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Evaluation of feed digestibility in goats based on palm oil industry waste and fisheries in Southwest Papua

Evaluasi kecernaan pakan pada ternak kambing berbasis limbah industri kelapa sawit dan perikanan di Papua Barat Daya

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ABSTRACT

Palm oil and fishery waste are recognized as potential environmental concerns, necessitating their processing for reuse as feed material. This study aimed to evaluate the digestibility of feed materials based on palm oil waste and fish waste, utilizing EM4 and *Aspergillus niger* in goats. Six male goats was randomly used to assess the digestibility of dry matter (DM) and crude protein (CP) in six types of feed, each featuring distinct waste and fermenter, employing a 6x6 Latin Square Design. Digestibility data were obtained through *in vitro* and *in vivo* methods. The *in vivo* method showed that T2, made from palm oil waste and *Aspergillus niger*, demonstrated the highest DM digestibility of 62.10±7.64%. Conversely, the highest CP digestibility was found in T4, which consists of fish waste with *Aspergillus niger*, yielding an average protein digestibility value of 67.21±9.81%. In contrast, the *in vitro* method indicated that the highest DM digestibility occurred in T6, which combines palm and fish waste with *Aspergillus niger*, averaging 65.25±5.59%. Meanwhile, T4 (fish waste with *Aspergillus niger*) showed a protein digestibility of 71.69±8.7%. These findings suggest that palm oil waste and fish waste can be tailored to meet livestock nutritional requirements. Furthermore, they indicate that utilizing *Aspergillus niger* is a more cost-effective approach compared to EM4.

ABSTRAK

Limbah kelapa sawit dan perikanan dapat menyebabkan permasalahan lingkungan, sehingga perlu pengolahan untuk dimanfaatkan kembali menjadi bahan pakan. Penelitian ini bertujuan untuk mengevaluasi kecernaan bahan pakan berbasis limbah kelapa sawit dan limbah ikan dengan fermentator (EM4) dan Aspergillus niger pada kambing. Enam kambing jantan secara acak digunakan untuk mengukur kecernaan bahan kering (BK) dan protein kasar (PK) dari enam jenis pakan (P1 hingga P6) yang memiliki komposisi limbah dan fermentator yang berbeda menggunakan metode pengacakan Rancangan Bujur Sangkar Latin (RBSL) 6X6. Data diperoleh melalui simulasi proses pencernaan di laboratorium (In Vitro) dan pengujian langsung pada hewan (In Vivo). Metode in vivo menunjukkan bahwa P2 (limbah kelapa sawit dengan Aspergillus niger) menunjukkan kecernaan BK tertinggi sebesar 62,10±7,64%. Sebaliknya, kecernaan PK tertinggi diamati pada P4 (limbah ikan dengan Aspergillus niger), dengan nilai kecernaan protein rata-rata 67,21±9,81%. Sedangkan metode in vitro menunjukkan kecernaan BK pada P6 (limbah sawit dan ikan dengan Aspergillus niger) yang tertinggi dengan rata-rata 65,25±5,59%, sedangkan kecernaan PK pada P4 (limbah ikan dengan Aspergillus niger) 71,69±8,7%. Hasil ini menunjukkan bahwa pemanfaatan limbah kelapa sawit dan limbah ikan dapat disesuaikan dengan kebutuhan ternak. Selain itu, hasil ini juga menunjukkan bahwa penggunaan Aspergillus niger lebih menguntungkan daripada EM4.

Kata kunci:
Protein kasar
Kecernaan
Bahan kering
Limbah ikan
Limbah kelapa sawit

INTRODUCTION

The palm oil and fisheries industries in Indonesia play an important role in the national economy. Palm oil production in Indonesia in 2023 was 46,986 tons, while fisheries production from marine catches in Indonesia was around 5,284 (BPS, 2024). However, along with the increase in production, the amount of waste generated from these two industries was also getting bigger. Palm oil processing companies generate several types of waste when fresh fruit bunches (FFBs) are processed to produce palm oil. These wastes included 23% empty bunches, 12% mesocarp fiber, 5% palm shells, and 60% Palm oil mill effluent (POME) (Umar et al., 2021). According to Rashidi & Yusup (2017) , every 1 kg of palm oil produced could produce 4 kg of dry biomass waste. In addition to the processing plant waste, there were also palm fronds and palm trunks obtained from the plantation. Fisheries waste included heads, viscera, fins, scales, bones, and pieces of fish meat (Rathod et al., 2024). The amount of waste generated from fish depended on the type of fish, with waste conversion typically reaching between 30% and 70% of the fish's live weight (Zhang, Akyol, & Meers, 2023).

