Weight Change and Growth Performance

The initial body weights of meat goats in Groups 1, 2, and 3 were 17.39, 18.17, and 18.28 kg, respectively. At the end of the 90 days feeding period, the final body weights were 26.37, 22.23, and 22.95 kg, respectively. The corresponding body weight gains were 8.98, 4.06, and 4.67 kg, and the average daily gains (ADG) were 100.90, 45.62, and 52.43 g/head/day, respectively. However, no statistically significant differences were observed in body weight gain or ADG among the treatment groups (Table 3). The numerically higher ADG observed in goats fed with Leucaena may be attributed to its superior nutritional composition and ruminal fermentation characteristics. Leucaena contains a balanced proportion of rumen-degradable protein (RDP) and rumen-undegradable protein (RUP), which enhances microbial growth and amino acid flow to the small intestine. This improves nitrogen utilization efficiency and supports muscle protein synthesis. Additionally, the higher digestibility and metabolizable energy content of Leucaena likely increased energy availability for growth, resulting in a better feed conversion efficiency. The moderate tannin concentration in Leucaena may have further contributed to improved nitrogen retention by reducing excessive protein degradation in the rumen (Silanikove *et al*., 2001; NRC, 2007.) In contrast, Pakchong 1 Napier grass and Pangola grass have higher NDF and ADF contents, resulting in lower digestibility and reduced nutrient utilization. Van Soest *et al*. (1991) indicated that when the NDF content exceeds 60%, it can suppress feed intake and adversely affect the digestive efficiency of ruminants. Furthermore, although all goats in the experiment received the same level of concentrate supplementation (261.78 g/head/day), the efficiency of concentrate utilization also depended on the type of roughage provided. Goats fed with leucaena were better able to utilize protein and energy from the concentrate in conjunction with the roughage, whereas those fed with high fiber grasses showed lower ruminal fermentation and digestibility.

Table 2 Dry matter intake (DMI), total protein intake and dry matter digestibility coefficient of meat goat (Mean ± Standard deviation)

Item	Group[1]			P-value
	group 1	group 2	group 3	
Dry matter intake (g/head/day)				
Roughage	806.15±12.16[a]	511.15±18.51[b]	847.40±72.80[a]	0.0002
Concentrate feed	261.78±0.00	261.78±0.00	261.78±0.00	-
Total	1,067.93±12.16[a]	772.93±18.51[b]	1,109.18±72.80[a]	0.0002
Dry matter intake (%BW)				
Roughage	3.74±0.15[a]	2.50±0.21[b]	4.13±0.48[a]	0.0078
Concentrate feed	1.22±0.07	1.28±0.06	1.27±0.04	0.3999
Total	4.96±0.22[a]	3.79±0.26[b]	5.40±0.52[a]	0.0040
Crude protein intake (g/head/day)				
Roughage	185.58±2.80a	33.28±1.21c	49.32+4.24b	‹.0001
Concentrate feed	37.80+0.00	37.80±0.00	37.80±0.00	-
Total	223.38±2.80a	71.08±1.21c	87.12±4.24b	‹.0001
Feed conversion ratio				
Roughage	9.56±5.35	12.46±4.34	16.95±04.50	0.2380
Concentrate feed	3.09±1.68	6.40±2.30	5.29±1.68	0.1780
Total	6.33±3.52	9.43±3.31	11.12±3.08	0.2739
Dry matter coefficient (%)	67.62±3.24a	55.01±2.11b	57.35±2.77b	0.0029

[a, b] Mean values within a row indicated with different superscripts are significantly different (P < 0.05).

[1] Group 1 = Leucaena; Group 2 = Pakchong 1 Napier grass; Group 3 = Pangola grass.

Table 3 Average body weight and growth rate of meat goats (Mean ± Standard deviation)

Item	Group[1]			P-value
	group 1	group 2	group 3	
Initial weight (kg/head)	17.39±2.48	18.17±1.26	18.28±1.01	0.7931
Final weight (kg/head)	26.37±1.94[a]	22.23±0.79[b]	22.95±0.48[b]	0.0136
Body weight gain (kg/head)	8.98±4.07	4.06±1.78	4.67±1.25	0.1220
Average daily gain (g/head/day)	100.90±45.72	45.62±19.83	52.43±14.08	0.1219

[a, b] Mean values within a row indicated with different superscripts are significantly different (P < 0.05).

[1] Group 1 = Leucaena; Group 2 = Pakchong 1 Napier grass; Group 3 = Pangola grass.

