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Effect of Combination of Mangrove (*Rhizophora apiculata*) Leaves and *Mirasolia diversifolia* in Rations on Production Performance of Goats

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ABSTRACT

The objective of this research is to identify the most effective blend of Mangrove (*Rhizophora apiculata*) leaf hay and fermented *Mirasolia diversifolia* (FMd) as sources of fiber and protein for goats in-vivo. In this study, an experimental approach was utilized, employing a randomized group design with four distinct treatments, each with four separate groups serving as replicates. The treatments included T1 (35% mangrove leaf hay (MLH) + 5% FMd + 60% concentrate), T2 (30% MLH+ 10% FMd + 60% concentrate), T3 (25% MLH + 15% FMd+ 60% concentrate), T4 (20% MLH + 20% FMd + 60% concentrate). The measured variables included the consumption and digestibility of food substances: crude fiber, crude fat, and Nitrogen-free extract (NFE), as well as the digestibility of fiber fractions: NDF, ADF, cellulose, and hemicellulose. Additionally, body weight gain, ration efficiency, and feed conversion ratio were assessed. The analysis outcomes revealed that each treatment insignificantly impacted (P>0.05) the consumption and digestibility of crude fiber, crude fat, NFE, ration efficiency, and feed conversion ratio in distinct ways. However, there were significant differences (P<0.05) in the digestibility of NDF, ADF, cellulose, hemicellulose and body weight gain, The findings from the study revealed that the T4 treatment produced the most favorable outcome in terms of consumption and digestibility of crude fiber, crude fat, NFE, NDF, ADF, cellulose, hemicellulose, body weight gain, ration efficiency, and feed conversion ratio.

Key words: Mangrove leaves, *Mirasolia diversifolia*, Crude fiber digestibility, Crude fat digestibility, NFE digestibility

INTRODUCTION

Rhizophora apiculata is a species of mangrove plant that is found in various mangrove ecosystems, and it contains essential nutrients for livestock. According to Ikhlas et al. (2023), Mangroves can serve as feed for ruminants due to its widespread availability in nature (Ikhlas et al. 2023). *R. apiculata* has been reported to contain 92.58% dry matter, 8.86% ash, 91.14% organic matter, 5.76% crude protein, 16.83% crude fiber, 3.07% crude fat, 48.62% acid detergent fiber (ADF), 54.51% neutral detergent fiber (NDF), 15.10% cellulose, 5.89% hemicellulose, and 14.53% lignin. Moreover, mangrove leaves contain 13.37% crude protein and 79% total digestible nutrient (TDN) (Jamarun et al. 2020; Sari et al. 2022a). To ensure the long-term storage of mangrove leaves and prevent the need for repeated harvesting, they are sun-dried, a process referred to as mangrove leaf hay.

In addition to mangroves, *M. diversifolia* leaves have also been widely used as forage feed and can be combined with other forages. *M. diversifolia* leaves boast high nutrients content, especially crude protein. The research conducted by Jamarun et al. (2018) found that whole *M. diversifolia*, including leaves and stems, contains 84.01% organic matter, 25.57% dry matter, 22.98% crude protein, and 18.17% crude fiber. Pazla et al. (2021a) also reported

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that *M diversifolia* is rich in crude protein, with levels reaching 22.95%, which is highly conducive to rumen microbial growth. In the leaves, crude protein is higher, while crude fiber is lower at 21.4 and 14.5%, respectively (Adrizal et al. 2021). However, there are obstacles to the use of *M. diversifolia* as animal feed, primary due to its low palatability resulting from the high presence of phytochemical compounds or antinutrients, especially phytic acid. Pazla et al. (2023a) found that *M. diversifolia* contains harmful antinutrients such as phytic acid.

Phytic acid (79.1mg/100g) is one of the antinutrients that can bind to the nutrients in feed ingredients and inhibit digestibility (Fasuyi et al. 2010), Therefore, it is necessary to process *M. diversifolia*, one method being the fermentation of *M. diversifolia* using *Aspergillus ficuum* fungi over a period of five to seven days. The use of *A. ficuum* fungi is encouraged because this fungus has been proven to produce phytase enzymes capable of hydrolyzing phytic acid in *M. diversifolia* leaves (Pazla et al. 2023b). Pazla et al. (2021b) pointed out that one of the microbes producing phytase enzyme is *A. ficuum*, making it suitable for use as an inoculum in *M. diversifolia* fermentation. Furthermore, according to Zhang et al. (2010) and Wang et al. (2014), *A. ficuum* has produced the latest phytase strain, NTG-23, which operates optimally at specific pH levels and exhibits resistance to pepsin and renin, thus making it a potential animal feed additive. It is also documented that *A. ficuum* is a type of fungus widely employed as fermentation process (Jamarun et al. 2023). Moreover, fermentation serves the purpose of extending the shelf life of *M. diversifolia*, particularly when large quantities are collected.

Providing mangrove leaves, combined with fermented *M. diversifolia*, in complete rations is expected to meet the nutritional needs of ruminants and increase body weight, especially in Kacang goats. Sari et al. (2022b; 2022c) reported that a combination of 16% mangrove leaf hay with 24% field grass, 10% rice straw, and 50% concentrate for Kacang goats gave the best digestibility results of crude fiber, crude fat, and NFE, which were 67.98, 63.73, and 61.38%, respectively. However, the practice of using a combination of mangrove leaf hay and fermented *M. diversifolia* as goat feed has not been widely adopted. This research aims to identify the most effective blend of Mangrove (*Rhizophora apiculata*) leaf hay and fermented *M. diversifolia* as sources of fiber and protein for goats in-vivo.

MATERIALS AND METHODS

Ethical Approval

This experiment has followed research ethics related to livestock as outlined in Section 66 of the Republic of Indonesia Government Law Number 18 of 2009. This section specifically pertains to the management, breeding, euthanasia and appropriate treatment and welfare of animals. This experiment also followed the guidelines provided in the 'Guide for the Care and Use of Agricultural Animals in Research and Teaching' outlined by the Federation of Animal Science Societies (American Dairy Science Association 2020).

Materials and Research Tools

This study utilized individual iron cages measuring 1.5 x 1 x 1.5m, each equipped with food and water stations. The materials used in this research included mangrove leaves from *R. apiculata*, *M. diversifolia* and concentrates comprising palm kernel meal, rice bran, tofu dregs, and ground corn.

