Accredited by Kemenristek Dikti No 32a/E/KPT/2017. ISSN 1411-2027

In Vitro Digestibility Evaluation Ammoniated Palm Frond as Cattle Feed

Jul Andayani[1*], Sadarman[2], Sri Novianti[1], Teja Kaswari[1], Fatati[1], Novia Qomariyah[3], Sandri Sastrawan[4], and Tri Rachmanto Prihambodo[5]

[1] Faculty of Animal Science, Universitas Jambi, Jambi, Indonesia
[2] Department of Animal Science, Universitas Islam Negeri Sultan Syarif Kasim, Pekanbaru, Indonesia.
[3] Research Center for Animal Husbandry, National Research and Innovation Agency of The Republic of Indonesia (BRIN), Cibinong Sciences Center, Bogor, Indonesia.
[4] Study Program of Animal Science, Faculty of Agriculture, Universitas Gajah Putih, Takengon, Indonesia
[5] Faculty of Animal Science, Jenderal Soedirman University, Purwokerto, Indonesia.
***Corresponding author's email: jul.andayani@yahoo.com**

Abstract. This study aimed to assess the potential of ammonia-treated palm fronds as a substitute for conventional forage in animal feed through in vitro analysis. The materials used were palm fronds, elephant grass, fine bran, corn, coconut meal, and urea. This study employed a Completely Randomized Design (CRD) with five treatments and four replications. The treatments applied in this study were: T0: 70% forage (all grass, no ammoniated palm fronds) + 30% concentrate, T1: 70% forage (75% grass, 25% ammoniated palm fronds) + 30% concentrate, T2: 70% forage (equal portions of grass and ammoniated palm fronds) + 30% concentrate, T3: 70% forage (25% grass, 75% ammoniated palm fronds) + 30% concentrate, and T4: 70% forage (entirely ammoniated palm fronds, no grass) + 30% concentrate. The observed variables in this study encompassed pH, digestibility of dry matter, organic matter, and crude protein, as well as the digestibility of NDF, ADF, and hemicellulose. The data obtained in this experiment were analyzed using analysis of variance (ANOVA) according to the design used. The post hoc test used was Duncan's multiple range test. The experimental results indicated that the treatments did not significantly affect ($P>0.05$) pH after in vitro testing. However, they had a significant impact ($P<0.05$) on the digestibility of dry matter, organic matter, crude protein, NDF, ADF, and hemicellulose. Digestibility increased with the increasing percentage of ammoniated palm fronds in the diet. In conclusion, this research demonstrates that the ammoniation process can improve the quality of palm fronds, leading to increased digestibility of palm fronds in the diet. Ammoniated palm fronds can replace forage in cattle feed based on nutrient digestibility *in vitro*.

Keywords: Ammoniation, Digestibility, *in vitro*, Palm frond.

Abstrak. Penelitian ini bertujuan untuk mengevaluasi pemanfaatan pelepah sawit yang telah diamoniasi sebagai pengganti pakan hijauan pada ternak secara in vitro. Bahan yang digunakan pelepah sawit, rumput gajah, dedak halus, jagung, bungkil kelapa, dan urea. Penelitian ini menggunakan Rancangan Acak Lengkap (RAL) yang terdiri dari 5 perlakuan dengan 4 kali ulangan. Perlakuan yang diberikan adalah T0: 70% hijauan (100% rumput + 0% pelepah kelapa sawit yang diamoniasi) + 30% konsentrat, T1: 70% hijauan (75% rumput + 25% pelepah kelapa sawit yang diamoniasi) + 30% konsentrat, T2: 70% hijauan (50% rumput + 50% pelepah kelapa sawit yang diamoniasi) + 30% konsentrat, T3: 70% hijauan (25% rumput + 75% pelepah kelapa sawit yang diamoniasi) + 30% konsentrat, T4: 70% hijauan (0% rumput + 100% pelepah kelapa sawit yang diamoniasi) + 30% konsentrat. Variabel yang diamati meliputi pH, kecernaan bahan kering, kecernaan bahan organik, kecernaan protein kasar, kecernaan NDF, kecernaan ADF, dan kecernaan hemiselulosa. Data yang diperoleh di analisis varian (ANOVA). Uji post hoc yang digunakan adalah uji rentang berganda Duncan. Hasil percobaan menunjukkan bahwa perlakuan tidak memberikan pengaruh nyata ($P>0{,}05$) terhadap pH tetapi memberikan pengaruh nyata ($P<0{,}05$) terhadap kecernaan bahan kering, kecernaan bahan organik, kecernaan protein kasar, kecernaan NDF, kecernaan ADF, dan kecernaan hemiselulosa. Peningkatan persentase pelepah sawit memberikan pengaruh pada peningkatan kecernaan pakan. Proses amoniasi dapat meningkatkan kualitas pelepah sawit, yang mengarah pada peningkatan kecernaan pelepah sawit dalam pakan. Pelepah sawit yang diamoniasi dapat menggantikan hijauan dalam pakan ternak berdasarkan kecernaan nutrisi secara in vitro.