Waste from the palm oil and fisheries industries can cause environmental problems, with waste from fisheries and the palm oil industry identified as a major source of greenhouse gas emissions (Kahar et al., 2022). In addition to causing environmental problems, palm oil and fisheries waste also represents wasted potential if not utilized. Based on research conducted by Azizi, Loh, Foo, & Teik Chung (2021) revealed that palm oil waste can be used as a substitute for soybean meal and corn as an animal feed ingredient with a crude protein content of 14% to 18%. Meanwhile, fishery waste had a nutrient content that was rich in nutrients such as protein, minerals, which can be utilized as a source of protein and mineral feed ingredients for livestock (Afreen & Ucak, 2020a). The use of animal protein sources in ruminant livestock is quite effective due to their relatively high protein content compared to plant-based proteins, but their cost is relatively high (Bira et al., 2024). The implementation of cattle treatment has been demonstrated to enhance the physical and chemical quality of the feed, thereby ensuring optimal nutritional outcomes (Wijaya et al., 2024). Given the increasing need for quality animal feed in Indonesia, efforts to process this waste into animal feed have promising prospects.

The utilization of palm oil and fisheries waste as animal feed raw materials offers an innovative solution to overcome waste problems while meeting animal feed needs. Palm oil and fisheries waste have great potential to be used as animal feed ingredients, but there are several limitations if used without proper processing. Oil palm waste had a high crude fiber content that could deter and limit livestock from degrading feed ingredients (Rusli et al., 2020). Fishery waste was especially susceptible to spoilage if not properly processed and stored because pathogenic and spoilage microorganisms can enter the fish and fish by-products (Sheng & Wang, 2021). Fish silage can be utilized as a substitute for fishmeal, offering a more advantageous alternative (Afreen & Ucak, 2020b). Through the processing of feed ingredients, it was able to improve the quality of nutrients contained therein and increase the shelf life of animal feed ingredients (Wijaya, Ismartoyo, & Natsir, 2023)

Processing feed ingredients, especially in waste to become animal feed can make feed ingredients derived from waste have high digestibility and extend the shelf life of feed due to the presence of lactic acid bacteria (Ali, Harahap, & Juliantoni, 2023). Silage is a feed processing method that utilizes microorganisms with natural or artificial acidification stored without oxygen and is often used as animal feed. The main principle in silage feed processing was the rapid achievement of low pH through lactic acid fermentation and the maintenance of anaerobic conditions (Driehuis, Wilkinson, Jiang, Ogunade, & Adesogan, 2018). The utilization of EM4 (Effective Microorganism 4) and *Aspergillus niger* fungi as substrates in silage has been demonstrated. The use of EM4 as a substrate in silage processing for waste used as animal feed ingredients improved the quality of nutrients contained in feed (Ali, Suhartina, Muktiani, & Pangestu, 2020). Meanwhile, *Aspergillus niger* was one of the microorganisms commonly used in feed fermentation which can increase the digestibility of nutrients in feed (Kong et al., 2021).

This study aims to develop a method for processing palm oil waste and fishery waste as local resources that can be utilized as efficient animal feed. In this study, a comparison was made between palm oil waste and fishery waste in Sorong, Southwest Papua with the use of EM4 and A*spergillus niger.* In addition to comparing the two types of waste, tests were also carried out by mixing them into feed. The objective of this research is twofold: first, to assess the quality of DM and CP feed produced from this processing, and second, to provide a comprehensive solution for the management of palm oil and fishery waste in Sorong, Southwest Papua. Through an innovative and research-based approach, it is hoped that synergy can be created between waste management and increasing the productivity of the livestock sector in Indonesia.

