Pertanika J. Trop. Agric. Sci. 48 (6): 2057 - 2085 (2025)

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Effect of *Pennisetum purpureum* cv. Gama Umami and *Calliandra calothyrsus* Silage on Growth Performance of Thin-Tailed Sheep

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ABSTRACT

The issue of ruminant livestock feed shortages can be addressed by utilizing innovative feed that is both nutritionally rich and available year-round. The study aimed to examine how silage influences the growth performance of thin-tailed sheep. The study was conducted in Sleman, Yogyakarta. The study involved thirty thin-tailed ewes, aged 10 to 12 months and weighing 15.03±1.09 kg. A completely randomized design (CRD) with a unidirectional arrangement was applied, involving three diet treatments and ten replications. In this study, the silage consisted of *Pennisetum purpureum* cv. Gama Umami and *Calliandra calothyrsus* in a 70:30 ratio, respectively. The diets were as follows: T0 = 60% concentrate and 40% water spinach straw, T1 = 40% concentrate and 60% silage, and T2 = 60% concentrate and 40% silage. The study focused on variables such as growth performance, apparent nutrient digestibility, and nitrogen (N) utilization. The data were examined through analysis of variance (ANOVA), followed by Duncan's new multiple range test (DMRT) for comparisons of significant differences. The performance indicators for treatments T0, T1, and T2 were as follows: dry matter intake (DMI) of 57.99, 60.12, and 65.57 g/kg $LW^{0.75}$/day, respectively; crude protein intake (CPI) of 5.98, 8.36, and 6.78 g/kg $LW^{0.75}$/day; average daily gain (ADG) of 38.96, 43.94, and 49.10 g/sheep/day; N intake of 0.90, 1.34, and 1.09 g/kg $LW^{0.75}$/day; N digestible of 0.70, 0.95, and 0.80 g/kg $LW^{0.75}$/day; and N retention of 0.56, 0.85, and 0.70 g/kg $LW^{0.75}$/day. Therefore, no single dietary treatment was universally superior, but each offered unique advantages.

Keywords: Calliandra calothyrsus, digestibility, nitrogen balance, *P. purpureum* cv. Gama Umami, sheep performance, silage

ARTICLE INFO

Article history:
Received: 10 March 2025
Accepted: 27 August 2025
Published: 25 November 2025

DOI: https://doi.org/10.47836/pjtas.48.6.20

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e-ISSN: 2231-8542

INTRODUCTION

Indonesia is a country where small ruminants play a crucial role in the daily lives of its people. These animals not only meet the national demand for meat but also have deep cultural and religious significance (Udo & Budisatria, 2011). In the Yogyakarta region, sheep are an integral part of the local culinary tradition. However, the region faces a shortage in local sheep supply due to limited population, necessitating reliance on neighboring areas such as Central Java and Solo. According to data from the Central Bureau of Statistics Indonesia, the sheep population in Yogyakarta decreased by 36.17% between 2021 and 2023 (Badan Pusat Statistik [BPS], 2024). The rising demand for sheep, both for meat consumption and religious practices, presents a business opportunity for sheep farmers. Nevertheless, challenges persist due to limited feed availability (quality, quantity, and continuity) and high production costs.

To address the forage shortage in Indonesia, a superior grass variety, *P. purpureum* cv. Gama Umami was introduced. This variety is a mutation of the conventional Napier grass, developed through Gamma ray radiation at 100 Gy to create a new breed (Sanjaya et al., 2022). *Pennisetum purpureum* cv. Gama Umami was cultivated at the Faculty of Animal Science, Universitas Gadjah Mada, and was granted a plant variety protection certificate (889/pvhp/2020) by the Indonesian Ministry of Agriculture (Mudhita et al., 2024; Sanjata et al., 2022). It was officially recognized as a new Napier grass variety, distinguished by its longer, broader leaves compared to conventional varieties. The benefits of this grass include higher yields of fresh biomass (141.9 tons/ha), dry matter (25.85 tons/ha), and organic matter (22.96 tons/ha), all of which exceed the productivity of conventional Napier grass (104.47, 16.67, and 16.67 tons/ha, respectively) (Nurjanah et al., 2023). The high biomass potential of this grass offers an opportunity to fulfill the forage demands of ruminant livestock, though seasonal variations remain a challenge.

The grasses often lack essential nutrients and proteins necessary for optimal growth performance, leading to reduced weight gain (Marsetyo et al., 2022). Many studies have shown that supplementation of low-quality grasses with legumes not only enhances the nutritional value of animal diets but also improves growth performance. Incorporating legumes such as *C. calothyrsus* can effectively address these deficiencies due to their high protein content and favorable nutrient composition. This legume is widely cultivated in Yogyakarta and provides an affordable protein source. Therefore, as animal feed, its use must be optimized (Mudhita et al., 2024; Nurjanah et al., 2023; Roychan et al., 2023).

A strategy is needed to address the current challenges. One promising approach is to develop an innovative feed by combining *P. purpureum* cv. Gama Umami with *C. calothyrsus* and converting it into silage. This method provides an effective solution to ensure long-term feed availability while maintaining nutrient quality for ruminants. Producing silage with legume supplementation presents some challenges, as legumes can increase silage protein content but may also lead to undesirable fermentation (Mudhita et al., 2024). However, these issues can be mitigated by carefully controlling factors such as pH levels, lactic acid bacteria (LAB) growth, moisture content, and anaerobic conditions (Dong et al., 2023; Mudhita et al., 2024). Mudhita et al. (2024) demonstrated that silage made with *P. purpureum* cv. Gama Umami and *C. calothyrsus* yielded promising results for chemical quality and *in vitro* digestibility.

In addition to forage, farmers depend on concentration, particularly when fattening thin-tailed sheep to promote rapid weight gain (Alqaisi et al., 2021; Hao et al., 2020; Huang et al., 2021). However, the heavy reliance on concentrates is problematic due to the cost of protein, which competes with human consumption and is mainly dependent on imports (Roychan et al., 2023). The synergistic effect of optimizing the forage-to-concentrate ratio in livestock is essential for maintaining nutritional balance, enhancing animal productivity, and improving cost efficiency.

Building on these findings, it hypothesized that incorporating silage (*P. purpureum* cv. Gama Umami and *C. calothyrsus*) and increasing concentrate can also improve the growth performance of thin-tailed sheep compared to water spinach straw, an alternative forage commonly used by sheep farmers in this area. However, the ratio of forage and concentration needs to be further tested. The main purpose of this study was to investigate the effect of *P. purpureum* cv. Gama Umami and *C. calothyrsus* silage affected the growth performance, nutrient digestibility, and nitrogen utilization of thin-tailed sheep.

MATERIALS AND METHODS

Animal Care

The Animal Care and Use Committee at the Faculty of Veterinary Medicine, Universitas Gadjah Mada, Yogyakarta, Indonesia, approved this study (Certification no. 32/EC-FKH/int./2024).

Description of the Study Area

The study was carried out at Savana Farm, situated in Sardonoharjo, Ngaglik, Sleman, Yogyakarta, Indonesia, with geographic coordinates 7°42'23.4"S and 110°24'02.5"E, at an altitude of 290 meters above sea level (masl). The region experienced an average temperature of 28.62±1.07°C and a humidity of 79.03±5.35%, typical of tropical climates. The area also had an average light intensity of 5.49±2.83 hr/day and a relatively low wind speed of 1.77±0.43 m/s, making it suitable for diverse ecosystems. Data from the Indonesian Agency for Meteorological, Climatological and Geophysics (2024) supports these findings. Table 1 presents the details of the agroecological zones in the study area.