3.4 Blood Metabolites and Volatile Fatty Acids in the Rumen

The blood urea nitrogen levels prior to feeding (0 h) for goats in Groups 1, 2, and 3 were 35.40, 9.57, and 12.70 mg/dL, respectively. At 4 h post-feeding, the BUN values increased to 36.60, 10.37, and 14.63 mg/dL, respectively. The BUN levels differed significantly among treatments (*P<0.05*), as shown in Table 4. The BUN concentrations of goats fed with Pakchong 1 Napier grass and Pangola grass were within the normal physiological range of 6.30–25.50 mg/dL (Wanapat, 1990), which is consistent with the findings of Preston and Leng (1987), who reported that optimal rumen microbial function occurs at ammonia nitrogen concentrations between 5–25 mg/dL. The increase in BUN is directly related to the amount of protein consumed and its conversion to ammonia in the rumen (Kohn *et al*., 2005). The significantly higher BUN concentration observed in goats fed with Leucaena could be explained by the high content of rumen-degradable protein (RDP) in Leucaena, which led to increased ammonia production in the rumen.

Excess ammonia that was not incorporated into microbial protein was absorbed into the bloodstream and converted to urea in the liver, resulting in higher BUN levels. This elevation indicates greater nitrogen turnover associated with high-protein diets. The higher BUN in Group 1 corresponded with greater dry matter digestibility and growth performance, suggesting that a substantial proportion of the degraded nitrogen was efficiently utilized for microbial protein synthesis and tissue growth. However, excessive ruminal ammonia may also imply partial inefficiency in nitrogen utilization, which should be considered in future feeding management (Kohn *et al*., 2005; NRC, 2007).

However, excessively high BUN concentrations may indicate inefficiencies in nitrogen utilization and place additional metabolic load on the liver for urea detoxification. Furthermore, elevated BUN leads to increased urinary nitrogen excretion, which has implications for environmental nitrogen pollution and overall feeding cost efficiency. Therefore, optimizing the balance between protein intake and microbial utilization is crucial to maximize growth performance while minimizing N loss and potential health risks.

The blood glucose concentrations prior to feeding for goats in Groups 1, 2, and 3 were 66.30, 65.00, and 56.67 mg/dL, respectively. Although the differences tended to higher in Group 1, they were not statistically significant ($P=0.078$). At 4 h after feeding, these values increased to 71.33, 66.33, and 62.00 mg/dL, respectively with no significant differences observed among the groups ($P=0.1199$). There were no statistically significant differences among the treatment groups. All measured glucose concentrations remained within the normal physiological range for healthy goats (50–75 mg/dL), as reported by Kaneko (1980) and supported by more recent references (Kaneko *et al*., 2008; Thrall, 2012). This indicates that the diets provided an adequate energy supply, primarily through propionic acid, a major volatile fatty acid (VFA) produced from ruminal carbohydrate fermentation and subsequently utilized for hepatic gluconeogenesis in ruminants (Owens *et al*., 1998). The absence of significant differences in blood glucose concentrations among the treatment groups further reflects the strong regulatory capacity of ruminants to maintain glucose homeostasis, as their blood glucose is tightly controlled by gluconeogenesis rather than direct intestinal absorption, even when fed different roughage sources.

The ruminal pH values before feeding in Groups 1, 2, and 3 were 6.60, 6.60, and 6.20, respectively. Four hours after feeding, the pH values decreased significantly ($P<0.05$) to a range of 5.67–5.93. This decrease indicates intensive fermentation during the postprandial period, particularly within 2-4 h after feeding, when VFA production peaks (Van Soest, 1994). The optimal ruminal pH for the growth and activity of fibrolytic bacteria is typically 6.2–6.8, and a ruminal pH below 6.0 can compromise fiber digestion (Russell and Dombrowski, 1980). However, the rumen has physiological buffering mechanisms, primarily through salivary bicarbonate, which help maintain pH within a functional range. Additionally, appropriate diet formulation such as providing sufficient long fiber and controlling concentrate inclusion may help prevent excessive pH decline and thereby sustain microbial activity and roughage utilization efficiency.