MATERIALS AND METHODS

Research Sample The sampling of fishery waste research was carried out at the DKP Fish Market in Sorong City and the Jembatan Puri Fish Auction Center (TPI) in Sorong City, Southwest Papua. Meanwhile, the sampling of palm oil waste was carried out at palm oil plantation companies in South Sorong, Southwest Papua. The test animals for this study were male PE goats with an average age of 16 months with an average weight of 21.74±3.29%, and this study was conducted in accordance with the principles of animal welfare.

The preparation of test feed ingredients and the maintenance of six goats as test animals were carried out at the Education Muhammadiyah Sorong University Campus in Sorong, Indonesia. Meanwhile, testing of feed composition and digestibility was carried out at the Feed Chemistry Laboratory, Faculty of Animal Science, Hasanuddin University, Makassar. The present study measured several parameters, namely feed composition using proximate and Van Soest tests, feed consumption, and *in vitro* and *in vivo* feed digestibility of dry matter (DM) and crude protein (CP) content.

Data Collection

Data collection on the composition of feed ingredients is done through Laboratory analysis. Samples of feed that will be given to livestock are taken and tested in the Laboratory to determine their nutritional composition. The analysis method to be used is the AOAC method used to measure the composition of feed ingredients such as dry matter, organic matter, crude protein, crude fiber, and crude fat (Thiex, 2009). Then proceed with testing the feed fiber fraction using the Van Soest method to determine the fiber content consisting of NDF, ADF, lignin, cellulose, and hemicellulose (Soest, 1990; Van Soest, Robertson, & Lewis, 1991). The second parameter was to calculate the feed consumption tested in the form of fresh and dry matter. Feeding was based on 3% DM/ body weight of the tested livestock with the ratio of forage and complete feed being 70:30. The forage given was elephant grass (*Pennisetum purpureum*). The complete feed consisted of fishery waste meal, palm waste, corn, bran, molasses, and premix.

The complete feed homogeneously mixed with a percentage of 50% palm oil waste and or fishery waste + 25% corn + 24.5% bran + 0.5% premix in pellet form. The fish waste used consisted of fish bones and fish heads while the palm oil industry waste was palm sludge and palm kernel meal. The use of EM4 for fermentation of fishery and palm oil waste-based feed was that EM4 mixed first with water as much as 8%/ liter of water and molasses was added as much as the provision of EM4 and then complete feed was given EM4 liquid with an incubation period of 14 days. Meanwhile, the use of *Aspergillus niger* for feed fermentation was that every hundred grams of complete feed fermented with *A. niger* as much as 5% and then fermented for 14 days. The feeding of test animals can be seen in Table 1 as follows:

Before the feed treatment was given to the test animals, a feed adaptation period of 5 days carried out to familiarize the animals to consume the tested feed. This is achieved in order to ensure that livestock consumption data is not influenced by fluctuations in livestock feed. The third parameter was feed digestibility of dry matter and crude protein in the treatment feed tested using *in vitro* and *in vivo* methods. As for the measurement of *in vitro* methods used to test the digestibility of concentrates made based on waste. The calculation formula for *in vitro*

Table 1. Ingredients (g/kg) of the total mixed ration given to goats

Feed ingredients	T1 (%)	T2 (%)	T3 (%)	T4 (%)	T5 (%)	T6 (%)
Elephant grass	70.00	70.00	70.00	70.00	70.00	70.00
Palm waste	18.00	18.00	-	-	9.00	9.00
Fish waste	-	-	18.00	18.00	9.00	9.00
Corn	7.50	7.50	7.50	7.50	7.50	7.50
Bran	4.35	4.35	4.35	4.35	4.35	4.35
Premix	0.15	0.15	0.15	0.15	0.15	0.15
Fermentor	EM-4	A. niger	EM-4	A. niger	EM-4	A. niger
Total	100.00	100.00	100.00	100.00	100.00	100.00

digestibility was as follows (Tilley & Terry, 1963; Hambakodu, 2021):

$$DMD\% = \frac{DM\ Sample\ (g) - DM\ Residue\ (g) - DM\ Blank\ (g)}{DM\ Sample\ (g)} \times 100\%$$

$$CPD\% = \frac{CP\ Sample\ (g) - CP\ Residue\ (g) - CP\ Blank\ (g)}{CP\ Sample\ (g)} \times 100\%$$