Table 1
Measurement of environmental conditions during the study

Variables	Mean±Standard deviation	Minimum	Maximum
Temperature (°C)	28.62±1.07	24.19	31.74
Wind velocity (m/s)	1.77±0.43	1.00	3.94
Humidity (%)	79.03±5.35	66.00	88.00
Light intensities (h)	5.49±2.83	0.30	10.30

Source: Indonesia Agency for Meteorological, Climatological, and Geophysics (2024)

Experimental Animals

Thirty thin-tailed ewes, with an initial live weight of 15.03±1.09 kg, aged 10 to 12 months, were used in the study. Each ewe was identified with an ear tag, and a deworming treatment using Leva-200® (containing levamisole, PT Tekad Mandiri Citra, Bandung, Indonesia) was administered orally at a dose of 1 cc/20 kg of live weight to ensure proper health management and facilitate observation throughout the study. Additionally, Wormectine® (containing ivermectin, PT Medion, Bandung, Indonesia) was provided to the sheep at the study's onset (adaptation period) to prevent worm infection. Ewes were randomly placed in individual pens, each measuring 70 × 150 cm, with water available *ad libitum*. Each sheep pen was fitted with separate containers for collecting feces and urine (metabolic pens). All animals were healthy, non-pregnant, and non-lactating adults.

Silage Material

Both grass (*P. purpureum* cv. Gama Umami) and legume (*C. calothyrsus*) were planted in Turi, Sleman, Yogyakarta, Indonesia (-7.6743080°S, 110.3729523°E), and harvested at 60 and 90 days of age, respectively. After harvesting, both the grass and legume were air-dried naturally for 2 to 4 days. It was considered ready for processing into silage if only a small amount of moisture was released when the material was squeezed in the palm. The edible parts of the grass and legumes were selected for silage. They were then chopped into 3-5 cm pieces using a chopping machine. The final silage mixture consisted of grass and legumes in a 70:30 ratio, respectively, with the addition of 7.5% wheat pollard as an accelerator to stimulate LAB fermentation. All components were thoroughly mixed and then placed into the drum silos gradually. Each layer was compacted by manually stepping on it with the feet to minimize trapped air and create an anaerobic condition during the fermentation process. Finally, the drum silos were closed with an airtight seal and then placed upside down (the silo lid was at the bottom). In this study, the silo used PVC drum silos that stand 82 cm tall and had a diameter of 42 cm, with a 100 kg capacity. Each silo was fermented for 21 days with a daily temperature of 24 to 27°C and a relative humidity of 55 to 65%. The silage was composed of *P. purpureum* cv. Gama Umami (21.10% DM), legumes (34.36% DM), and wheat pollard (86.00% DM). The chemical composition (%) of the silage is shown in Table 2.

Table 2
Chemical composition (%) of the raw materials used in the experimental diets

Composition (%)	**Ingredients**		
	Silage (*Pennisetum purpureum* cv. Gama Umami x *Calliandra calothyrsus*)*	**Nutrifeed® concentrate****	**Water spinach straw***
DM	28.19	86.00	88.56
OM	73.11	87.00	85.18
CP	13.58	13.00	6.28
CF	28.61	12.00	29.18
EE	5.76	7.00	2.45
NFE	25.16	45.00	42.49
TDN***	60.48	70.00	56.39

Note. *Analysis results from Forage and Pasture Laboratory, Faculty of Animal Science, Universitas Gadjah Mada; **KJUB Puspetasari; *** Calculated according to Hartadi et al. (1990); DM = Dry matter; OM = Organic matter; CP = Crude protein ; CF = Crude fiber ; EE = Extract ether ; NFE = Nitrogen-free extract; TDN = Total digestible nutrients

Diets

The diet treatments were formulated based on dry matter requirements, approximately 3.3% of the sheep's body weight, to support a daily weight gain of 25 g/day according to the National Research Council (NRC) (2007). Specifically, the diets delivered 42 g of crude protein (CP) and 240 g of total digestible nutrient (TDN) per day for sheep weighing 15 kg (Kearl, 1982). The diets were provided in equal portions, given twice a day at 8 a.m. and 4 p.m. For each treatment, the forage (either silage or water spinach straw) was mixed with a Nutrifeed® concentrate sourced from KJUB Puspetasari Klaten, Central Java, Indonesia, in different ratios. The composition included rice bran, wheat bran, molasses, palm kernel meal, cassava pulp, coconut cake, corn bran, corn gluten feed (CGF), and distiller's dried grains with soluble (DDGS). While the water spinach straw was taken from local farmers in Krasaan, Jogotirto, Berbah, Sleman Regency, Yogyakarta, with geographic coordinates 7°48′56″S and 110°27′49″E. Before it was given to the sheep, the water spinach straw had been cut into 1 to 3 cm pieces. The experimental diet treatments were as follows: T0 = 60% concentrate and 40% water spinach straw, T1 = 40% concentrate and 60% silage, and T2 = 60% concentrate and 40% silage. Table 1 presents the chemical composition (%) of the raw materials used in the experimental diets, while Table 3 presents the ingredient proportions and chemical compositions (% on DM basis) for the experimental diets for thin-tailed sheep.

Table 3
Ingredients proportion and chemical compositions in the feed ratio treatments (% on DM basis) of thin-tailed sheep

Ingredients	Treatments (%)		
	T0	T1	T2
Silage based on *Pennisetum purpureum* cv. Gama Umami x *Calliandra calothyrsus*	0	60	40
Nutrifeed® concentrate	40	40	60
Water spinach straw	60	0	0
Total	100	100	100
Chemical compositions [(%) DM]			
DM	87.02	51.31	62.88
OM	86.27	78.67	81.44
CP	10.31	13.35	13.23
CF	18.87	21.97	18.64
EE	5.18	6.26	6.50
NFE	44.00	33.10	37.06
TDN	64.56	64.29	66.19

Note. T0 = 60% concentrate and 40% water spinach straw; T1 = 40% concentrate and 60% silage; T2 = 60% concentrate and 40% silage; DM = Dry matter; OM = Organic matter; CP = Crude protein; CF = Crude fiber; EE = Extract ether; NFE = Nitrogen-free extract; TDN = Total digestible nutrients

Determination of Nutrient Intake, Growth Performance, and Feed Conversion

The *in vivo* period lasted for 56 days, including 14 days as an adaptation period (from day 1 to day 14), followed by 42 days as the actual study period (from day 15 to day 56).

During the adaptation period, all sheep were weighed before entering to determine their initial body weight as a basis for feed requirements. The purpose of this period was to acclimate the sheep to the diet treatment and to eliminate the effects of the previous feed. Feed was given twice a day at 8 a.m. and 4 p.m. Feeding and drinking water were provided *ad libitum*.

The actual study period began on day 15 (after the adaptation period was completed) and lasted until day 56 (the end of the *in vivo* period). During this period, the measurements of nutrient intake, ADG, and feed conversion were carried out. The treatment diet was administered daily at 8 a.m., while the remaining feed was collected and weighed at 7 a.m. the following day. Samples of both the provided feed and the remaining feed were collected daily for each individual sheep (g/sheep/day). The samples were weighed, placed in sample bags, and dried in an oven at 55°C for five days or until a constant weight was achieved. After drying, the samples were ground using a Willey mill with a 1 mm sieve for subsequent nutrient content analysis in the laboratory. The nutrient intake was determined based on metabolic live weight (g/kg $LW^{0.75}$). This method was adopted from Sanjaya et al. (2022):

nutrient intake was measured by subtracting the remaining feed from the provided feed and multiplying this value by the nutrient content of the feed, including dry matter (DM), organic matter (OM), crude protein (CP), crude fiber (CF), extract ether (EE); nitrogen-free extract (NFE), and total digestible nutrients (TDN). The ADG was carried out before morning feeding every two weeks (d-14, d-28, d-42, and d-56) to monitor the increase in sheep body weight during the dietary treatment period. In the ADG calculation (Suhartanto et al., 2022), the weight of each sheep was recorded before feeding, both at the initial body weight (IBW) and at the final body weight (FBW). The ADG absolute was determined by the formula: (FBW – IBW) / 14 days, while the relative ADG was determined by the formula: ADG absolute x 100%. Feed conversion was determined based on the ratio of DMI to ADG, measured by the formula: DMI/ADG (Suhartanto et al., 2022).

Determination of the Apparent Nutrient Digestibility and Nitrogen Utilization

Ten days before the end of the actual study period (from day 46 to day 56), feces and urine were collected from each sheep to analyze the apparent nutrient digestibility and nitrogen content in urine. These samples were collected every morning before the sheep were fed. The feces and urine sample collection method was adopted from Rahayu et al. (2021).