Kata kunci: Amoniasi, *in vitro*, Kecernaan, Pelepah sawit.

Introduction

Livestock forage availability varies throughout the year, being plentiful during the ~~rainy~~ wet season but significantly decreasing in the arid season. This fluctuation creates challenges for farmers in maintaining sufficient and high-quality feed for their animals. A shortage of forage can lead to reduced livestock productivity due to inadequate nutrition. One possible solution is utilizing agricultural by-products as an alternative feed source. Palm fronds are a viable option due to their abundance in plantation areas. However, their high crude fiber content poses a limitation for direct use as animal feed. To improve their nutritional value and digestibility, treatments such as ammoniation are required.

In Indonesia, particularly in Jambi Province, there is an abundance of agricultural and plantation waste, including palm fronds, which have potential as cattle feed. Oil palm is a rapidly expanding plantation crop, with its cultivated area increasing from 956,889 hectares in 2019 to 1,033,354 hectares in 2020. Palm oil processing generates both liquid and solid waste. Palm Oil Mill Effluent (POME) is produced at a rate of approximately 600-700 liters per ton of fresh fruit bunches (FFB). Given that palm oil mills in Jambi process around 1,230 tons of FFB per hour and operate for 20 hours daily, the estimated annual POME production is about 5.4 million cubic meters. Additionally, solid waste, including empty fruit bunches, shells, and fiber, is generated in substantial amounts. The potential for oil palm waste utilization in Jambi reaches approximately 89,080 tons annually, offering opportunities for conversion into alternative fuels such as briquettes (Jambi Province Plantation Office, 2021).

Considering their price and availability, feed derived from agricultural and plantation waste like palm fronds has better economic value because these food sources are not fully utilized as cattle feed. Furthermore, utilizing palm fronds as cattle feed is one way to mitigate environmental pollution. However, the use of palm fronds as the main cattle feed is limited by their low quality, as reflected in their low digestibility. This poor quality of feed has a direct impact on livestock productivity, such as decreased growth rate, low feed efficiency, and decreased body weight. Cows that consume high -fiber feed with low digestibility will have difficulty in using nutrition optimally, thus impacting the low production of meat and milk. This is a challenge in the livestock system based on oil palm waste, so that processing technology is needed, such as ammoniation, to improve the quality of nutrition and digestibility of oil palm fronds as animal feed.

Fiber-rich feed such as palm fronds can be improved in quality through alkali treatment, whether using NaOH, Ca(OH)2, or NH3 gas. Among these, ammoniation using urea is the most cost-effective and accessible method for small-scale farmers, compared to NaOH or Ca(OH)2 treatment, which may involve higher costs and logistical challenges. Alkali treatment can dissolve some lignin from the feed and break the hydrogen bonds between carbon two of one glucose molecule and carbon six of another glucose molecule in cellulose (Saha and Fathak, 2021).

One alkali treatment that can improve the quality of fiber feed like palm fronds is ammoniation using urea (Fitria dkk., 2023). Ammoniation treatment with urea not only loosens lignocellulosic bonds for easier digestion by rumen bacteria but also increases the crude protein content of the feed to meet the nitrogen needs for rumen bacteria growth (Liang et al., 2024). Using urea in the ammoniation process is a simple, cost-effective, and easily applicable treatment for rural farmers since urea is readily available and does not require substantial costs. A urea level of 6% and an ammoniation duration of 28 days are suitable levels for ammoniation processes on corn husks (Andayani et al., 2005; Chen et al., 2020). Furthermore, Andayani

(2008) stated that ammoniation treatment with urea can increase the degradation of rice straw, palm fiber, corn husks, and sugarcane tops by 10-15%.