Research Methods

In vivo research took place in the experimental barn of the Task Implementation Unit of the Faculty of Animal Husbandry, Universitas Andalas, located in Padang City, West Sumatra, Indonesia. In this study, 16 Kacang goats between 10 and 14 months with good health were employed and categorized into 4 groups based on their body weight. Firstly, goats were given brown sugar water, dewormer, and vitamin B complex. The categorization of these groups was as follows: Group I had an average body weight of 13.41±0.51kg (CV=3.80%), Group II had an average body weight of 11.95±0.47kg (CV=3.93%), Group III had an average body weight of 10.51±0.25kg (CV=2.35%) and Group IV had an average body weight of 9.71±0.27kg (CV=2.77%).

Four ration formulations were utilized in the treatment, which were as follows:

T1: 35% Mangrove Leaf Hay + 5% Fermented *M. diversifolia* + 60% Concentrate

T2: 30% Mangrove Leaf Hay + 10% Fermented *M. diversifolia* + 60% Concentrate

T3: 25% Mangrove Leaf Hay + 15% Fermented *M. diversifolia* + 60% Concentrate

T2: 20% Mangrove Leaf Hay + 20% Fermented *M. diversifolia* + 60% Concentrate

In this study, a Randomized Group Design was utilized, following the mathematical model proposed by Steel and Torrie (1991), which is outlined as follows:

$$Yij = \mu + Ti + \beta j + \sum ij$$

Description: Yij = Observation Results on the treatment labeled as 'i' and the replication labeled as 'j.

i = Treatment (1, 2, 3, 4)

j = Repeat (1, 2, 3, 4)

μ = General mean value

Ti = Effect of the i-th treatment of feed ingredient content

Bj = jth group effect

∑ ij = the effect of errors that get the i-th treatment, j-th replication

The research design employed a Randomized Group Design with four treatments and four replicates. Rations were administered at 4% of body weight in the form of dry matter. This research consisted of three distinct periods: an initial adaptation period lasting 21 days, followed by a preliminary period of 14 days, and finally, a data collection period that spanned 5 days. During the collection period, 10% of feces were collected to be used as samples for analysis. The analysis of the nutritional composition of feed ingredients and feces took place at the Ruminant Nutrition Science Laboratory at the Faculty of Animal Husbandry, Andalas University. Proximate analysis was performed using the AOAC (2016) method, and fiber fraction (NDF, ADF and cellulose) analysis was performed following the methodology outlined by Van Soest et al. (1991). Details of feed ingredients' chemical composition used in the treatment ration is presented in Table 1. Table 2 provides an overview of the treatment ration's composition, while Table 3 presents the nutrient content within the treatment ration.

Table 1: Chemical composition of the feed ingredients of treatment rations (% DM)

Nutrient Content (%)	Feed Ingredients					
	MLH	FMd	TD	RB	PMK	Corn
Dry matter	84.27	91.22	90.47	88.29	90.32	87.55
Organic matter	90.26	85.49	94.18	88.99	96.13	95.87
Ash	9.74	14.51	5.82	11.01	3.87	4.13
Crude protein	10.13	25.85	24.62	8.94	22.29	13.87
Crude fiber	14.87	12.43	21.94	25.74	29.96	9.61
Crude fat	2.45	2.61	8.12	7.52	6.15	3.09
NFE	62.81	44.60	39.5	46.79	37.73	69.30
TDN*	75.58	64.61	69.65	70.10	66.19	82.81
NDF	34.01	54.17	42.66	48.11	72.59	49.96
ADF	22.67	36.82	22.92	25.69	50.33	36.76
Cellulose	14.87	23.12	20.44	19.63	26.85	29.52
Hemicellulose	11.34	17.35	19.74	22.42	22.26	13.2
Lignin	7.54	4.57	1.84	3.78	9.25	7.5
Silika	0.26	4.07	0.64	2.28	14.23	0,70
Tanin	11.00	-	-	-	-	-

TD: Tofu Dregs; PKM: Palm Kernel Meal; RB: Rice Bran; MLH: Mangrove Leaves Hay; FMd: Fermented *Mirasolia diversifolia*; Min: Mineral; TDN: Total Digestible Nutrient; NDF: Neutral Detergent Fiber; ADF: Acid Detergent Fiber: TDN calculated based on Moran's Formula (2005): TDN: 5.31+0.412 crude protein+0.249 crude fiber+1.444 crude fat+0.937 NFE.

Table 2: The composition of the treatment rations

Feed Ingredient (%)	Treatment (%)			
	T1	T2	T3	T4
MLH	35	30	25	20
FMd	5	10	15	20
Tofu dregs	5	2	1	1
Rice bran	25	28	29	29
Palm kernel meal	14	5	1	1
Corn	15	24	27	28
Mineral	0.5	0.5	1.0	0.5
Salt	0.5	0.5	1.0	0.5
Total	100	100	100	100

MLH: Mangrove Leaves Hay; FMd: Fermented *Mirasolia diversifolia.*

Table 3: Nutritional contents of the treatment rations

Nutritional Content (%)	Treatments			
	T1	T2	T3	T4
Dry matter	86.43	86.46	85.80	87.02
Organic matter	90.66	90.24	88.98	89.70
Ash	8.34	8.76	9.02	9.30
Crude protein	13.51	13.06	13.22	14.14
Crude fiber	18.99	17.15	16.16	16.13
Crude fat	4.60	4.31	4.16	4.20
NFE	53.56	55.71	55.44	55.23
TDN	72.38	73.34	72.63	72.91
NDF	46.57	45.79	45.48	47.00
ADF	30.05	29.70	29.56	30.64
Cellulose	20.48	21.11	21.42	22.03
Hemicellulose	16.52	16.09	15.92	16.36
Lignin	6.58	6.58	6.56	6.74
Silica	2.00	1.66	1.73	2.02

Note: Calculated from Table 1 and 2.

Research Phase

Mangrove Leaf Drying (Hay) and *M. diversifolia* Fermentation

Drying mangrove leaves into hay aims to reduce their water content and extend their shelf life. The drying of mangrove leaves is achieved under direct sunlight for two days, after which they are stored in sacks. Meanwhile, the fermentation of *M. diversifolia* using *A. ficuum* mould was carried out following these steps:

Aspergillus ficuum Mould Rejuvenation

The rejuvenation of *A. ficuum* mould was performed on a slanted agar medium called Potato Dextrose Agar, which was then incubated at room temperature for 7 days. Subsequently, 100g of cracked corn were weighed, soaked for 24h, and sterilized by autoclaving at 121°C for 30min. After cooling, *A. ficuum* was introduced into the corn-based medium from the slanted agar medium, and this mixture was incubated for a period of 14 days and ready for use.