In vivo measurements were made to measure the digestibility of dry matter and crude protein in the feed consumed. This measurement was carried out using livestock feces samples collected every day during the treatment feed was given. The *in vivo* formula is as follows (Greenhalgh et al., 2022):

$$DMD\% = \frac{(Feed\ Intake\ x\ DM\ Feed) - (feces - DM\ feces)\ x\ 100\%}{Feed\ Intake}$$

$$CPD\% = \frac{(Feed\ Intake\ x\ CP\ Feed) - (Feces - CP\ Feces)\ x\ 100\%}{(Feed\ Intake\ x\ CP\ Feed)}$$

Data Analysis

The present study utilized a 6 x 6 Latin Square Design, comprising six treatment units and six replicates. The employment of a Latin Square Design has the advantage of reducing the number of test animals required, with each test animal receiving each treatment (Zanton, 2019). Each period or feed treatment was administered for five days of feed adaptation and six days of observation. The experimental data were subjected to analysis of variance using the IBM SPSS Statistics Version 27 program, followed by the Tukey distance test if deemed relevant. The experimental unit of analysis was the average, and a 5% probability level was considered statistically significant.

RESULTS AND DISCUSSION

Feed Composition

The highest dry matter (DM) composition was observed in T2, which registered at 92.35%, while the lowest composition was observed in T3, registering at 81.74%. These data indicate that the dry matter content of the feed is derived from palm oil waste, which has a dry matter content ranging from 88% to 94.5% (Alshelmani, Kaka, Abdalla, Humam, & Zamani, 2021). This finding suggests that the feed possesses a dense and nutritious composition. It is well established that the presence of complex organic compounds, such as carbohydrates, fats, proteins, and other fiber components, is directly proportional to the dry matter content of a feed (Fitriani, Husmimi, Masyitha, & Akmal, 2021).

The feed with the highest crude protein content is T4, which has a value of 31.36%. Another study revealed that the crude protein content derived from fish waste averages 31.11%. This indicates that T3 has an adequate supply of protein for livestock, thereby ensuring the performance and health of the animals are maintained. In contrast, T1 has the lowest crude protein content, at 10.72%. The comparatively lower crude protein content of palm waste is attributable to the raw material of empty fruit bunches, which contains approximately 4.54% crude protein. These findings underscore the significance of variations in raw materials and feed formulations on the crude protein content of livestock feed.

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Table 2. Feed chemical composition (%DM/g)

Feed composition (%)	T1	T2	T3	T4	T5	T6
Dry material	87.65	92.35	81.74	84.73	88.35	89.74
Organic material*	81.73	84.81	70.35	81.88	82.84	82.62
Crude protein*	10.72	13.73	29.82	31.36	17.08	21.28
Crude fat*	11.58	9.29	14.27	13.72	7.24	7.51
Crude fiber*	22.31	19.45	6.36	6.29	14.63	15.87
NDF*	34.76	28.14	16.65	34.27	39.55	38.91
ADF*	23.62	19.47	12.37	19.54	20.64	21.82
Lignin*	8.72	6.38	6.46	4.27	6.95	5.50
Cellulose*	16.68	13.25	2.45	12.38	16.73	15.32
Hemicellulose*	18.32	15.98	14.45	10.93	12.38	12.62

Note: */% Dry matter, T1: EM4 fermented palm oil waste concentrate, T2: A. niger fermented palm oil waste con centrate, T3: EM4 fermented fishery waste concentrate, T4: A. niger fermented fishery waste concentrate, T5: EM4 fermented palm and fishery waste concentrate, T6: A. niger fermented palm and fishery waste concentrate.

content derived from fish waste averages 31.11% (Ariana, Bawole, & Sabariah, 2018). This indicates that T3 has an adequate supply of protein for livestock, thereby ensuring the performance and health of the animals are maintained (Schumacher, Rodehutscord, Südekum, & Kehraus, 2025). In contrast, T1 has the lowest crude protein content, at 10.72%. The comparatively lower crude protein content of palm waste is attributable to the raw material of empty fruit bunches, which contains approximately 4.54% crude protein (Wu, Zhou, Yang, & Meng, 2020). These findings underscore the significance of variations in raw materials and feed formulations on the crude protein content of livestock feed.