To determine the beneficial value of a feed, digestibility trials on livestock need to be conducted because chemical analyses of a feed only describe its nutrient values without its actual benefits This study seeks to assess the potential of ammoniated palm fronds as a substitute for forage in animal feed through in vitro analysis.

Materials and Methods

Research location

The production, harvesting, pH testing, and evaluation of dry matter digestibility, oraganic matter digestibility, crude protein digestibility, neutral detergent fibre, acid detergent fibre, and hemicellulose were carried out at the Animal Nutrition and Feed Laboratory, Faculty of Animal Science, Universitas Jambi.

Research materials

The materials used included palm fronds, elephant grass, fine bran, corn, coconut meal, urea, saturated $HgCl_2$ solution, Solution A (200 mL containing 45.5 grams Na_2PO_4, $_{12}H_2PO_4$, 49 grams $NaHCO_3$, 2.35 grams NaCl, and 2.85 grams KCl), Solution B (6 grams $MgCl_2$ 6%), Solution C (6 grams $CaCl_2$ 4%), distilled water (1000 mL), pepsin, and 0.10 N HCl. The equipment used consisted of a set of tools for ammoniated and in vitro digestibility measurement.

Research designs

This study employed an experimental method using a Completely Randomized Design (CRD) consisting of 5 treatments with 4 replications. The treatments applied were the use of ammoniated palm fronds in cattle feed, as follows:

T0: 70% forage (entirely grass, no ammoniated palm fronds) + 30% concentrate
T1: 70% forage (75% grass, 25% ammoniated palm fronds) + 30% concentrate
T2: 70% forage (50% grass, 50% ammoniated palm fronds) + 30% concentrate
T3: 70% forage (25% grass, 75% ammoniated palm fronds) + 30% concentrate
T4: 70% forage (fully replaced with ammoniated palm fronds, no grass) + 30% concentrate

Research procedure

The process of ammoniating oil palm fronds, as outlined by Belanche et al. (2021), begins by preparing the fronds, which are cut into smaller pieces of approximately 5-10 cm for easier handling. Urea is then applied as the ammonia source, typically at a concentration of 3-5% of the dry weight of the palm fronds. Before mixing with the fronds, the urea is dissolved in water to ensure even distribution. Once the fronds are thoroughly mixed with the urea solution, they are stored in an anaerobic or sealed environment, often using silage plastic, to initiate fermentation. The fermentation period lasts between 3 and 4 weeks, depending on ambient temperature and humidity conditions (Julianti et al., 2024). When fermentation is complete, the fronds are exposed to air for 1-2 days.

Variables to be measured

In vitro testing followed the Tilley and Terry (1963) method. A 0.50 g sample was placed in a 100 mL tube containing 40 mL McDougall buffer and 10 mL rumen fluid. CO_2 was passed through for 30 seconds before sealing the tube and incubating it at 39°C for 4 hours. After incubation, Volatile Fatty Acids (VFA) and ammonia nitrogen ($N\text{-}NH_3$) were analyzed. After 48 hours, 2–3 drops of saturated $HgCl_2$ were added, followed by centrifugation at 3000 rpm for 15 minutes. The supernatant was discarded, and 50 mL of 0.2% HCl pepsin solution was introduced for further digestion over 48 hours. The residue was filtered using Whatman No. 41 paper, dried at 105°C for 24 hours, and ashed in a furnace for 6 hours. Dry Matter Digestibility (DMD) and Organic Matter Digestibility (OMD) were calculated using Theodorou and Brook (1990), while Crude Protein Digestibility (CPD) followed Katoch (2023). NDF, ADF, and hemicellulose content according to Van Soest (1965) method.

Data analysis

Data obtained from the in vitro experiment were analyzed using analysis of variance (ANOVA) according to the design used. Post hoc tests employed Duncan's multiple range test (Adams and McGuire, 2022).

Results and Discussion

pH

The pH of rumen fluid, which is slightly acidic to neutral, is essential for the proper functioning of microbial activity and digestion in the rumen. If you're working with rumen fluid in experiments, making sure it stays within this range is important for accurate results. According to McDonald et al. (2022), the pH of the rumen ranges from 6.8-7, under these conditions digestive activity in the rumen can run normally. The post-incubation rumen pH values for ammoniated palm fronds are T0 (6.86), T1 (6.88), T2 (6.87), T3 (6.87) and T4 (6.89).