The feces excreted by each sheep over 24 hours were collected daily in a collection tray, separated from impurities such as remaining feed or foreign materials, and weighed to determine the total daily output. Subsequently, up to 50% of the total daily feces were sampled, placed into sample bags, and dried in an oven at 55°C for 5 days or until a constant weight was achieved to prevent decomposition and nitrogen loss. The dried samples were then weighed and stored in a refrigerator. At the end of the collection period (day 56), a daily sample from each sheep was ground, and as much as 10% of each was composited to produce a homogeneous composite sample. A sub-sample of the composite was then taken for chemical analysis of the feces. Apparent nutrient digestibility was calculated by the formula: (nutrient intake [NI] – a nutrient in feces) / NI × 100% (Rahayu et al., 2021).

Urine excreted by each sheep over 24 hours was collected daily in a plastic bucket, then filtered to remove contaminants. As much as 10% of the total daily volume was taken and acidified with 10% sulfuric acid (H_2SO_4 98%, Merck, Germany) to achieve an acidic pH (below 3), in order to preserve nitrogen content. The acidified samples were transferred into 50 ml bottles and stored in a freezer at -20°C. Daily urine samples collected from each sheep over a 10-day collection period were combined to obtain a homogeneous composite sample. Sub-samples from the composite were then used for nitrogen analysis in the urine. The nitrogen balance was assessed by determining the difference between input nitrogen from feed and the nitrogen excreted in feces and urine (Rahayu et al., 2021).

Chemical Analysis

The analysis of feed and feces was conducted following the Association of Official Analytical Chemists (AOAC) guidelines to determine dry matter (AOAC 934.01), crude protein (AOAC 2001.11), crude fiber (AOAC 978.10), ether extract (AOAC 920.39), and ash (AOAC 942.05) (AOAC, 2005). The nitrogen-free extract (NFE) was calculated by subtracting the sum of CP, EE, CF, and ash from the DM, as follows: NFE = [100 - (CP + EE + CF + ash)]. The total digestible nutrients (TDN) were calculated by the formula: TDN = -26.685 + 1.334(CF) + 6.598(EE) + 1.423(NFE) + 0.967(CP) – 0.002$(CF)^2$ – 0.67$(EE)^2$ – 0.024(CF)(NFE) – 0.055(EE)(CP) + 0.039(EE)(CP) (Hartadi et al., 1990). The nitrogen concentration in urine was assessed using Kjeldahl method (AOAC 2001.11) in the AOAC-recommended method (AOAC, 2005).

Study Design and Data Analysis

The data was analyzed by a CRD with a unidirectional arrangement, involving three different diet treatments and ten replications. The independent factor was the diet treatment: T0 = 60% concentrate and 40% water spinach straw, T1 = 40% concentrate and 60% silage, and T2 = 60% concentrate and 40% silage. The variables examined were nutrient intake, ADG, feed conversion, apparent nutrient digestibility, and nitrogen utilization. Statistical analysis was performed using analysis of variance (ANOVA) through SPSS software (version 26.0). A *p*-value < 0.05 was considered to determine significant differences between the treatment means.

RESULT AND DISCUSSION

Nutrient Intake

Nutrient intake observed in this study was expressed on a metabolic live weight (g/kg $LW^{0.75}$) basis, including DM, OM, EE, CF, CP, and NFE in each treatment. The statistical analysis results in this study show that nutrient intake (DM, OM, EE, CF, CP, and NFE) exhibited significant differences among treatments ($p<0.05$). Nutrient intake of thin-tailed sheep fed based on silage in different ratios (g/kg $LW^{0.75}$/day) is presented in Table 4.

According to the statistical analysis, the incorporation of *P. purpureum* cv. Gama Umami and *C. calothyrsus* silage (T1 and T2) in different ratios significantly increased DMI by 3.67 and 13.07%, respectively, compared to water spinach straw (T0) ($p<0.05$). Moreover, T2 exhibited a significantly higher DMI than T1, with an increase of 9.06% ($p<0.05$). The results of this study indicate that feed containing high CP and low CF produced higher DMI. The higher DMI in the silage (T1 and T2) than in water spinach straw (T0) resulted in higher CP content in T1 and T2. Meanwhile, the higher DMI in T2 than in T1 influenced the low CF content in T2. Several factors influenced the high DMI

Table 4
Nutrient intake of thin-tailed sheep fed based on silage in different ratios (g/kg LW$^{0.75}$/day)

Nutrient intake (g/kg LW$^{0.75}$/day)	**Treatments**			**SEM**	***p*-value**
	T0	**T1**	**T2**		
DM	57.99^{c}	60.12^{b}	65.57^{a}	0.63	0.00
OM	50.03^{b}	45.66^{c}	52.76^{a}	0.58	0.00
EE	3.00^{c}	4.14^{a}	3.47^{b}	0.09	0.00
CF	10.95^{b}	12.23^{a}	12.06^{a}	0.13	0.00
CP	5.98^{c}	8.36^{a}	6.78^{b}	0.18	0.00
NFE	25.51^{b}	18.84^{c}	28.76^{a}	0.77	0.00

Note. Different superscripts in the same row represent significant differences ($p<0.05$); T0 = 60% concentrate and 40% water spinach straw; T1 = 40% concentrate and 60% silage; T2 = 60% concentrate and 40% silage; SEM = Standard error of the mean; DM = Dry matter; OM = Organic matter; EE = Ether extract; CF = Crude fiber; CP = Crude protein; NFE = Nitrogen-free extract

in the silage (T1 and T2) compared to water spinach straw (T0). First, the inclusion of *Calliandra* in the forage ratios increased the protein content of the silage. Legumes such as Calliandra are known for their high protein content, which enhances the overall nutritional value of the feed. This is supported by the chemical composition of silage, which contained 13.58% CP compared to 6.28% in water spinach straw, as shown in Table 2. Furthermore, CP contents in T1 (13.35%) and T2 (13.23%) were higher than in T0 (10.31%), as shown in Table 3. Second, a synergistic interaction between pollard and Calliandra in the silage may have enhanced rumen microbial activity. Such synergy can optimize fermentation, accelerate rumen emptying, and ultimately increase feed intake. Third, fermented feeds generally exhibit more desirable physical characteristics (e.g., aroma, texture, and shape), which improve palatability and acceptance by ruminants. The findings of this study align with those of Abdelraheem et al. (2023), who observed that sheep fed with higher CP levels tend to consume more feed, likely due to the improved palatability and nutritional content. A study on Assaf lambs revealed that those on high-protein diets (23% CP) had significantly higher DMI at 885 g/day than lambs fed lower-protein diets (16% CP) (Saro et al., 2020). The combination of legumes and grasses in silage not only enhances protein content but also improves its overall nutritional value (Castro-Montoya & Dickhoefer, 2018; Niderkorn et al., 2015). Previous studies have shown that increasing the proportion of legumes, such as *Calliandra*, in ruminant rations can increase the degradation of other feeds, such as grasses (Rira et al., 2022). This synergistic blending not only increases the overall digestibility of the ration but also accelerates rumen emptying. Increasing the rumen turnover rate is essential for optimizing feed intake and utilization, as faster rumen emptying allows animals to consume more feed (Knowles et al., 2017; Sriyani et al., 2018).

Fermented feeds are generally more palatable than non-fermented ones due to factors like aroma, texture, and shape, which influence sheep's feeding preferences (Ahmad et al., 2023; Berthel et al., 2022). Additionally, LAB involved in silage fermentation can contribute to a better taste and scent, thereby encouraging greater intake (Ridwan et al., 2023). Han et al. (2022) noted that LAB plays a key role in shaping the fermentation process and the microbial community within silage.