The proportions of volatile fatty acids (VFAs) in the rumen fluid of goats at 4 hours post-feeding showed that acetic acid was the predominant VFA in all treatment groups, ranging from 76.56% to 84.39%. Propionic acid levels were significantly higher ($P<0.05$) in Group 2 compared to the other groups. The proportions of volatile fatty acids (VFAs) in the rumen fluid of goats at 4 hours post-feeding showed that acetic acid was the predominant VFA in all treatments, indicating that roughage served as the primary fermentative substrate. The variation in acetic and propionic acid proportions among treatments was closely related to differences in roughage intake and nutrient composition. Goats fed with Leucaena and Pangola grass consumed greater amounts of roughage (806.15 and 847.40 g/head/day, respectively) compared to those fed with Pakchong 1 Napier grass (511.15 g/head/day), while the concentrate intake was similar across treatments (261.78 g/head/day). The higher roughage intake in Groups 1 and 3 promoted more fiber fermentation in the rumen, leading to greater acetic acid production, which is a typical end product of cellulose degradation by fibrolytic bacteria (Van Soest, 1994). This explains the higher acetic acid proportions observed in these groups. In contrast, the lower roughage intake but relatively higher proportion of concentrate in Group 2 (Napier grass) favored starch fermentation, which stimulated amylolytic bacteria and resulted in significantly higher propionic acid levels ($P<0.05$) (France and Dijkstra, 2005). Propionate serves as a major glucogenic precursor, providing more readily available energy in the form of glucose. Although the overall VFA concentrations were within the physiological range reported for ruminants (Wanapat, 1990), the differences in acetic-to-propionic ratios reflected the distinct fermentation patterns among the forage types used. A higher acetic-to-propionic ratio, as observed in the Leucaena and Pangola groups, indicates greater reliance on fiber fermentation and may be associated with lower energy efficiency but improved fiber digestibility. Conversely, the Napier group exhibited a lower acetic-to-propionic ratio, which suggests a more efficient energy conversion process. These findings imply that the type and amount of roughage intake directly influenced rumen fermentation characteristics, energy metabolism, and consequently, the growth performance of goats observed in this study (France and Dijkstra, 2005; NRC, 2007; Van Soest, 1994).

Table 4 Blood chemical composition of meat goats (mean±standard deviation)

Item (mg/dl)	Group[1]			P-value
	group 1	group 2	group 3	
Blood urea nitrogen				
0 h-pre feeding	35.40±6.85[a]	9.57±0.42[b]	12.70±4.20[b]	0.0009
4 h-post feeding	36.60±7.49[a]	10.37±0.23[b]	14.63±4.58[b]	0.0015
Blood glucose				
0 h-pre feeding	66.33±6.65	65.00±4.00	56.67±1.15	0.0785
4 h-post feeding	71.33±5.69	66.33±4.93	62.00±2.65	0.1199

[a, b] Mean values within a row indicated with different superscripts are significantly different (P < 0.05).

[1] Group 1 = Leucaena; Group 2 = Pakchong 1 Napier grass; Group 3 = Pangola grass.

Table 5 pH and volatile fatty acid (VFA) concentration in rumen fluid of meat goats (mean±standard deviation)

Item	Group[1]			P-value
	group 1	group 2	group 3	
Ruminal (pH)				
0 h-pre feeding	6.60±0.10[a]	6.60±6.20[a]	6.20±0.10[b]	0.0203
4 h-post feeding	5.93±0.058[a]	5.77±0.12[ab]	5.67±0.12[b]	0.0448
Total VFA (mmol/dl)				
0 h-pre feeding	16.91±3.85	17.90±4.08	20.22±2.24	0.5269
4 h-post feeding	20.50±4.46	19.84±4.12	21.33±3.69	0.9071
Acetic (% of total VFA)				
0 h-pre feeding	84.39±1.81	83.83±1.34	84.11±1.32	0.9021
4 h-post feeding	80.71±0.87	76.56±2.65	82.20±3.38	0.0786
Propionate (% of total VFA)				
0 h-pre feeding	8.46±0.78[b]	11.21±1.75[a]	7.40±1.23[b]	0.0292
4 h-post feeding	10.63±0.72[b]	16.30±2.68[a]	10.31±1.86[b]	0.0150
Butyrate (% of total VFA)				
0 h-pre feeding	4.27±1.72[ab]	2.88±0.82[b]	6.32±0.78[a]	0.0329
4 h-post feeding	6.40±0.93	5.11±0.87	5.87±1.25	0.3671
Acetate:Propionate				
0 h-pre feeding	10.04±1.03[ab]	7.60±1.19[b]	11.60±2.10[a]	0.0469
4 h-post feeding	7.62±0.55[a]	4.81±0.99[b]	8.14±1.68[a]	0.0267

[a, b] Mean values within a row indicated with different superscripts are significantly different (P < 0.05).