The analysis of variance revealed that the treatment rations did not have a significant effect (P>0.05) on the in vitro pH values. This is likely because the nutritional composition of the rations was fairly similar, leading to no significant impact on pH levels after in vitro testing. Moreover, since the same rumen fluid and buffer solution were used in equal quantities, the pH remained stable. The pH values observed in this study fell within the normal range for supporting optimal rumen microbial activity.

McDonald et al. (2022) states that the ideal pH range for optimal microbial activity in the rumen is between 6.50 and 7, which supports efficient feed digestion. A drop in pH during in vitro testing is typically due to fermentation, leading to lactic acid production, which increases acidity and inhibits microbial activity (Sadarman et al., 2023). Maintaining an optimal rumen pH is crucial for effective feed breakdown, as it allows fiber-digesting microbes to function at their best (Sadarman et al., 2024).

McDonald et al. (2022) observed that cellulolytic bacteria are very sensitive to acidic environments and perform optimally at a pH of 6.40-7.0. The pH values obtained in this study suggest that the buffer system effectively maintained the pH within the normal range (Pardosi, 2018). This indicates that the pH achieved through this treatment supports optimal rumen microbial activity.

Dry matter digestibility, organic matter, and crude protein digestibility

The digestibility of ammoniated oil palm fronds can vary depending on several factors, including the specific treatment and the conditions under which they are processed. The values for rumen dry matter digestibility, organic matter digestibility, and crude protein digestibility following the in vitro incubation of ammoniated palm fronds are shown in Table 1.

Table 1. Dry matter, organic matter, and crude protein of palm frond ammoniated

Parameters	Dietary Treatment					
	T0	T1	T2	T3	T4	SEM
DMD (%)	34.0^{a}	35.7^{a}	38.6^{b}	39.9^{b}	38.9^{b}	8.42
OMD (%)	31.3^{a}	34.8^{b}	37.6^{c}	39.4^{c}	39.1^{c}	0.87
CPD (%)	58.9^{a}	63.1^{b}	63.2^{b}	65.8^{c}	67.9^{d}	0.23

P values marked by different superscript in the same row differ significantly (P<0.05) due to dietary treatment; DMD – dry matter digestibility; OMD – organic matter digestibility; CPD – crude protein digestibility

Dry matter digestibility

The analysis of variance results the treatment indicates a significant effect ($P<0.05$) on dry matter digestibility in vitro. Duncan's multiple range test reveals that the dry matter digestibility in treatment T0 is not significantly different from T1, but differs significantly from T2, T3, and T4. Treatment T1 also shows significant differences from T2, T3, and T4. Treatments T2, T3, and T4 do not differ significantly from one another. These differences are likely due to the impact of using ammoniated palm fronds in the ration.

Differences in structure and composition between elephant grass and ammoniated palm fronds may enhance dry matter digestibility as the inclusion of ammoniated palm fronds in the diet increases. The average dry matter digestibility across treatments ranged from 34.0% to 39.9%. This enhancement is likely due to the effect of urea used in the ammoniation process. Urea treatment helps break down lignocellulosic and lignohemicellulosic bonds in the palm fronds, which facilitates increased dry matter digestibility.

Mor (2018) reported that treating fibrous feeds with urea ammoniation improves their nutritional quality. According to him, urea ammoniation enhances the nutritional value of fibrous feed by increasing its nitrogen content, improving digestibility, enhancing rumen fermentation, and reducing fiber content, which collectively make the feed more palatable, digestible, and beneficial for ruminants' health and productivity. Additionally, Obada et al. (2023) reported that the ammoniation process helps to loosen fiber bonds and partially disrupts lignin-cellulose and lignin-hemicellulose bonds. Mohammadi et al. (2024) observed that urea ammoniation not only breaks down lignocellulosic bonds to facilitate digestion by rumen bacteria but also provides nitrogen to support bacterial growth. Furthermore, Andayani (2008) noted that ammoniation loosens both lignocellulosic and lignohemicellulosic bonds, improving dry matter degradation.