Although both silage treatments improved DMI, T2, which contained 60% concentrate, resulted in a significantly higher DMI than T1, which contained 40% concentrate ($p<0.05$). This may be due to the inverse relationship between CF content and DMI. Despite having comparable CP levels (T1: 13.35%, T2: 13.23%), T2 had a lower CF content (18.64%) than T1 (21.97%), contributing to its higher DMI, as presented in Table 3. A higher concentrate ratio reduces the structural carbohydrate content of the diet, which facilitates rumen emptying and enhances feed intake. This finding aligns with Ipharraguerre et al. (2002), who reported that diets high in neutral detergent fiber (NDF) reduce DMI due to increased gut fill and slower digestion rates. High CF content increases satiety by slowing digestion, potentially limiting overall nutrient intake. Several studies have shown that extended rumination times are associated with reduced DMI, as animals spend more time chewing fibrous feeds and less time-consuming additional feed. Parente et al. (2016) demonstrated that diets high in fiber increase chewing and rumination time, thereby reducing voluntary intake. Similarly, Sanjaya et al. (2022) reported that low-quality forages with high CF content are associated with reduced DMI. Additionally, CF content influences the metabolic energy (ME) value of the feed. According to Utama et al. (2023), CF can improve the ME value, potentially leading to higher feed consumption. In the present study, DMI was highest in T2, followed by T1 and T0, with values of 65.57, 60.12, and 57.99 g/kg $LW^{0.75}$/day, respectively. However, these values were lower than those reported by Sanjaya et al. (2022), who observed a DMI of 78.88 g/kg $LW^{0.75}$/day in thin-tailed sheep fed a diet consisting of 25% *P. purpureum* cv. Gama Umami + 8% water spinach + 68% concentrate.

Organic matter intake (OMI) in this study showed a significant effect on all treatments ($p<0.05$). Interestingly, the OMI value at T2 was significantly higher than in T0, whereas T1 exhibited a lower value than T0 ($p<0.05$). Although T0 and T2 had the same concentrate ratios (60%), OMI in T2 remained significantly higher than in T0 ($p<0.05$). This finding is consistent with the DMI, which was also highest in T2 compared to the other treatments. These results suggest a synergistic effect of the balanced combination of silage and concentrate in T2, enhancing the efficiency of both DMI and OMI. The close relationship between DMI and OMI can be attributed to the fact that the majority of dry matter consists of organic matter (Abun et al., 2022). Accordingly, an increase in DMI tends to be accompanied by a rise in OMI, provided the feed composition is of good quality. Carvalho et al. (2020) further emphasized the critical role of feed quality in determining nutrient intake, which correlates strongly with both DMI and OMI. Interestingly, DMI in T1 was higher than in T0; OMI in T1 was the lowest among all treatments. This discrepancy is likely due to the suboptimal feed composition in T1, particularly its high CF or indigestible lignin content, which limits the proportion of OM that can be effectively utilized by livestock. As noted by Carvalho et al. (2020), feed quality is a critical factor influencing nutrient intake efficiency. Diets with poor nutritional value—characterized by high CF content—may result in high DMI but low nutrient absorption, including OMI. Specifically, elevated levels of NDF or acid detergent fiber (ADF) can lead to this paradoxical effect: DMI increases while the absorption of organic matter remains limited due to the physical constraints imposed by fibrous components on digestion (Huuskonen & Pesonen, 2017; Oliveira et al., 2020). In the present study, OMI was highest in T2, followed by T0 and T1, with values of 52.75, 50.03, and 45.66 g/kg $LW^{0.75}$/day, respectively. However, these values were lower than those reported by Sanjaya et al. (2022), who observed an OMI of 71.06 g/kg $LW^{0.75}$/day in thin-tailed sheep fed a diet consisting of 25% *P. purpureum* cv. Gama Umami, 8% water spinach, and 68% concentrate.

Ether extract intake (EEI) in this study showed a significant effect on all treatments (p<0.05). The incorporation of *P. purpureum* cv. Gama Umami and *C. calothyrsus* silage (T1 and T2) in different ratios significantly increased EEI compared to water spinach straw (T0) (p<0.05). Interestingly, although both silage treatments increased EEI, the value was significantly higher in T1 than in T2 (p<0.05). These results indicate a strong correlation between EEI and total energy intake in thin-tailed sheep, with consistent trends observed across treatments. Notably, T1 produced the highest EEI despite exhibiting the lowest OMI. This condition reflects a compensatory physiological response, where livestock increase fat consumption to meet energy needs and maintain energy balance. In contrast, at T2, energy balance has been achieved. The relationship between EEI and energy intake becomes especially critical under conditions of limited OMI availability. Tewari et al. (2022) reported that supplementation with crude lecithin derived from rice bran EE increased the digestibility of crude lecithin but reduced the digestibility of DM and OM. This supports the notion that under suboptimal feeding conditions, livestock may rely more heavily on fat as an alternative energy source, influencing overall metabolic function. Furthermore, dos Santos et al. (2011) found a significant interaction between EEI and energy intake levels in sheep fed different corn varieties, highlighting the broader relevance of EEI in ruminant energy metabolism. Overall, the interaction between EEI and energy retention is vital for maintaining energy balance, particularly in animals under nutritional constraints. In the present study, EEI was highest in T1, followed by T2 and T0, with values of 4.14, 3.47, and 3.00 g/kg $LW^{0.75}$/day, respectively. Sanjaya et al. (2022), who observed an EEI of 3.89 g/kg $LW^{0.75}$/day in thin-tailed sheep fed a diet consisting of 25% *P. purpureum* cv. Gama Umami, 8% water spinach, and 68% concentrate.

Crude fiber intake (CFI) in this study showed the incorporation of *P. purpureum* cv. Gama Umami and *C. calothyrsus* silage (T1 and T2) in different ratios significantly increased CFI compared to water spinach straw (T0) (p<0.05). While T1 and T2 did not show a significant difference (p>0.05). In this study, CFI values were closely associated with other intake parameters such as DMI and OMI. The lowest CFI observed in T0 correlated with its lowest DMI (57.99 g/kg $LW^{0.75}$/day). In contrast, T2 recorded the highest DMI (65.57 g/kg $LW^{0.75}$/day), accompanied by a proportional increase in CFI, indicating that the ration in T2 supported fiber intake without compromising overall feed consumption. While T1 also showed relatively high CFI, it was accompanied by the lowest OMI (45.66 g/kg LW0.75/day), suggesting an imbalance in organic matter composition, likely due to the ration's high fiber content (21.97%; Table 3). Therefore, T2 appears to represent a more optimal balance among DMI, OMI, and CFI, reflecting a ratio that supports both nutrient intake and utilization. Fiber plays a key role as a physical stimulant in ruminants, promoting grazing behavior, mastication, and salivation—all of which are essential for maintaining rumen health and facilitating efficient fermentation (Carvalho et al., 2020). High CFI generally reflects low energy density of feed. To meet energy needs, ruminants will increase DMI as a form of compensation (Carvalho et al., 2020). This means that when forage quality is low, animals tend to increase CFI to maximize nutrient acquisition. One reason for the increase in CFI in low OMI conditions is the decrease in forage digestibility. Forage-based diets, such as hay, typically contain high CF but low levels of digestible organic matter, prompting animals to increase fiber intake despite its limited energy yield. In the present study, CFI was highest in T1, followed by T2 and T0, with values of 12.23, 12.06, and 10.95 g/kg $LW^{0.75}$/day, respectively. However, these values were lower than those reported by Sanjaya et al. (2022), who observed a CFI of 14.75 g/kg $LW^{0.75}$/day in thin-tailed sheep fed a diet consisting of 25% *P. purpureum* cv. Gama Umami, 8% water spinach, and 68% concentrate.