Feed Material Preparation

Mangrove topmost 10 leaves (one pickup truck) were collected from the Tarusan area in South Pesisir Regency. Meanwhile, *M. diversifolia* was obtained from the sugar cane plantation area Puncak Lawang, Agam, amounting to 2 pickup trucks. *M. diversifolia* was dried, then chopped, and inoculated with *A. ficuum*.

Mirasolia diversifolia Fermentation Process

M. diversifolia fermentation was carried out for 7 days. Inoculum (10%) was added to the feed material. Facultative anaerobic fermentation began with the preparation of feed ingredients, sacks, and inoculum. First, 10kg of feed material and 1kg of inoculum were weighed. The feed ingredients, *A. ficuum* inoculum, and bran as an energy source were placed on a tarpaulin to be stirred and mixed thoroughly before being transferred into plastic sacks, which were then tightly sealed to prevent the entry of air.

Harvesting of Mangrove Leaf Hay and Fermented *M. diversifolia*

Mangrove leaves were removed after two days of drying, while fermented *M. diversifolia* was harvested after 7 days of fermentation process and then dried in the hot sun until the moisture content reached 10-15%.

Statistical Analysis

The data were analyzed using Analysis of Variance (ANOVA) in IBM SPSS Statistics version 26.0 (IBM Corp., NY, USA). Subsequent tests were carried out using the Duncan Multiple Range Test (DMRT). The Calculation Formula:

Ration intake (fresh) (g/day) = Total ration provided – remaining ration

Dry matter intake (g/day) = Consumption of fresh ration ∗ Dry matter ration

Crude matter intake (g/day) = DM ration consumption ∗ Crude fiber ration

Crude fat intake (g/day) = DM ration consumption ∗ Crude fat ration

$$(\text{Crude fiber digestibility }(\%)\,) = \frac{\text{CFI} - \text{Feces}}{\text{CFI}} * 100\%$$

$$(\text{Crude fat digestibility }(\%)\,) = \frac{\text{CFatI} - \text{Feces}}{\text{CFatI}} * 100\%$$

$$(\text{NFE Digestibility }(\%)\,) = \frac{\text{NFEI} - \text{Feces}}{\text{NFEI}} * 100\%$$

$$(\text{NDF digestibility }(\%)\,) = \frac{\text{NDFI} - \text{Feces}}{\text{NDFI}} * 100\%$$

$$(\text{ADF digestibility }(\%)) = \frac{\text{ADFI} - \text{Feces}}{\text{ADFI}} * 100\%$$

$$(\text{Cellulose digestibility } (\%)) = \frac{\text{CelluloseI} - \text{Feces}}{\text{CelluloseI}} * 100\%$$

$$(\text{Hemicellulose digestibility } (\%)) = \frac{\text{HemicelluloseI} - \text{Feces}}{\text{HemicelluloseI}} * 100\%$$

$$(\text{Body weight gain (g/day)}) = \frac{\text{Final weight} - \text{Initial weight}}{\text{Research Time}}$$

$$(\text{Ration Eficiency } (\%)) = \frac{\text{Body Weight Gain}}{\text{Feed Intake}}$$

$$(\text{Feed Convertion Ratio}) = \frac{\text{Feed Intake}}{\text{Body Weight Gain}}$$

Where:

DM= Dry matter; DMI = Dry matter intake; CF = Crude Fiber; CFI = Crude Fiber Intake; CFat = Crude Fat; CFatI= Crude Fat Intake; NFE = Nitrogen-Free Extract; NFEI = Extract Intake; NDF = Neutral Detergent Fiber; NDFI = Neutral Detergent Fiber Intake; ADF = Acid Detergent Fiber; ADFI = Acid Detergent Fiber Intake.

RESULTS

Consumption of Crude Fiber, Crude Fat, and Nitrogen-Free Extract

The mean consumption of crude fiber ranged from 58.63 to 68.35g/d. The highest mean consumption was obtained in treatment T1, and the lowest mean crude fiber consumption was observed in treatment T3 (Table 4). The average crude fat consumption ranged from 15.10 to 16.55g/d, with the highest average fat consumption observed in treatment T1 and the lowest average fat consumption recorded in treatment T3 (Table 4). The average consumption of Nitrogen free Extract ranged from 192.75 to 215.82g/d, with the highest average consumption of NFE observed in treatment T4 and the lowest average consumption recorded in treatment T1 (Table 4). Based on the results of statistical analysis, the addition of mangrove leaf hay in a complete ration had no significant effect (P>0.05) on the average consumption of crude fiber, crude fat, and NFE in Kacang goats.

Digestibility of Crude Fat, Crude Fiber, Nitrogen-Free Extract

The average digestibility of crude fiber ranged from 63.02 to 65.81%. The lowest result was found in treatment T1, while the highest was found in treatment T4 (Table 5). The average value of crude fat digestibility for each treatment is quite favorable, ranging from 67.42 to 68.02%, with the highest average digestibility found in treatment T4 and the lowest average digestibility observed in treatment T1. The average digestibility of NFE can be observed. The average NFE digestibility ranged from 68.07 to 69.07%, with the greatest level of digestibility observed in treatment T4 and the lowest digestibility obtained in treatment T1. The statistical analysis results indicated that varying the treatment combinations, which included 35, 30, 25, and 20% of mangrove leaf hay along with 5, 10, 15, and 20% of fermented *M. diversifolia* in complete rations, did not result in significant (P>0.05) differences on in vivo digestibility of crude fiber, crude fat, and NFE in Kacang goats (Table 5).

Digestibility of Fiber Fraction

The digestibility of fiber fraction can be observed. The results of statistical analysis showed that the combination treatment of mangrove leaf hay with fermented *M. diversifolia* had a highly significant effect (P<0.01) on the digestibility of NDF, ADF, cellulose and hemicellulose in Kacang goats. The average NDF digestibility ranged from 41.91 to 51.98%, with the highest average obtained in treatment T4 and the lowest average was obtained in treatment T1 (Fig. 1A). The average ADF digestibility ranged from 40.57 to 51.97%, with the highest average observed in treatment T4 and the lowest average obtained in treatment T1 (Fig. 1B). The average hemicellulose digestibility ranged from 54.42 to 64.29% where the highest average was obtained in treatment T4 and the lowest average was obtained in treatment T1 (Fig. 1C). The average digestibility of cellulose ranged from 44.35 to 52.15%, with the highest average obtained in treatment T4 and the lowest average obtained in treatment T1 (Fig. 1D).