The feed with the highest crude fiber content is T1 with a value of 22.31%. In contrast, T3 and T4 have the lowest crude fiber content, which is almost the same at around 6%. The crude fiber content of palm waste is very high, at 50.96%/DM, compared to the very small content of fish waste, which is 0.6%/DM. Crude fiber is important for maintaining the digestive health of livestock, but the crude fiber content of feed can also affect the digestibility of other nutrients found in the feed.

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Table 3. Consumption of feed nutrients given to goats (n = 6)

Feed	Consumption (g/day)		
	Basal feed	Dry matter	Crude protein
T1	993.61 ± 41.27^{b}	693.81 ± 33.73^{d}	86.08 ± 3.63^{e}
T2	992.93 ± 67.92^{b}	626.92 ± 57.6^{c}	140.06 ± 9.33^{d}
T3	997.93 ± 49.26^{b}	697.45 ± 40.27^{d}	181.70 ± 8.60^{cd}
T4	1029.20 ± 45.56^{a}	668.06 ± 39.06^{bc}	149.95 ± 10.08^{a}
T5	997.07 ± 42.51^{b}	669.26 ± 37.55^{b}	106.26 ± 7.99^{c}
T6	1016.20 ± 78.15^{a}	676.55 ± 70.13^{a}	116.71 ± 14.92^{b}
Average	1004.49 ± 14.82	672.01 ± 25.30	130.13 ± 34.18

Note: */% Dry matter, T1: EM4 fermented palm oil waste concentrate, T2: A. niger fermented palm oil waste concentrate, T3: EM4 fermented fishery waste concentrate, T4: A. niger fermented fishery waste concen trate, T5: EM4 fermented palm and fishery waste concentrate, T6: A. niger fermented palm and fishery waste concentrate. abc Different superscripts in the same column indicate a significant effect (p<0.05).

BDM, compared to the very small content of fish waste, which is 0.6%/DM (Araujo et al., 2021; Dimawarnita et al., 2024). Crude fiber plays a pivotal role in maintaining the digestive health of livestock; however, its impact on the digestibility of other nutrients present in feed is also noteworthy (Paternostre, De Boever, & Millet, 2021).

The consumption of treatment feed in goats shows significantly different results (P <0.05). The feed consumption in fresh form in cattle is 1,004.49±14.82 g/day or 42.04 g/BW/day, while goats are able to consume silage feed in fresh form at around 37.3 g/BW/day to 43.7 g/BW/day (Maña, Niepes, & Abela, 2023). According to Han et al. (2019) the factors influencing feed consumption in livestock include the characteristics of feed ingredients, environmental factors, livestock condition, and palatability. Meanwhile, the dry matter consumption of feed in goats is 672.01±25.3 g/day or 28.12 g/BW/day. The findings of this study are consistent with Patra et al. (2024) the existing body of literature on goat nutrition, which indicates that goats can consume 351–1,045 grams of dry matter per day. These results are also the same as those obtained by Li et al. (2022) The range of dry matter consumption in goats is from 609 g/day to 765 g/day.

The mean crude protein consumption in goats is 130.13±34.18 g/day. This result is lower than the mean crude protein consumption value in goats obtained by Kidane, Øverland, Mydland, & Prestløkken (2018) The range of values obtained is from 86.08 g/day to 129.54 g/day. However, these results are lower than the consumption values obtained Kholif et al. (2022) the range of daily weight gain values for the experiment was from 135 to 171 grams. However, the application of feed with a consumption value of 110 to 150 g/day yielded an average weight gain value that was equivalent to that of the other groups (da Silva, Pereira, da Silva, Valadares Filho, & Ribeiro, 2016)

In Vivo Feed Digestibility

The findings of the present study demonstrated that feed treatment exerts a significant effect (P<0.05) on the digestibility of dry matter (DM) and crude protein (CP) *in vivo* (Table 4). Among the various feed treatments, T2 exhibited the highest dry matter digestibility, with an average of 62.10%±7.64%, signifying its superior efficiency in utilizing dry matter compared to other treatments. These outcomes align with existing research Avornyo et al. (2020) indicating that goats can digest dry matter between 41.8% and 73.9%. The digestibility of DM in feed serves as a metric for evaluating the quality of feed provided to livestock (Tahuk, Dethan, & Sio, 2021).