Crude protein intake (CPI) in this study showed a significant effect on all treatments (p<0.05). The incorporation of *P. purpureum* cv. Gama Umami and *C. calothyrsus* silage (T1 and T2) in different ratios significantly increased CPI compared to water spinach straw (T0) (p< 0.05). Interestingly, although both silage treatments increased CPI, the value was significantly higher in T1 than in T2 (p< 0.05). In this study, the increase in CPI was related to the CP content in the ration and the availability of digestible protein. Higher dietary protein levels enhance the likelihood of meeting the animals' protein requirements. The CP content in the rations for T0, T1, and T2 was 10.31%, 13.35%, and 13.23%, respectively (Table 3), with CPI values reflecting this composition. These findings are consistent with those of Fajemisin et al. (2020), who reported that goats fed diets with higher-quality protein sources exhibited greater CPI. In this study, the CPI value at T1 (8.36 g/kg $LW^{0.75}$/day) was recorded as higher than that at T2 (6.78 g/kg $LW^{0.75}$/day), although the CP content in both rations was relatively similar. This difference can be attributed to the feed composition, where T1 has a forage to concentrate ratio of 60:40, while T2 is 40:60. The higher CPI at T1 suggests that protein derived from silage may be more bioavailable, leading to greater protein utilization despite a lower total DMI than T2. These findings align with Yousefi et al. (2025) , who noted that fermentation can enhance nutritional quality by improving protein solubility and digestibility. Furthermore, the activity of rumen microbes in degrading protein plays a critical role in determining CPI, implying that silage-derived protein in T1 was more effectively utilized by rumen microorganisms, resulting in greater protein intake. In the present study, CPI was highest in T1, followed by T2 and T0, with values of 8.36, 6.78, and 5.98 g/kg $LW^{0.75}$/day, respectively. However, these values were lower than those reported by Sanjaya et al. (2022), who observed a CPI of 11.84 g/kg $LW^{0.75}$/day in thin-tailed sheep fed a diet consisting of 25% *P. purpureum* cv. Gama Umami, 8% water spinach, and 68% concentrate.

Nitrogen-free extract intake (NFEI) in this study was significantly affected by all treatments (p<0.05). Notably, NFEI at T2 was significantly higher than T0, while T1 showed a significantly lower value than T0 (p<0.05). The NFEI was found to correlate with other nutritional components, such as CP, EE, and CF. In T1, there was high CF content and CFI, and it also had the lowest TDN value at 64.29% exhibiting the lowest NFEI. In contrast, T2 recorded the highest TDN value at 66.19% resulting in the highest NFEI. The availability of energy-rich NFE in the diet is directly correlated with microbial protein synthesis in the rumen (Abdelkader., 2019; Parchami et al., 2024). When ruminants consume a diet high in NFE, the microbial population utilizes carbohydrates to synthesize microbial proteins from non-protein nitrogen sources such as urea and ammonia (Molitor et al., 2023). Microbial proteins are crucial because they pass into the small intestine, where they are absorbed and provide essential amino acids for growth and production. Thus, maintaining a balanced NFE intake is critical for maximizing microbial protein synthesis and optimizing the animal's nutritional status (Wei et al., 2024). A balanced NFEI supports optimal rumen fermentation processes, resulting in increased production of volatile fatty acids (VFAs), which serve as the primary energy source for their host ruminants (Mudgal et al., 2018). Research has demonstrated that diets with appropriate NFE levels enhance the production of key VFAs, particularly propionate and butyrate, thereby improving overall energy availability (Liu et al., 2024).

Growth Performance and Feed Conversion

Growth performance determination can be done by measuring ADG absolute, ADG relative, and feed conversion. The statistical analysis results in this study show that ADG absolute and ADG relative differed significantly among treatments (p<0.05). While incorporating *P. purpureum* cv. Gama Umami and *C. calothyrsus* silage (T1 and T2) exhibited lower feed conversion ($p<0.05$) than water spinach straw (T0), although T1 and T2 showed no significant difference ($p>0.05$). The comparison of ADG absolute, ADG relative, and feed conversion of thin-tailed sheep fed based on silage in different environments is presented in Figure 1.

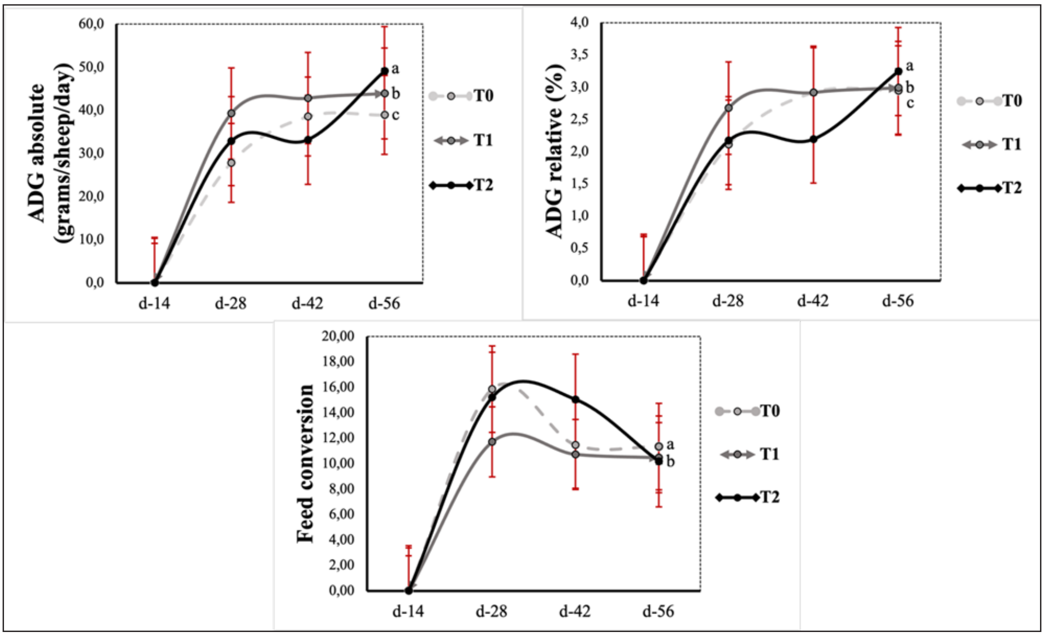

Figure 1. Comparison between the average daily gain (ADG) absolute, relative, and feed conversion of thin-tailed sheep fed based on silage in different ratios
Note. T0 = 60% concentrate and 40% water spinach straw; T1 = 40% concentrate and 60% silage; T2 = 60% concentrate and 40% silage; a, b, and c represent significant differences ($p<0.05$)

As shown in Figure 1, the incorporation of *P. purpureum* cv. Gama Umami and *C. calothyrsus* silage (T1 and T2), combined with different concentrate ratios, significantly increased ADG by 12.78 and 26.02%, respectively, compared to water spinach straw (T0) ($p<0.05$). Furthermore, T2 showed a higher ADG than T1 ($p<0.05$). Relative ADG is a percentage result of absolute ADG, so it will follow the results shown as absolute ADG.

In this study, ADG was positively associated with the nutrient content and the intake of nutrients, as indicated in Tables 3 and 4. The nutrient content is a key factor in determining ADG in sheep. The addition of high-protein feed improves nutrient availability, thereby enhancing growth performance. Increased feed intake typically results in higher ADG, as long as the feed is of high quality. Suhartanto et al. (2022) highlighted the strong relationship between feed intake and ADG, emphasizing the need to ensure adequate feed intake to support growth. This aligns with the findings of this study, where thin-tailed sheep fed on silage showed DMI ranked from highest to lowest were T2, T1, and T0, at 65.57, 60.12, and 57.99 g/kg $LW^{0.75}$/day, respectively, with both absolute and relative ADG following the same pattern. The ADG was influenced by multiple factors, especially when considering the use of fermented feeds. This study incorporated silage based on *P. purpureum* cv. Gama Umami x *C. calothyrsus* (T1 and T2), which was easier to digest due to rumen activity in breaking down fiber. Silage enhances nutrient availability, increases palatability, and promotes better digestion, all of which contribute to improved ADG (Y. Xu et al., 2024). In this study, the use of silage enhanced the overall fermentation quality of the silage, as presented in Table 2. Previous research demonstrated that combining legumes with grasses can enhance the fermentation properties of silage, leading to better nutrient availability and improved growth performance (Niderkorn et al., 2015). To prevent weight loss in sheep, the minimum CP content in their diet should exceed 7.5% of DM (Yimenu & Abebe, 2023). According to the results of this study, the absolute ADG from lowest to highest were T0, T1, and T2 at 38.96, 43.94, and 49.10 grams/sheep/day, respectively. The results were lower than those reported by Sanjaya et al. (2022), who found that thin-tailed sheep fed 25% *P. purpureum* cv. Gama Umami+8% water spinach straw+68% concentrate had an ADG of 105.48 grams/sheep/day.