Table 4: Consumption (g/d) of crude fiber, crude fat, and nitrogen-free extract

Parameters	Treatments			
	T1	T2	T3	T4
Crude fiber intake	62.75±0.23	63.45±0.28	64.52±0.16	64.95±0.21
Crude fat intake	15.25±0.32	15.85±0.31	16.10±0.29	16.82±0.27
Nitrogen free extract intake	198.75±0.18	201.06±0.24	203.16±0.32	205.82±0.29

There is no significant between treatments (P>0.05).

Table 5: Digestibility (%) of crude fiber, crude fat and nitrogen free extract

Digestibility	Treatments			
	T1	T2	T3	T4
Crude fiber	63.02±0.34	63.63±0.32	64.86±0.26	65.81±0.27
Crude fat	67.42±0.35	67.58±0.26	67.63±0.40	68.02±0.37
Nitrogen-free extract	68.07±0.33	68.62±0.34	68.72±0.22	69.07±0.27

There is no significant between treatments (P>0.05).

Table 6: Body weight gain, ration efficiency, ration conversion

Parameters	Treatments			
	T1	T2	T3	T4
Body weight gain (g/d)	54±0.31c	57.50±0.26bc	60.06±0.28b	62.25±0.30a
Ration efficiency (%)	12.99±0.18	13.14±0.27	13.17±0.28	13.39±0.19
Feed conversion ratio	7.69±0.25	7.61±0.31	7.59±0.29	7.47±0.22

Values (Mean+SD) bearing different alphabets in a row differ significantly (P<0.05).

Body Weight Gain, Ration Efficiency, and Feed Conversion Ratio

The combination of mangrove leaf hay with fermented *M. diversifolia* in the ration had a very significant (P <0.01) effect on daily body weight gain (Table 6). The highest body weight gain was achieved in treatment T4, which included 20% mangrove leaf hay and 20% fermented *M. diversifolia*, along with 60% concentrate, while the lowest body weight gain was observed in treatment T1, consisting of 35% mangrove leaf hay, 5% fermented *M. diversifolia*, and 60% concentrate. The average body weight gain ranged from 54.00 to 62.25g/h/d, with the highest average obtained in treatment T4 (20% ML + 20% TF + 60% Concentrate) and the lowest average obtained in treatment T1.

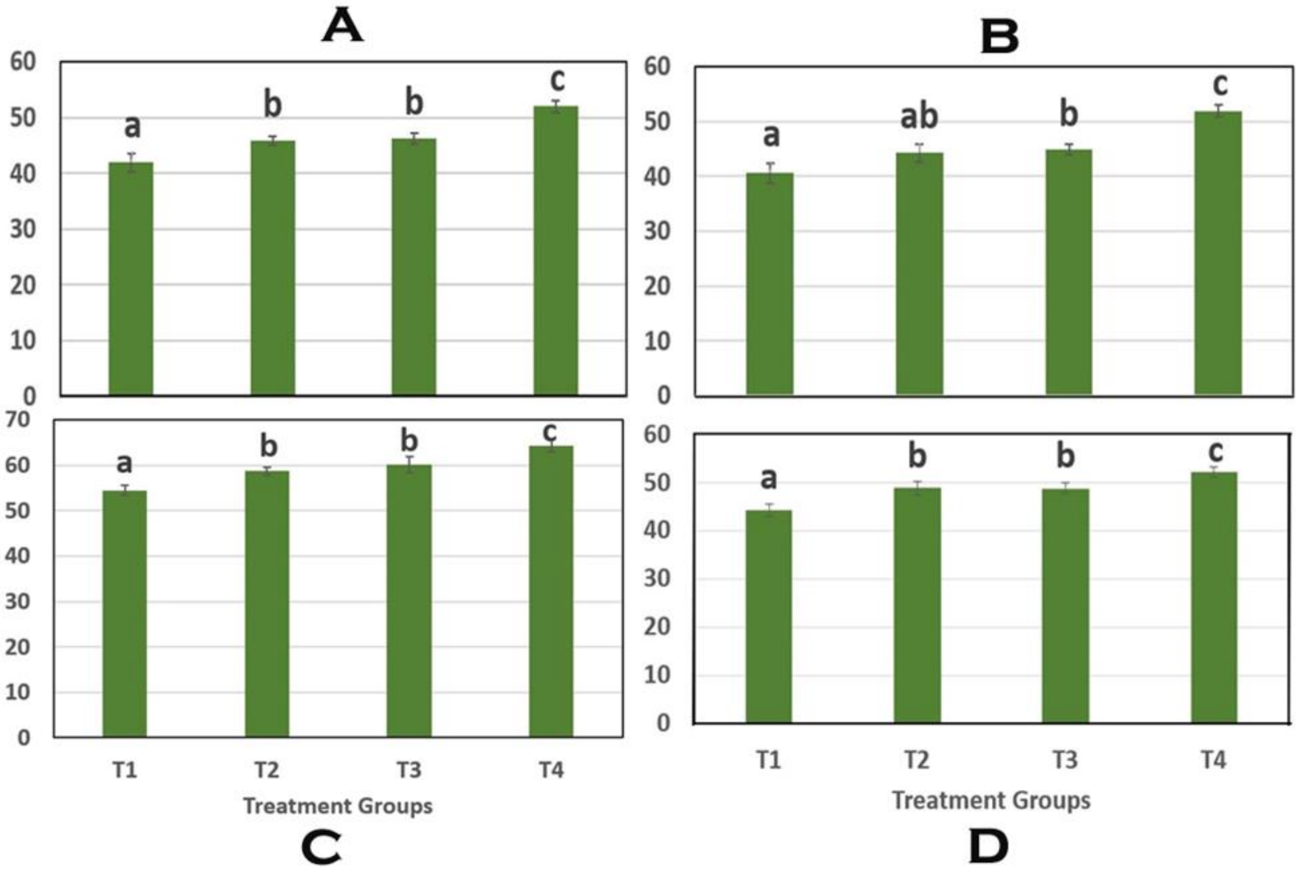

Fig. 1: Digestibility (%) of A) neutral detergent fiber, B) acid detergent fiber, C) hemicellulose and D) cellulose of treatment ration.