The CP digestibility of T2 is notably high at 51.67±1.63%, placing it second in this study. Conversely, the T3 feed treatment exhibited the lowest DM digestibility at 53.93±5.02%. The observed DM digestibility values may be attributable to the dry matter content present in the treatment feed, which exerts an influence on the fermentation activity carried out by rumen microbes (Banu Sanjaya et al., 2022). Other perspectives suggest that this digestibility can be influenced by the speed of feed flow in the rumen and the amount of energy consumed by the treatment (Pazla, Adrizal, & Sriagtula, 2021).

Table 4. *In vivo* nutrient digestibility dry matter (DM) and crude protein (CP)

Feed	*In vivo* digestibility	
	Dry matter (%)	Crude protein (%)*
T1	57.41±1.87^{d}	57.34±2.47^{e}
T2	62.10±7.64^{a}	61.67±1.63b^{c}
T3	53.93±5.02^{e}	63.27±3.63^{b}
T4	56.64±1.26^{cd}	67.21±9.81^{a}
T5	58.28±3.76^{c}	59.35±3.18^{d}
T6	61.11±5.59^{b}	60.68±4.16^{c}

Note: */%Dry matter, T1: EM4 fermented palm oil waste concentrate, T2: A. niger fermented palm oil waste concentrate, T3: EM4 fermented fishery waste concentrate, T4: A. niger fermented fishery waste conctrate, T5: EM4 fermented palm and fishery waste concentrate, T6: A. niger fermented palm and fishery waste concentrate. abc Different superscripts in the same column indicate a significant effect (p<0.05).

The digestibility of crude protein in treatment T4 feed was found to be 67.21±9.81%, which is consistent with the observed da Silva et al. (2016) average digestibility of crude protein silage in livestock, ranging from 66% to 75.5%. This variability can be attributed to the high concentration of crude protein present in T4 feed. The digestibility value of roughage protein can also be influenced by the distribution between true protein nitrogen (N) and non-protein nitrogen (NPN) (Johansen, Hellwing, Lund, & Weisbjerg, 2017). The lowest result was obtained in T1 feed with a digestibility value of 57.34±2.47%. The high or low digestibility of crude protein in feed can be caused by anti-nutritional substances which have a negative effect on the digestibility of crude protein (Rodríguez-Rodríguez, Barroso, Fabrikov, & Sánchez-Muros, 2022). These anti-nutritional substances have been shown to form complex compounds with amino acids, enzymes, and proteins, thereby reducing the digestibility of protein in animal feed (Xu et al., 2016). One such anti-nutritional substance that has been identified as a factor affecting the digestibility of crude protein is lignin content (de Freitas et al., 2021).

The results of this study demonstrate that, despite the low utilization of dry matter in T3, the crude protein content of this feed is more readily digestible. The digestibility of dry matter and protein was found to vary among the other feed treatments (T1, T4, T5, and T6), with each treatment exhibiting a unique set of advantages and disadvantages. This study offers a comprehensive insight into the determination of the most suitable animal feed, with the efficiency of dry matter utilization and crude protein content serving as the primary selection criteria.

In Vitro Feed Digestibility

The impact of feed treatment on dry matter digestibility and *in vitro* crude protein digestibility is significant (P <0.05). The highest dry matter digestibility was observed in treatments T6 and T4, with values of 65.25% and 63.59%, respectively. Previous studies have shown that the digestibility of dry matter in silage ranges from 46% to 70% (Q. Zhang, Zhao, Wang, Yu, & Na, 2017). Furthermore, the utilization of Aspergillus mold in the fermentation process of animal feed has been shown to enhance dry matter digestibility by up to 85.94% (Uwineza et al., 2023). This observation aligns with the findings Kong et al. (2021) that *Aspergillus niger* has the capacity to elevate the digestibility of feed nutrients. Conversely, treatments T1 and T3 exhibited low digestibility values, with an average digestibility of 51.37±5.73% and 50.02±3.12% respectively. These treatments utilized an EM-4 fermenter. Numerous studies have demonstrated that silage produced using Aspergillus niger exhibits higher digestibility compared to EM-4 (Adam, Nurliana, & Samadi, 2018; Hartutik, Sudarwati, Putri, & Oktadela, 2020).