Thin-tailed sheep that were fed the incorporation of *P. purpureum* cv. Gama Umami and *C. calothyrsus* silage (T1 and T2), combined with different concentrate ratios, exhibited lower feed conversion ($p<0.05$) than water spinach straw (T0), although T1 and T2 showed no significant difference ($p>0.05$). Feed conversion in this study was influenced by factors such as feed quality, digestibility, and the efficiency with which sheep utilize nutrients. The higher the nutrient content, the lower the feed conversion. According to the results of this study, the nutrient content of feeds T1 and T2 was higher than that of T0, resulting in lower feed conversion. Sheep consuming higher-quality feed requires less feed to meet their nutritional needs compared to those consuming lower-quality feed. This supports the findings of Sileshi et al. (2021), who stated that livestock performance improves when they are provided with high-quality feed that has a balanced nutrient composition. Therefore, the nutrient levels in feed play an indirect role in determining the feed conversion. Feed conversion showed how much feed was needed to add 1 kg of animal body weight, and a smaller feed conversion value meant that more feed was used efficiently. The feed conversion value depends on the quality of the feed distributed. Sanjaya et al. (2020) stated that the smaller the ratio conversion values are, the less ratio is used to produce units of body weight gain. The nutrients in the feed play an essential role in determining the feed conversion value. Increasing body weight requires more building components, namely water, protein, fat, carbohydrate, and minerals. Feed conversion was closely related to production costs (Ahmed et al., 2020). The feed conversion in this study, from the lowest to the highest, was T2, T1, and T0 at 10.20, 10.47, and 11.38. For increasing 1 kg of body weight, the treatment T2 required 10.20 kg of feed, while T1 and T0 required 10.47 and

11.38 kg, respectively. The feed conversion in this study was higher than reported by Sanjaya et al. (2022), thin-tailed sheep fed a diet consisting of 25% *P. purpureum* cv. Gama Umami+8% water spinach + 68% concentrate showed feed conversion of 5.75.

Apparent Nutrient Digestibility

Apparent nutrient digestibility was measured for DM, OM, EE, CF, CP, NFE, and TDN in each treatment. The statistical analysis results in this study showed apparent digestibility of OM, NFE, and TDN exhibited significant differences among treatments (p<0.05). The apparent digestibility of DM, EE, CF, and CP did not show any statistical differences among treatments (p>0.05). The apparent nutrient digestibility of thin-tailed sheep fed based on silage in different rasios (%) is presented in Table 5.

Table 5
Apparent nutrient digestibility of thin-tailed sheep fed based on silage in different ratios (%)

Nutrient digestibility (%)	Treatments			SEM	*p*-value
	T0	T1	T2		
DM	67.97	68.60	69.76	0.55	0.42
OM	66.15^{a}	62.52^{b}	66.38^{a}	0.71	0.04
EE	77.54	82.58	79.48	0.91	0.07
CF	65.77	61.13	61.26	1.05	0.12
CP	73.06	70.84	73.68	0.53	0.07
NFE	57.27^{b}	51.10^{c}	63.23^{a}	1.18	0.00
TDN	54.17^{a}	51.13^{b}	56.10^{a}	0.65	0.00

Note. Different superscripts in the same row represent significant differences (p<0.05); T0 = 60% concentrate and 40% water spinach straw; T1 = 40% concentrate and 60% silage; T2 = 60% concentrate and 40% silage; SEM = Standard error of the mean; DM = Dry matter; OM = Organic matter; EE = Ether extract; CF = Crude fiber; CP = Crude protein; NFE = Nitrogen-free extract; TDN = Total digestible nutrients

According to the statistical analysis, dry matter digestibility (DMD) did not differ significantly among treatments (p>0.05). DMD is influenced by multiple factors, including nutrient composition of the feed, processing methods, intake levels, and retention time within the rumen. When examined alongside the intake data presented in Table 4, treatment T2 exhibited the highest DMI, followed by T1 and T0. Despite these differences in DMI, DMD values remained consistent across treatments. Notably, T0 and T2 shared the same forage-to-concentrate ratio of 40:60, whereas T1 had a ratio of 60:40. These findings suggest that, under identical forage-to-concentrate ratios, silage-based feed (T2) may facilitate a faster digesta flow rate than water spinach straw (T0). The digesta flow rate in the rumen refers to the speed at which feed passes through the rumen compartment. J. Xu et al. (2025) explained that the fermentation process can reduce the size of feed particles, thereby enabling them to exit the rumen more rapidly. In general, smaller particles have a higher passage rate than larger ones, which are typically retained longer to undergo further fermentation (Al-Mamouri & Al-Ani, 2024; F. Li et al., 2019). Moreover, increased feed intake is associated with an accelerated digesta flow rate, which may shorten retention time and potentially diminish digestive efficiency. However, ruminants that consistently consume high-quality forage tend to maintain a stable and efficient rumen microbial ecosystem, which is essential for optimal fermentation and nutrient synthesis (Husain et al., 2018). In contrast, abrupt changes in digesta flow rate, particularly those induced by high concentrate diets, can disrupt the rumen microbial population and elevate the risk of metabolic disorders such as subacute ruminal acidosis (SARA) (Franzolin & Dehority, 2010). In the present study, DMD ranged from 67.97 to 69.76%. However, these values were lower than those reported by Sanjaya et al. (2022), who observed a DMD of 71.14% in thin-tailed sheep fed a diet consisting of 25% *P. purpureum* cv. Gama Umami, 8% water spinach, and 68% concentrate.

Organic matter digestibility (OMD) in T1 was lower than in T0 and T2 ($p<0.05$). While T0 and T2 did not show a significant difference ($p>0.05$). One of the primary factors contributing to the low OMD is the high CF in the feed, particularly due to the presence of cellulose and lignin. In this study, treatment T1 included a higher proportion of forage (60%) than the other treatments, which resulted in the highest CF content of 21.97%. In contrast, treatments T0 and T2 each contained 40% forage and exhibited similar CF levels, measured at 18.87 and 18.64%, respectively. Click or tap here to enter text.When forages form a substantial part of the diet, they frequently contain higher fiber levels, which can lead to decreased digestibility if not balanced adequately with concentrates that supply rapidly fermentable carbohydrates (Manthey et al., 2016). Furthermore, as reported by J. Li et al. (2022), different types of roughages affect the digestibility of organic matter and NDF, with higher forage intake associated with improved digestive efficiencies in Holstein calves. According to Jamarun et al. (2024), feeds such as mature grasses or the stem portions of green forages contain higher levels of lignin. This lignin can inhibit the activity of rumen enzymes and microbes that break down fibrous components, thereby reducing the efficiency of nutrient utilization in ruminant livestock. In the present study, OMD ranged from 62.52 to 66.38%. However, these values were lower than those reported by Sanjaya et al. (2022), who observed an OMD of 73.08% in thin-tailed sheep fed a diet consisting of 25% *P. purpureum* cv. Gama Umami, 8% water spinach, and 68% concentrate.

Ether extract digestibility (EED) did not differ significantly among treatments ($p>0.05$), indicating a pattern similar to that observed for DMD. DMD strongly influences fat digestibility in livestock, as both parameters are closely linked in the digestive process.

Several studies have demonstrated that an increase in DMD is generally accompanied by an improvement in EEI, highlighting the interrelationship between these two variables (Mukhopadhyay, 2001). Similarly, Widiana et al. (2021) emphasized that high DMD indicates good feed quality, which, in turn, enhances the digestibility of fat and protein. In the present study, EED ranged from 77.54 to 79.48%. However, these values were lower than those reported by Sanjaya et al., (2022), who observed an EED of 86.23% in thin-tailed sheep fed a diet consisting of 25% *P. purpureum* cv. Gama Umami, 8% water spinach, and 68% concentrate.