[1] Group 1 = Leucaena; Group 2 = Pakchong 1 Napier grass; Group 3 = Pangola grass

3.5 Carcass Characteristics and Fatty Acid Composition of Goat Meat

The results showed that the use of Leucaena as a roughage source in goat feeding led to a significantly greater Longissimus dorsi muscle area compared to goats fed with Pakchong 1 Napier grass or Pangola grass (*P<0.05*). This finding can be attributed to the higher crude protein content and superior digestibility of Leucaena, which enhanced amino acid availability and metabolizable energy supply for muscle development. The combination of Leucaena with concentrate supplementation provided a more balanced nutrient intake, improving nitrogen utilization efficiency and promoting greater lean tissue accretion. The efficient digestion and utilization of protein from Leucaena likely contributed to higher body weight gain and a more developed loin muscle compared with the grass-fed groups. This result corresponds with the higher average daily gain (ADG) and dry matter digestibility (DMD) observed in Group 1. The better nutritional quality and rumen fermentation pattern of Leucaena promoted microbial protein synthesis, resulting in greater amino acid absorption for muscle protein synthesis. These mechanisms explain the larger loin eye area found in goats fed with Leucaena in this study. Similar trends have been reported by Kongman and Prasanpanich (2016), who found that the type of roughage significantly affects growth and carcass characteristics. Atti *et al*. (2004) also demonstrated that diets with higher protein content improve muscle development, particularly in red muscle regions such as the loin and hind limbs. Moreover, Solomon *et al*. (2008) and Conrad and Hibbs (1968) emphasized that improved digestibility and ruminal fermentation efficiency contribute directly to increased carcass weight and muscle deposition. The present study supports these findings and highlights Leucaena as an effective protein-rich forage for enhancing muscle growth and carcass yield in goats.

Significant differences (P<0.05) were observed in the fatty acid composition of goat meat among the three dietary treatments (Table 7). Goats fed with Leucaena (Group 1) had a significantly lower proportion of myristic (C14:0), pentadecanoic (C15:0), and palmitic acid (C16:0) but a higher level of stearic acid (C18:0) compared with the other groups. Moreover, the Leucaena group exhibited significantly higher levels of alpha-linolenic acid (C18:3 n3) and trans-oleic acid (C18:1 n9t), resulting in the lowest n6:n3 ratio (3.59). This indicates that Leucaena feeding improved the nutritional quality of meat fat by increasing beneficial unsaturated fatty acids and decreasing the proportion of hypercholesterolemic SFAs. The higher UFA levels in the Leucaena group may be attributed to its higher crude protein content and the presence of secondary plant compounds that reduce ruminal biohydrogenation (Jenkins *et al*., 2008). These factors allow more UFAs, particularly omega-3 fatty acids, to bypass the rumen and deposit in muscle tissue. In contrast, goats fed with Pakchong 1 Napier grass (Group 2) showed the highest proportions of palmitic and myristic acids, likely due to enhanced hydrogenation associated with higher fiber fermentation (Van Soest, 1994). The Pangola grass group (Group 3) showed intermediate values between the Leucaena and Napier groups, reflecting its moderate fiber and protein contents.

In terms of fatty acid composition, the meat from all three experimental goat groups contained palmitic acid (C16:0) and stearic acid (C18:0) as the predominant saturated fatty acids (SFAs), both of which are commonly found in the fat of meat and dairy products (Redah *et al*., 2011). Among the unsaturated fatty acids (UFAs), oleic acid (C18:1 cis-9) was the most abundant. This monounsaturated fatty acid is also widely present in olive oil, avocado oil, and canola oil, and is known for its beneficial effects in reducing the risk of cardiovascular disease, lowering blood cholesterol, and improving blood sugar control (Guasch-Ferré *et al*., 2020).

Although conjugated linoleic acid (CLA) was not detected in this study, all groups contained appreciable levels of beneficial unsaturated fatty acids such as oleic (C18:1), linoleic (C18:2), and alpha-linolenic (C18:3), which are associated with improved lipid metabolism and anti-inflammatory effects in humans (Dhiman *et al*., 2005; Guasch-Ferré *et al*., 2020). The results of this study therefore suggest that feeding Leucaena leucocephala as a primary forage source can improve the nutritional profile of goat meat by increasing omega-3 fatty acid content and reducing the n6:n3 ratio, thereby enhancing its value for human health.

The absence of detectable CLA in the present study may be due to insufficient dietary precursors for CLA synthesis or extensive ruminal biohydrogenation of unsaturated fatty acids prior to absorption. Additionally, it is possible that the detection limit of the analytical method used may not have been sensitive enough to quantify low concentrations of CLA in goat muscle. Further investigation is therefore recommended to optimize dietary strategies that could enhance CLA deposition in meat.