The results of statistical analysis showed that the provision of a combination of mangrove leaf hay and fermented *M. diversifolia* in the ration had a no significant effect (P>0.05) on ration efficiency and feed conversion ratio. The average ration efficiency ranged from 12.99% to 13.39%, with the highest average obtained in treatment T4 and the lowest average obtained in treatment T1. The average feed conversion ranged from 7.69 to 7.47 (Table 6).

DISCUSSION

Effect of Treatment on Crude Fiber, crude fat and NFE Consumption

Statistical analysis revealed that the provision of mangrove leaf hay combined with fermented *M. diversifolia* did not significantly increase crude fiber consumption (Table 4). However, the average crude fiber consumption in this study tended to increase from T1 to T4. The lack of significant difference in average crude fiber consumption can be attributed to the similar palatability of the feed to livestock, where the nutrient content, especially crude fiber in the ration, had a significant impact on fiber consumption. Arief et al. (2023a) have previously stated that a high crude fiber content in the ration affects both the digestibility and consumption of the ration, as well as ration efficiency. Similarly, Solon-Biet et al. (2014) mentioned that the amount of ration consumption is strongly influenced by the levels of energy and protein in the ration. Rations with similar energy content result in ration consumption values that do not significantly differ (Shen et al. 2021). Mangrove leaf hay still contains a fairly high crude fiber content of 14.87% (Table 1), so even though the percentage of its use is reduced in the ration to T4, it still has no significant effect on crude fiber consumption. This is due to the bulky nature of the fiber, which greatly affects the condition and volume of the rumen, where the crude fiber fills and expands. Crude fiber expansion in the rumen is triggered by the feed flow rate, which is also relatively slow, causing precipitation and resulting in fiber consumption not increasing. Arief et al. (2023b) noted that, apart from the nutritional composition of a feed ingredient, the rate at which feed is delivered also plays a substantial role in ration intake, and this feed delivery rate is impacted by effective digestibility. The feed flow rate depends on the nutrient content of the feed, especially protein and fiber. The T1 treatment contains high fiber and low protein, while the T4 treatment contains low fiber and high protein (Table 3). Consequently, the feed flow rate in T4 is faster, causing livestock to quickly feel hungry again and having an impact on increasing ration consumption in T4, including crude fiber, although there is no statistical significance.

Ration consumption is closely related to digestibility, with a positive correlation between them. When digestibility is high, ration consumption also increases. Wojtunik et al. (2020) stated that when digestibility is high, the value of ration consumption will increase. The T4 treatment is the treatment with the highest fiber consumption value of 64.95g/h/d. The highest consumption was obtained in the T4 treatment because T4 contained higher fermented *M. diversifolia* at 20% and lower mangrove leaf hay at 20% of the total ration. The percentage of 20% fermented *M. diversifolia* proved to be able to optimize microbial performance in the rumen because fermented *M. diversifolia* contains very high crude protein. Therefore, the highest crude fiber consumption value in this study was also obtained in treatment T4. Mangrove leaf hay contains tannins, which can bind nutrients contained in feed ingredients, especially proteins and carbohydrates (Elihasridas et al. 2023a). In T4, the percentage of mangrove leaf hay was lower than the other treatments, so there was a decrease in tannin levels, which had an impact on the optimal process of fiber degradation by rumen microbes. The ability of tannins to bind protein results in reduced protein availability, so microbial protein supply also decreases, which has an impact on reducing digestibility. If digestibility is low, consumption will also decrease.

The T4 treatment is considered to have the optimal balance of protein and energy, resulting in the high consumption value. This is because the content of nutrients, particularly protein and energy, can increase palatability, leading to increased consumption. According to Pazla et al (2021c), ration nutrition, especially protein and energy, significantly influences palatability in addition to physical quality. In this study, using fermented *M. diversifolia* that can increase the consumption of rations, including crude fiber, as evidenced by an increase in the percentage of fermented *M. diversifolia*, can increase the amount of fiber consumption, although not statistically significantly different. Therefore, a decrease in the percentage of mangrove leaf hay and an increase in the percentage of *M. diversifolia* from T1 to T4, respectively, by (35% MLH + 5% FMd), (30% MLH + 10% FMd), (25% MLH + 15% FMd), and (20% MLH + 20% FMd), were able to increase the consumption value of crude fiber in *Kacang* goats, although they did not yield statistically significant effect.

Crude fiber consumption is also related to dry matter consumption. Arief et al. (2023c) stated that a decrease in dry matter was followed by a decrease in the consumption of nutrients such as crude fiber, crude fat, and NFE, whereas an increase in dry matter led to an increase in nutrient consumption.

Table 4 shows that the highest mean value of crude fat consumption was obtained in the T4 treatment, which was 16.82g/h/d, followed by goat treated with T3 16.10g/h/d, T2 15.85g/h/d, and the lowest consumption was observed in the T1 treatment, which was 15.25g/h/d. The results of fat consumption in this study were higher than the fat consumption obtained in the study by Anggoro et al. (2015), which reported 14.17g/h/d for cattle fed a ration consisting of 800g of elephant grass, 300g of Gamal, 200g of Waru, and 200g of concentrate.

Crude fat consumption is closely related to crude fiber consumption, so if fiber consumption increases, fat consumption also tends to increase. This is because fat is a nutrient located in the cytoplasm or cell contents, and cell contents are wrapped by cell walls, where most of the cell walls are composed of crude fiber. If fiber consumption is high, it means that fiber digestibility is also high, thus impacting crude fat digestibility, which, in turn, accelerates fat consumption in livestock. As stated by Van Soest et al. (1991), crude fat is part of the cell contents, which causes fat consumption to depend on crude fiber consumption. Therefore, crude fat consumption in this study also tends to increase in line with the reduction in the percentage of mangrove leaf hay and the increase in fermented *M. diversifolia* in the ration from treatment T1 to treatment T4.

Treatment T4 produced the highest consumption of NFE, which used 20% mangrove leaf hay, 20% fermented *M. diversifolia*, and 60% concentrate, while the lowest NFE consumption was observed in treatment T1 with a composition consisting of 35% mangrove leaf hay, 5% fermented *M. diversifolia*, and 60% concentrate. Although statistically, the proportion of forage in each treatment in this study did not show significant differences, NFE consumption tended to increase from T1 to T4.