Crude fiber digestibility (CFD) did not differ significantly among treatments (p>0.05). Interestingly, although T1 included a higher forage proportion (60%) to concentrate (40%), its CFD value was comparable to those of T0 and T2, both of which had a lower forage proportion (40%) and a higher concentrate level (60%). This finding suggests that silage, despite its high fiber content, can still be effectively degraded by rumen microbes. A key factor supporting the digestibility of CF in silage is the activity of specific rumen microorganisms that efficiently break down fibrous components. Ferreira et al. (2016) reported that the synergistic interaction between proteolytic and cellulolytic bacteria in the rumen plays a crucial role in fiber degradation, thereby enhancing digestibility. The complex interplay among diverse microbial populations increases the efficiency of fiber breakdown, allowing for high digestibility even in fiber-rich feeds. Ribas et al. (2019) also noted that silage with good fermentation quality exhibited greater dry matter loss in the rumen, indicating a positive relationship between fermentation quality and fiber digestibility. Effective fermentation promotes an environment conducive to microbial activity, which in turn improves the digestibility of CF in silage. In the present study, CFD ranged from 61.13 to 65.77%. However, these values were lower than those reported by Sanjaya et al. (2022), who observed a CFD of 57.99% in thin-tailed sheep fed a diet consisting of 25% *P. purpureum* cv. Gama Umami, 8% water spinach, and 68% concentrate.

Crude protein digestibility (CPD) did not differ significantly among treatments (p>0.05). Although T1 included a higher proportion of forage (60%) relative to concentrate (40%), its CPD was comparable to that of T0 and T2, both of which contained a lower proportion of forage (40%) and a higher proportion of concentrate (60%). It is important to note that the silage used in this study was a mixture of *P. purpureum* cv. Gama Umami and *C. calothyrsus* in a 70:30 ratio. Calliandra species, including *C. calothyrsus*, are known for their relatively high levels of condensed tannins (CT), which can influence protein utilization in ruminants. Mudhita et al. (2024) reported that a silage blend of *P. purpureum* cv. Gama Umami and *C. calothyrsus* (70:30) contained 2.10% total tannins. Tannins are known to form complexes with feed proteins, thereby protecting them from ruminal degradation and increasing the flow of amino acids to the small intestine (Yanza et al., 2021). Therefore, the potential formation of tannin-protein complexes in the T1 ration may have conferred a protective effect, reducing excessive protein degradation in the rumen and enhancing protein utilization efficiency. This aligns with findings by Jayanegara et al. (2019), who reported that moderate tannin levels can increase the rumen undegradable protein (RUP) fraction, making more protein available for intestinal absorption and improving overall nitrogen efficiency. Similarly, Kondo et al. (2007) demonstrated that tannins can slow ruminal protein degradation and increase amino acid flow to the intestine. Controlled inclusion of tannins in ruminant diets has been shown to enhance protein utilization efficiency (Arik et al., 2024). Supporting this, Mudhita et al. (2024) found that supplementing Gama Umami silage with *Calliandra* at 10, 20, and 30% increased *in vitro* protein digestibility to 13.22, 14.68, and 16.86%, respectively. These findings reinforce the notion that moderate tannin inclusion can improve protein digestibility in ruminant feed. In the present study, CPD ranged from 70.84 to 73.68%. However, these values were lower than those reported by Sanjaya et al. (2022), who observed a CPD of 77.06% in thin-tailed sheep fed a diet consisting of 25% *P. purpureum* cv. Gama Umami, 8% water spinach, and 68% concentrate.

Nitrogen-free extract digestibility (NFED) showed significant differences among treatments ($p<0.05$), with the highest value observed in T2, followed by T0, and the lowest in T1. The elevated NFED in T2 is likely attributed to its higher energy content and greater proportion of readily digestible carbohydrates. In contrast, the low NFED in T1 suggests limitations in the availability or quality of non-fiber carbohydrates accessible to the animals. According to McDonald et al. (2011), NFE digestibility is strongly influenced by the composition of feed ingredients—particularly the proportion of rapidly fermentable energy sources such as starch and sugars—and by the presence of anti-nutritional factors that may inhibit digestion. The reduced NFED in T1 may also be associated with its high CF content (21.97%), which can hinder the utilization of non-structural carbohydrates (Van Soest, 1994). Elevated fiber levels can increase rumen emptying rate and reduce fermentation efficiency, thereby limiting substrate availability for digestive enzymes.

The results demonstrated that the Total Digestible Nutrients (TDN) values in thin-tailed sheep differed significantly among treatments ($p<0.05$), with the highest value observed in T2, followed by T0, and the lowest in T1. The TDN values represent the total utilizable energy derived from feed and are influenced by the digestibility of various nutrient fractions, including dry matter, organic matter, NFE, and fat. The elevated TDN value in T2 indicates that a higher concentrate proportion in the diet enhances energy utilization, as corroborated by the high NFE digestibility (63.23%), reflecting increased availability of readily fermentable non-structural carbohydrates. Conversely, the reduced TDN value in T1 is likely attributable to the high silage proportion (60%) with a substantial crude fiber content (21.97%). Excessive fiber may impair ruminal fermentation efficiency, accelerate rumen evacuation, and consequently limit optimal energy utilization. Additionally, the lower NFE digestibility observed in T1 (51.10%) further contributes to the decreased TDN in this treatment. Nonetheless, the relatively high TDN value in T0 suggests that water spinach straw possesses potential as an energy source when appropriately balanced with concentrate. The critical role of energy-protein balance in the diet is underscored by Dutta et al. (2002), who reported that protein supplementation can enhance metabolizable energy and improve the efficiency of TDN utilization. Therefore, optimizing the proportional composition of feed ingredients is essential for maximizing the nutritional value and performance of livestock.

Nitrogen Utilization

Nitrogen utilization observed in this study included N intake, N fecal and urine, digestible nitrogen, N retention, and biological value in each treatment. The statistical analysis results in this study showed N intake, N fecal, N digestible, and N retention exhibited significant differences among treatments ($p<0.05$). While incorporating *P. purpureum* cv. Gama Umami and *C. calothyrsus* silage (T1 and T2) exhibited lower N urine and higher biological value than water spinach straw (T0) ($p<0.05$), although T1 and T2 showed no significant difference ($p>0.05$). Nitrogen content in feces and urine, and balance in thin-tailed sheep (g/kg $LW^{0.75}$/day) presented in Figure 2.

The elevated N intake observed in T1 was primarily due to the higher CPI. The relationship between N intake and CPI is displayed in Table 4. The feed ratio treatments in this study were ranked from highest to lowest in CPI as T1, T2, and T0, with values of 8.36±0.16, 6.78±0.13, and 5.98±0.00 g/kg $LW^{0.75}$/day, respectively, following a similar pattern for N intake. There is a positive correlation between CPI and N intake, meaning that as CPI increases, N intake also rises. Crude protein represents the total protein content in feed, which includes both true protein and non-protein nitrogen (NPN). When animals consume more protein, they are ingesting greater amounts of nitrogen, as proteins are made up of amino acids that contain nitrogen in their structure. Previous studies have shown that as the CP content in the diet increases, N intake also increases proportionally due to the nitrogen present in the protein sources (Shen et al., 2020).