Treatment T4 exhibited the highest crude protein digestibility, with an average of 71.69 ± 8.70%. Conversely, treatment T5 demonstrated the lowest digestibility, with an average of 51.85 ± 5.73%. The application of fermentation technology to waste-derived feed

Table 5. *In vitro* nutrient digestibility dry matter (DM) and crude protein (CP)

Feed	*In vitro* digestibility	
	Dry matter (%)	Crude protein (%)*
T1	51.37±5.73^{d}	60.01±2.63^{c}
T2	60.71±4.52^{b}	67.12±1.47^{b}
T3	50.02±3.12^{d}	55.94±3.12^{d}
T4	63.59±8.95^{a}	71.69±8.70^{a}
T5	54.12±3.25^{c}	51.85±5.73^{e}
T6	65.25±5.59^{a}	67.41±7.74^{b}

Note: */%Dry matter, T1: EM4 fermented palm oil waste concentrate, T2: A. niger fermented palm oil waste concentrate, T3: EM4 fermented fishery waste concentrate, T4: A. niger fermented fishery waste concetrate, T5: EM4 fermented palm and fishery waste concentrate, T6: A. niger fermented palm and fishery waste concentrate. abc Different superscripts in the same column indicate a significant effect (p<0.05).

has been shown to enhance the breakdown of nitrogen or crude protein in feed (Herremans, Decruyenaere, Beckers, & Froidmont, 2019). This improvement in digestibility, attributable to the use of fermentation technology, plays a significant role in addressing the protein requirements of livestock (Rupp, Westreicher-Kristen, & Susenbeth, 2021). Protein digestibility is influenced by several factors, one of which is the content of anti-nutrients commonly found in plants (Putra & Sjofjan, 2021). The quality of the protein content of a feed can be seen in its protein digestibility (Sousa et al., 2023).

The digestibility of nutrients in feed ingredients has been shown to vary both in vivo and *in vitro*. *In vivo* digestibility values are typically higher than *in vitro* digestibility, underscoring the necessity for optimization of the *in vitro* method (Traksele et al., 2021). However, several studies have also demonstrated that *in vitro* digestibility can exceed that *in vivo* digestibility (Kim, Jo, & Kim, 2022). The variability in these digestibility values can be attributed to the composition of nutrients, the physical characteristics of feed particles, the processing of feed, the content of crude fiber, and the presence of anti-nutrients in animal feed ingredients (Romano, Gallo, Ferranti, & Masi, 2021).

CONCLUSIONS

Evaluation of feed digestibility, employing both *in vitro* and *in vivo* methods, revealed discrepancies in the efficiency of each feed type in providing essential nutrients, including dry matter (DM) and crude protein (CP). The *in vivo* method recorded the highest DM digestibility in T2 (62.10±7.64%) and the highest CP in T4 (67.21±9.81%). Conversely, the *in vitro* method exhibited the lowest CP digestibility in T6 (65.25±5.59%) and the lowest CP in T4 (71.69±8.7%). These findings underscore the effectiveness of palm oil waste and fish waste in meeting the nutritional needs of livestock, thereby supporting the strategic utilization of these wastes. *Aspergillus niger* has been shown to be more effective than EM4 in providing nutrients, absorption, and metabolism by livestock. The enhancement of nutrient digestibility leads to increased nutrient absorption and utilization, consequently improving feed efficiency. The strategic selection of feeds characterized by high protein digestibility, such as T4, has been demonstrated to generate substantial economic and production benefits. The utilization of palm oil waste and fish waste contributes to environmental sustainability and more efficient use of resources.

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