The non-negligible NFE consumption of each treatment was due to the NFE content, which was also not significantly different in each treatment. In addition, the crude protein and TDN compiled in each treatment are also almost not much different, so the ability of livestock to degrade NFE is also not significantly different. Although not significantly different, the levels of NFE, crude protein, and energy from treatment T1 to treatment T4 tend to increase, accelerating the feed flow rate, increasing digestibility, and ultimately boosting increase NFE consumption.

Treatment T4 is has the highest proportion of fermented *M. diversifolia* and the lowest amount of mangrove leaf hay among all treatments. Mangrove leaf hay contains a limiting substance in the form of tannin, which is still relatively high at around 11%. Reducing the proportion of mangrove leaf hay also reduces tannin levels in the ration, and increasing fermented *M. diversifolia* can boost the amount of crude protein in the ration. This optimization allows rumen microbes to perform optimally, resulting in the best NFE consumption observed in treatment T4.

Effect of Treatment on Crude Fiber Digestibility

The statistical analysis results indicated that offering mangrove leaf hay at varying levels of 35, 30, 25, and 20% in the ration did not result in a statistically significant impact (P>0.05) on the digestibility of crude fiber in Kacang goats. The digestibility results obtained in this study were lower than the digestibility value obtained from the results of Petri research (2022), which reached 69.66% in vitro when combining mangrove leaf hay, field grass, and ammoniated straw, but higher than the results of crude fiber digestibility obtained by Zikri (2022), which only reached 55.46% when combining field grass and ammoniated citronella waste in complete rations.

The difference in crude fiber digestibility is strongly influenced by the levels of limiting factors, namely lignin and silica, which do not vary significantly in each treatment ration. According to Table 3, the lignin content in the treatment rations varies from T1 to T4, with values of 6.58, 6.58, 6.56, and 6.74%, respectively. Although there is an effect, it is not significantly different on crude fiber digestibility. The relatively consistent lignin content is due to the addition of mangrove leaf hay and fermented *M. diversifolia*, which both contain nearly the same amount of lignin, namely 7.54% in mangrove leaf hay and 4.57% in fermented *M. diversifolia*. Therefore, the highest lignin content is observed in treatment T4 (20% mangrove leaf hay + 20% fermented *M. diversifolia* + 60% concentrate), at 6.74%. However, this result still does not show a statistically significant difference in crude fiber digestibility.

Lignin levels in each of these treatment rations are still within normal limits. The tolerance limit of lignin for ruminants is up to 7% in the ration; beyond that, rumen microbes will begin to have difficulty in degrading fiber or other nutrients (Pazla et al. 2020). Lignin is a limiting factor in the digestibility of feedstuffs for ruminants because it can inhibit the ability and digestibility of rumen microbes in degrading crude fiber. The different digestibility of crude fiber in this study was also influenced by the silica content of the rations, which was not significantly different in each treatment ration. Jamarun et al. (2017a; 2017b; 2017c) emphasized that the digestibility of crude fiber is influenced by several factors, including the fiber content in the feed, the composition of crude fiber constituents like lignin and silica, and the activity of microorganisms. Pazla et al. (2021d) stated that lignin forms strong chemical bonds with plant polysaccharides and cell wall proteins, causing cell walls to become hard, and these components cannot be digested by rumen microbes.

In addition to lignin and silica, different fiber digestibility is also influenced by the crude fiber content itself, which is not significantly different even though it tends to decrease due to a reduction in the percentage of mangrove leaf hay addition in the treatment ration. Pazla et al (2023c) states that feed ingredients low in crude fiber have higher fiber digestibility.

The ration composition of this study is based on achieving a balance between CP and TDN to ensure good digestibility, allowing rumen microbes to digest food substances, including crude fiber. According to Table 3, which provides the nutritional content of the research rations, the crude protein content in rations T1 to T4 is as follows: T1 13.51%, T2 13.06%, T3 13.22%, and T4 14.14%. According to Putri et al. (2021), an elevation in dietary protein levels can enhance the population and activity of rumen microbes in digesting crude fiber. The protein levels are not significantly different, resulting in similar numbers and abilities of rumen microbes to degrade fiber, leading to no significant difference in crude fiber digestibility.

Effect of Treatment on Crude Fat Digestibility

The lack of difference (P>0.05) in crude fat digestibility in each treatment is attributed to the similar crude fat content in the research ration, as indicated in Table 3. The crude fat content in rations T1 to T4 remains relatively consistent at 4.60, 4.31, 4.16, and 4.20% (Table 3). This value falls within the normal limits of fat usage in the ration, thereby not affecting its digestion in the body of livestock. This aligns with Shirley (1986) statement that the fat content exceeding 5% of the total ration can interfere with livestock's ability to utilize consumed feed nutrients.

The digestibility of crude fat, which exhibits no significant difference (P>0.05), is likewise impacted by the amount of crude fiber present. As noted by Elihasridas et al. (2023b), elevated levels of crude fiber can disrupt the digestibility of various other substances. Additionally, Sklan et al. (2004) added that the crude fiber digestibility impacts the crude fat digestibility since crude fat is a component of plant cells contents encased in cell walls. This difference in crude fat digestibility corresponds with digestibility of fiber observed in this study.

Arief and Pazla (2023) also pointed out that the digestibility of a specific feed component is not solely determined by the chemical composition of one ingredient; the composition of other feed ingredients consumed together in the ration will also affect the digestibility of those ingredients. Furthermore, crude fat digestibility is influenced by feed quality. Suyitman et al. (2020) stated that livestock's ability to digest feed ingredients is influenced by the nutritional quality of those ingredients, thereby affecting the quality of rumen microbes produced. Hence, the consistent digestibility of fat (P>0.05) is also attributed to the chemical composition of feed ingredients. Basically, fat is a nutrient composed of simple triglycerides that are easily digested. Sari et al. (2022) emphasized that the ration's composition affects feed digestibility.

The reduction in the percentage of mangrove leaf hay, coupled with an increase in the percentage of fermented *M. diversifolia* in the ration, led to an increase in crude fat digestibility, although it was not statistically significant. Based on Table 5 of crude fat digestibility, the addition of 50% mangrove leaf hay from the total forage or at T4 (20% mangrove leaf hay + 20% fermented *M. diversifolia* + 60% concentrate) can enhance its rumen digestibility. However, according to the statistical analysis, the addition of 35% mangrove leaf hay (ration T1), 30% mangrove leaf hay (ration T2), 25% mangrove leaf hay (ration T3), and 20% mangrove leaf hay (ration T4) did not significantly affect crude fat digestibility. Therefore, providing 20% mangrove leaf hay in a complete ration can already yield the best crude fat digestibility value in *Kacang* goats.