The amount of nitrogen excreted in feces was influenced by microbial digestion. A reduction in N fecal leads to improved nitrogen digestibility, making nitrogen use more efficient. One key factor affecting N fecal was the protein content and feed quality. Diets with higher CP result in increased N intake, which can lead to greater N fecal as shown in this study (Figure 2). In this experiment, T1 had the highest N intake, followed by T2, and then T0, with N fecal following the same trend. Zhou et al. (2015) emphasized that the digestibility of protein sources plays a critical role, as diets with more digestible proteins typically result in lower nitrogen loss in feces due to improved absorption and utilization. Although this study utilized silage-based diets, the varying ratios of forage and

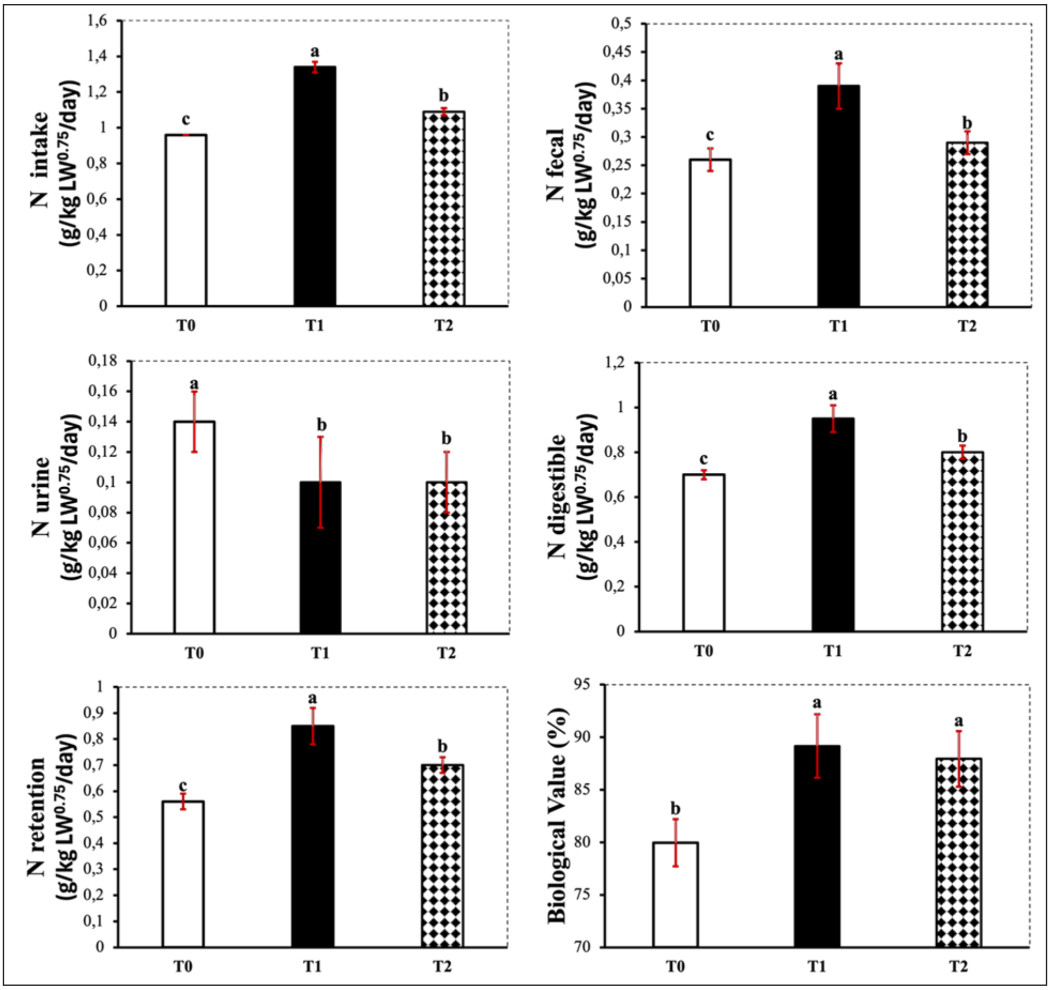

Figure 2. Nitrogen (N) content of feces and urine, and balance in thin-tailed sheep
Note. T0 = 60% concentrate and 40% water spinach straw; T1 = 40% concentrate and 60% silage; T2 = 60% concentrate and 40% silage; a, b, and c represent significant differences (p<0.05)

concentrate led to an imbalance between energy and protein content in the feed (Table 2). Diets that offer both sufficient protein and energy can optimize microbial growth and nitrogen utilization, thus reducing N fecal. Zhang et al. (2019) also reported that diets rich in fermentable carbohydrates promote the synthesis of microbial protein in the rumen, leading to better nitrogen retention and reduced N feces.

As shown in Figure 2, the silage-based diets (T1 and T2) resulted in significantly lower N urine (p<0.05) than the non-fermented diet (T0). This suggests that T1 and T2 had a higher feed solubility rate, which contributed to the reduced N urine. The fermentation characteristics of the diet, especially the balance between fiber and concentrate, play a crucial role in nitrogen metabolism. Diets that support effective rumen fermentation can enhance microbial protein synthesis, leading to improved nitrogen retention and reduced N excretion. Previous studies have shown that diets with higher CF content tend to reduce N urine, while high-concentrate diets can lead to excess nitrogen being excreted (Chelkapally et al., 2023; Ma et al., 2014).

The inclusion of mixed silage with *C. calothyrsus* positively influenced protein utilization efficiency in livestock because of the protective effect of tannins on protein. Tannins in high-quality feed proteins help protect these proteins from degradation by rumen microbes, thereby improving their utilization (Jayanegara et al., 2019). This protection process converts some rumen-degradable proteins (RDP) into rumen-undegradable proteins (RUP), which can then be metabolized, digested, and absorbed in the small intestine. Jayanegara et al. (2019) found that silages with higher tannin content were associated with lower levels of RDP, suggesting that tannins play a significant role in improving protein utilization in livestock.

The highest N digestible in T1 compared to T0 and T2 was attributed to the higher N intake. Digestible nitrogen levels were positively correlated with CPI and CP digestibility in thin-tailed sheep. When protein digestibility increases, so does the amount of nitrogen that can be digested. This process is facilitated by rumen microbial activity and improving this activity requires providing a balanced nutrient profile in the feed. Silva et al. (2022) emphasized that maintaining a balance between energy and protein is essential for optimizing rumen microbial performance, which plays a critical role in digestion. As protein digestibility increases, fecal nitrogen decreases, leading to greater N digestibility.

N retention reflects how effectively sheep utilize nitrogen, determined by the difference between N intake and the N excreted (feces and urine). Several factors can influence the amount of retained nitrogen, such as the amount of N intake, the nutrient content, nutrient digestibility, and the efficiency of the sheep's metabolic processes. In this study, T1 and T2 resulted in higher N retention than T0. The tannins in the mixed silage protected proteins from microbial breakdown in the rumen, thus enhancing the efficiency of protein utilization by the sheep. According to Loregian et al. (2023), tannins bind with proteins, decreasing protein degradation in the rumen and enhancing the proportion of RUP. Specific microbial populations in the rumen can help break down dietary proteins and synthesize microbial proteins, which act as a vital source of nitrogen for the animal (Cui et al., 2021).

Biological value refers to the quality of protein, measured by the percentage of nitrogen that is absorbed and used by the body, rather than being excreted in urine or feces. In this study, the higher biological value observed in T1 and T2 than in T0 suggests that the combination of concentrate feed and silage enhanced nitrogen utilization efficiency, likely due to the tannin content. The lower biological value in T0 may be attributed to increased protein degradation, leading to increased ammonia production. A higher biological value indicates more efficient protein use by livestock in the given feed treatments (Rahayu et al., 2021).

CONCLUSION

This study highlights that no single dietary treatment was universally superior, but each offered unique advantages. Feeding sheep a combination of 60% concentrate and 40% silage (*P. purpureum* cv. Gama Umami x *C. calothyrsus*), referred to as T2, has been shown to improve productivity, as reflected in better nutrient intake, higher average ADG, and improved feed conversion, positioning it as a strong alternative to water spinach straw (T0). In contrast, the T1 or feeding sheep a combination of 40% concentrate and 60% silage excelled in protein-related metrics, including crude protein and EEI, nitrogen digestibility, and retention, making it more effective for improving nitrogen utilization. These findings underline the importance of aligning dietary strategies with specific production goals. T2 may be best suited for a growth-focused system, whereas T1 offers strategic benefits for protein efficiency and nutrient retention.

ACKNOWLEDGMENT

The authors would like to express their deepest gratitude to the postgraduate program of the Faculty of Animal Science, Universitas Gadjah Mada, which has funded this research in the 2024 Postgraduate Competition Grant program with contract number 2041/UN1/PT.1.3/PT.01.00/2024.

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