Table 6 Carcass chracteristics and meat quality in goat (mean±standard deviation)

Item	Group[1]			P-value
	group 1	group 2	group 3	
Live weight after fasting (kg)	28.34±2.18	22.64±1.44	21.76±0.06	0.0405
Hot carcass weight (kg)	11.20±0.71	8.88±0.60	7.88±0.46	0.2113
Hot carcass percentage (%)	39.54±0.54	39.20±0.16	34.63±2.21	0.0771
Longissimus muscle area (cm^2)	14.44±0.06[a]	13.15±0.15[b]	13.24±0.39[b]	0.0223
$pH_{0\ min}$	7.41±0.61	6.52±0.21	6.42±0.57	0.2373
$pH_{24\ min}$	7.60±0.45	7.46±0.12	7.10±0.78	0.6566
L^*	36.41±3.29	36.04±3.82	36.35±3.78	0.9941
a^*	13.24±0.60	14.24±0.82	13.96±0.25	0.3591
b^*	11.98±2.25	13.35±0.32	12.78±0.86	0.6616
% cookin loss	22.95±5.68	24.04±2.15	19.01±9.01	0.7267
% drip loss	6.22±1.26	6.46±0.35	8.82±1.67	0.2125
Shear force (กก.)	9.47±2.69	7.22±1.07	11.73±1.52	0.2019

[a, b] Mean values within a row indicated with different superscripts are significantly different (P < 0.05).

[1] Group 1 = Leucaena; Group 2 = Pakchong 1 Napier grass; Group 3 = Pangola grass

Table 7 Fatty acid composition in longissimus dorsi muscle (as % of fatty acid) (mean±standard deviation)

Item	Group[1]			P-value
	group 1	group 2	group 3	
SFA				
C10:0	0.28±0.07	0.22±0.02	10.23±0.03	0.1532
C12:0	1.22±0.13	2.08±1.00	1.85±0.30	0.0671
C14:0	10.64±0.62[b]	15.31±3.39[a]	14.16±0.96[a]	0.0037
C15:0	1.42±0.26[b]	1.85±0.39[a]	1.44±0.22[b]	0.0475
C16:0	47.29±1.94[b]	53.87±3.90[a]	51.52±3.77[a]	0.0121
C18:0	38.90±1.00[a]	26.09±1.27[c]	30.37±2.89[b]	<.0001
C20:0	0.13±0.01	0.21±0.14	0.15±0.06	0.2801
C22:0	0.12±0.03[b]	0.36±0.06[a]	0.27±0.14[a]	0.0013
UFA				
C14:1	0.37±0.03[c]	1.00±0.27[a]	0.70±0.14[b]	<.0001
C16:1	5.68±0.18[b]	9.08±1.14[a]	8.50±0.28[a]	<.0001
C18:1 n9t	6.82±0.16[a]	3.96±0.97[b]	4.72±1.21[b]	0.0002
C18:1 n9c	81.86±0.96	81.14±3.23	81.50±0.90	0.8295
C18:2 n6c	4.05±0.56	4.17±0.74	3.83±0.16	0.5452
C18:3 n3	1.15±0.27[a]	0.41±0.04[c]	0.64±0.08[b]	<.0001
C20:1	0.13±0.00	0.12±0.01	0.11±0.03	0.5984
SFA (mg/g oil)	300.12±7.06	277.03±21.51	316.35±62.73	0.2383
UFA (mg/g oil)	190.67±3.60	206.07±12.56	179.91±14.88	0.0044
n6:n3 ratio	3.59±0.41[c]	10.17±1.67[a]	6.04±0.93[b]	<.0001

[a, b, c] Mean values within a row indicated with different superscripts are significantly different ($P < 0.05$).

[1] Group 1 = Leucaena; Group 2 = Pakchong 1 Napier grass; Group 3 = Pangola grass

4. Conclusion

The present study demonstrated that the type of roughage significantly influenced growth performance, carcass characteristics, and fatty acid composition in meat goats. Among the three treatments evaluated, feeding Leucaena supplemented with concentrate resulted in the most favorable outcomes. Goats in this group exhibited the highest dry matter digestibility, superior growth rate, and the largest *Longissimus dorsi* muscle area, reflecting more efficient nutrient utilization and muscle protein synthesis. Furthermore, the meat from this group contained higher levels of beneficial unsaturated fatty acids, particularly alpha-linolenic acid (C18:3n3), and a more desirable n6:n3 ratio, indicating enhanced nutritional quality.

These results collectively suggest that Leucaena is the most suitable roughage source for improving both production efficiency and meat quality in goats, especially when combined with an appropriate concentrate supplement. However, in areas where Leucaena is not readily available, Pakchong 1 Napier grass and Pangola grass remain practical alternatives, particularly when supplemented with protein-rich concentrates to improve their nutritional balance. The findings highlight the importance of integrating locally available forage resources with suitable concentrate formulations to optimize goat production under tropical feeding systems.

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