Effect of Treatment on Digestibility of Nitrogen-Free Extract (NFE)

In Table 5, based on the results of statistical analysis, the addition of mangrove leaf hay in a complete ration did not have significant effect (P>0.05) on NFE digestibility in Kacang goats. The difference in NFE digestibility among the four treatments was due to the NFE content, which was also relatively consistent in each treatment ration, namely 53.56, 55.71, 55.44, and 55.23% (Table 5). This variation in NFE levels occurred because of the influence of different levels of other food substances, including crude fiber, crude protein, crude fat, and ash. This is because the NFE is calculated as the difference between 100% and the sum of crude fiber, crude fat, ash, and crude protein. Spranghers et al. (2017) also reported that moisture content, ash, crude protein, crude fat, and crude fiber significantly affect the NFE content of a feed ingredient. Additionally, the relatively consistent NFE content in each treatment ration affects growth and microbial population, with the microbial population experiencing a relatively similar in each treatment. According to Zain et al. (2023), when protein and energy are easily digested, amylolytic bacteria are produced in greater numbers, and these bacteria play a role in digesting starch and protein, which are found in NFE. This explains why NFE digestibility did not significantly differ in the four treatments.

Although the results of statistical analysis showed no significant differences, when examining Table 5 of NFE digestibility, the average digestibility tends to increase along with a decrease in the provision of mangrove leaf hay in the research ration. This increase is thought to be due to the influence of crude fiber, where the fiber content of mangrove leaf hay is higher than fermented *M. diversifolia*. Therefore, when the percentage of mangrove leaf hay is reduced in the ration, NFE digestibility can increase. Referring to the perspective of Pazla et al. (2023c), reducing and decreasing the percentage of crude fiber in a ration formulation can increase NFE digestibility, and vice versa.

The average NFE digestibility of each treatment showed a relatively high value. This can occur because NFE is a class of nonstructural carbohydrates that are easily digested. Niu et al. (2015) said that when compared to other components such as crude fiber, NFE digestibility is higher. The high digestibility of NFE is because it is composed of easily digestible structures and is one of the nonstructural carbohydrate groups. Meanwhile, crude fiber is a food ingredient composed of structural carbohydrates that are difficult to digest, such as cellulose, hemicellulose, and lignin. As stated by Wijaya et al. (2018), NFE has a fraction that is easily digested, so its digestibility is always high. Bannink et al. (2021) further confirmed that NFE is composed of simple carbohydrate fractions and is easily digested because there are mono-, di-, tri-, and tetrasaccharide bonds as well as starch and some hemicellulose.

Effect of Treatment on NDF Digestibility

NDF digestibility is one component used to estimate the digestibility of a feed ingredient because NDF is part of the plant cell wall that can be used to measure fiber availability. The results of statistical analysis showed that the combination treatment of mangrove leaf hay with fermented *M. diversifolia* had significant effect ($P<0.05$) on the digestibility of NDF in Kacang goats.

The highest NDF digestibility was obtained in treatment T4 (20% mangrove leaf hay + 20% fermented *M. diversifolia* + 60% concentrate), which measured 51.98%, while the lowest digestibility was obtained in treatment T1 (35% mangrove leaf hay + 5% fermented *M. diversifolia* + 60% concentrate), at 41.91%. The high value of NDF digestibility in the T4 treatment is thought to be due to the high proportion of fermented *M. diversifolia* used and the low proportion of mangrove leaf hay used compare to other treatments in the ration. *M. diversifolia* has a high crude protein content, significantly enhancing the efficacy of rumen microbes in breaking down high-fiber feed. Additionally, a decrease in the proportion of mangrove leaf hay also further increases NDF digestibility because mangrove leaf hay contains relatively high levels of tannins, reaching 11%.

NDF digestibility is also influenced by the levels of lignin, hemicellulose, and NDF itself in the ration. Table 2 shows that the T4 treatment is the treatment with higher NDF levels, including hemicellulose levels. Hemicellulose is part of the NDF cell wall that is more easily digested. Despal et al. (2021) stated that the high digestibility of NDF is also caused by high levels of hemicellulose in the diet because hemicellulose is a fraction of NDF that is easily digested. We see in Table 2 that the lignin content of each treatment is almost the same, with a slightly higher percentage of lignin in the T4 treatment. However, NDF digestibility is still obtained from T4, which is due to the optimization of the use of fermented *M. diversifolia* in the ration, which is at a percentage of 20%. *M. diversifolia* fermentation is able to improve and optimize the performance of rumen bacteria due to the supply of microbial protein, which is also sufficient from *M. diversifolia* fermentation, so that NDF digestibility increases the more *M. diversifolia* fermentation is added in the ration.

Effect of Treatment on ADF Digestibility

The results of statistical analysis showed that each treatment of mangrove leaf hay in combination with *M. diversifolia* fermentation had a significant effect on ADF digestibility in Kacang goats. ADF is a fraction of fiber that makes up the cell wall and is more difficult to digest than the NDF fraction. This is because ADF contains lignin and silica that can bind cellulose and hemicellulose to form lignocellulose bonds, making both components difficult to digest by rumen microbes. The T4 treatment contained the highest ADF and lignin, but due to the optimal balance of energy and protein in T4, namely 14.14% crude protein and 72.91% energy, it was able to enhance rumen microbial performance, resulting in the best ADF digestibility in the T4 treatment. Putri et al. (2019) stated that to achieve high activity and performance of rumen microbes, a sufficient supply of nutrients, especially energy and protein, is really needed.

Lignin levels in each treatment are almost the same, as can be seen in Table 3. However, because the T1 treatment (35% mangrove leaf hay + 5% fermented *M. diversifolia* + 60% concentrate) contains less fermented *M. diversifolia*, it does not optimize rumen microbes in degrading ADF to the maximum, resulting in the lowest ADF digestibility in goats given the T1 treatment.

Effect of Treatment on Hemicellulose and cellulose Digestibility

The highest **c**ellulose and hemicellulose digestibility was obtained in treatment T4, while the lowest digestibility was obtained in treatment T1. This demonstrates that providing *M. diversifolia* at a 20% percentage in combination with 20% mangrove leaf hay results in better cellulose degradation compared to treatments T1, T2, or T3, which have lower *M. diversifolia* content and higher mangrove leaf hay percentages. Cellulose and hemicellulose digestibility is closely related to NDF and ADF digestibility because hemicellulose is part of the fiber fraction. Liu et al. (2022) indicated that the digestibility of NDF and ADF is positively correlated with hemicellulose digestibility; as the digestibility of NDF and ADF increases, so does the digestibility of hemicellulose. Despite the fact that the T4 treatment contains higher lignin levels, this difference is not statistically significant when compared to the T1, T2, or T3 treatments. However, the difference in the percentage of fermented *M. diversifolia* and mangrove leaf hay in the ration is quite substantial. Therefore, livestock receiving the treatment with the most *M. diversifolia* and the least mangrove leaf hay (T4) are better able to optimize cellulose and hemicellulose degradation.

Effect of Treatment on Body Weight gain

Body weight gain is one of the indicators of how effectively nutrient substances from feed can be absorbed and converted into meat. The results of statistical analysis in this study showed that the combination of mangrove leaf hay with fermented *M. diversifolia* in the ration had a significant effect (P<0.05) on daily body weight gain. The highest body weight gain was achieved in treatment T4, which included 20% mangrove leaf hay and 20% fermented *M. diversifolia*, along with 60% concentrate, while the lowest body weight gain was observed in treatment T1, consisting of 35% mangrove leaf hay, 5% fermented *M. diversifolia*, and 60% concentrate. The significant differences between each treatment can be attributed to the distinct nutritional composition of the feed in each treatment, as shown in Table 3.

The T4 treatment was shown to contain higher protein (14.14%), although the energy was slightly lower (72.91%) than the T2 treatment (73.34%) (Table 3). The balance of protein and energy, and the optimization of rumen performance, were still obtained in the T4 treatment, as evidenced by the achievement of the highest daily body weight gain in T4. In addition, the T4 treatment is also the treatment with the highest NFE consumption (Table 4), which is 205.82%, where NFE is a carbohydrate that is easily digested and becomes a source of energy for livestock. As explained by Pamungkas et al. (2009), the first nutrient component digested by rumen microbes is NFE and serves as the main carbohydrate source for growth.

Meanwhile, the lowest body weight gain was obtained in the T1 treatment, allegedly because the T1 ration contained more mangrove leaf hay, where mangrove leaf hay still contained high tannins, which caused the turn of ration palatability and was evidenced by the low ration consumption in the T1 treatment. Low ration consumption in T1 has an impact on low body weight gain because consumption with body weight gain is interrelated. As Salem and Smith (2008) and Pazla et al. (2018) state that increasing and fulfilling the consumption and dry matter needs of the ration results in other nutrients that can be utilized for both productivity and the augmentation of an individual's body mass. Therefore, the highest increase in body weight was observed in the livestock that received the T4 ration treatment (20% mangrove leaf hay + 20% fermented *M. diversifolia* + 60% concentrate).

Effect of Treatment on Feed Conversion ratio and Feed Efficiency

The results of the statistical analysis indicate that incorporating a combination of mangrove leaf hay and fermented *M. diversifolia* into complete rations had a no significant impact (P>0.05) on feed conversion ratio. Ration conversion is an illustration in determining ration efficiency. In accordance with Pazla et al. (2021c), there exists an inverse relationship between feed conversion and ration efficiency. As feed conversion increases, ration efficiency decreases. Conversely, when the ration conversion value is smaller, it results in a higher efficiency value. Perry et al. (2005) added that the amount of feed consumed to get an increase of one unit of live weight is defined as ration conversion. It is also said that feed conversion is related to the amount of fiber contained in the ration. High crude fiber in the ration causes low digestibility, so feed conversion will also decrease.

The results of statistical analysis showed that the provision of a combination of mangrove leaf hay and fermented *M. diversifolia* in the ration had a no significant (P>0.05) effect on ration efficiency. In this study, the highest ration efficiency value was obtained in the T4 treatment at 13.39%, and the lowest ration efficiency value was obtained in the T1 treatment at 12.99%. The high ration efficiency observed in the T4 treatment can be attributed to the substantial presence of fermented *M. diversifolia* and the reduced proportion of mangrove leaf hay. *M. diversifolia* contains high protein, allowing it to optimize the performance of rumen microbes in degrading feed, thereby increasing feed efficiency.

Feed efficiency is strongly influenced by ration consumption and body weight gain. The greater the body weight gain, the smaller the consumption, the higher the efficiency. As stated by Saputra et al. (2013), the level of feed consumption and body weight gain greatly affects ration efficiency. Besides that, ration efficiency is also closely related to ration conversion. The lower the ration conversion value, the better the ration efficiency value for the livestock.

The value of ration efficiency in this study aligns with the value of body weight gain and ration conversion obtained. Livestock that have the highest body weight gain and lowest ration conversion are found in the T4 treatment, so the highest ration efficiency is also obtained in the T4 treatment.

Conclusion

The blend comprising 20% mangrove leaf hay, 20% fermented *M. diversifolia*, and 60% concentrate produced the most favorable outcomes in ration intake (including crude fiber, crude fat, and NFE), crude fat digestibility, Non-Nitrogen Extracted Material, various fiber fractions (NDF, ADF, cellulose, and hemicellulose), as well as in terms of body weight gain, ration efficiency, and feed conversion ratio.

Authors' Contribution

This research project was a collective endeavor, with several team members playing pivotal roles in different aspects of the study. Novirman Jamarun and Roni Pazla led the project's conceptualization. Data curation was handled by Roni Pazla and Gusri Yanti, while formal analyses were conducted by Roni Pazla, Gusri Yanti, Zaitul Ikhlas, Juniarti, and Elihasridas. The In vivo treatments were performed by Zaitul Ikhlas, Gusri Yanti, Juniarti, and Roni Pazla. Novirman Jamarun was responsible for obtaining the project's funding, while Roni Pazla and Novirman Jamarun jointly supervised the development of the methodology. Project administration was under the guidance of Gusri Yanti, and Arief, in conjunction with Novirman Jamarun, provided overall supervision. Research validation was carried out by Roni Pazla and Elihasridas. Roni Pazla authored the initial draft of the manuscript, and both Roni Pazla and Novirman Jamarun participated in the manuscript's review and editing phases.

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Conflict of Interest

The authors confirm that they do not have any conflicts of interest to disclose.

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