Organic matter digestibility

The analysis of variance results indicate that the treatments had a significant effect ($P<0.05$) on organic matter digestibility in vitro. Duncan's multiple range test shows that organic matter digestibility in treatment T0 significantly differs from that in T1, T2, T3, and T4. Similarly, treatment T1 significantly differs from T2, T3, and T4. However, treatments T2, T3, and T4 do not show significant differences from one another. These variations are likely due to differing levels of ammoniated palm fronds in each treatment and the distinct structural and fiber component compositions of the feed ingredients used.

These variations play a role in enhancing organic matter digestibility across the treatments. The enhancement in digestibility is likely attributed to the urea used in the ammoniation process. Urea treatment causes the loosening of lignocellulosic and lignohemicellulosic bonds in the ammoniated palm fronds, thereby improving organic matter digestibility. This result aligns with Mohammadi et al. (2024), who stated that urea ammoniation of fibrous feeds aids in breaking lignocellulosic bonds, enhancing digestibility by rumen bacteria, while also supplying essential nitrogen for microbial growth.

Cavallini et al. (2023) observed that the pattern of organic matter digestibility in treatment rations is similar to that of dry matter digestibility. Andayani (2010) also pointed out that organic matter digestibility corresponds with dry matter digestibility since organic matter is a component of dry matter. Similarly, Novita et al. (2020) found that digestibility results for dry matter and organic matter often align when additives are used. This correlation occurs because organic matter is a subset of dry matter; thus, improvements in dry matter digestibility generally lead to increased organic matter digestibility, and vice versa, as noted by Morales et al. (2021).

Crude protein digestibility

Based on Table 1, the analysis of variance indicates that the treatment significantly affected (P<0.05) crude protein digestibility in vitro. Duncan's multiple range test revealed that crude protein digestibility in T0 differed significantly from T1, T2, T3, and T4. Meanwhile, T1 was not significantly different from T2 but showed significant differences compared to T3 and T4. Additionally, T4 exhibited the highest crude protein digestibility value. The high protein digestibility at T4 is likely influenced by variations in ammonia levels in palm fronds, along with differences in the structural and fiber composition of feed ingredients. Additionally, urea ammonia can enhance the protein content of the treated material. Structural differences and increased protein content resulting from ammoniation contribute to variations in crude protein digestibility observed across treatments.

The increase in crude protein digestibility is likely due to the effect of urea used in the ammoniation process. Treatment with urea will loosen the bonds of lignocellulose and lignohemicellulose in ammoniated palm leaves, resulting in higher protein content and increasing crude protein digestibility. These findings support Andrade et al. (2020) stated that urea ammonia not only facilitates the breakdown of lignocellulose bonds to make it more easily digested by rumen bacteria but also increases the crude protein content to meet the nitrogen requirements for bacterial growth. Additionally, the improved protein digestibility enhances the overall nutritional value of the feed, making it more beneficial for the growth and productivity of ruminant animals. By increasing the availability of protein in the diet, ammoniation helps meet the protein requirements of livestock, which is crucial for optimal performance and health. This aligns with broader research indicating that enhanced protein digestibility from ammoniated feeds can lead to better feed conversion rates and increased weight gain in ruminants.

Andayani (2010) observed that urea ammoniation can enhance the protein content in corn husks. Wahyono et al. (2019) added that lower fiber fraction components require less energy for microbial digestion, thereby increasing digestibility. Chen et al (2020) noted that using urea as an ammonia source in ammoniation is an effective method to improve feed quality by boosting dry matter and nitrogen content, which enhances both digestibility and dry matter consumption. Similarly, Fakhri et al. (2024) highlighted that treating feeds with urea or ammonia gas can improve waste feed quality by increasing cell wall digestibility and protein content.

NDF, ADF, and hemicellulose digestibility

NDF (Neutral Detergent Fiber) digestibility shows how well the total fiber in feed is digested. ADF (Acid Detergent Fiber) digestibility focuses on the more resistant fiber, mainly cellulose. Hemicellulose digestibility indicates how well this specific type of fiber breaks down. The digestibility values of NDF, ADF, and hemicellulose of palm frond ammoniated can be seen in Table 2.

Table 2. NDF, ADF, and hemicellulose of palm frond ammoniated

Parameters	Dietary Treatment					
	T0	T1	T2	T3	T4	SEM
NDF (%)	21.4^{a}	26.7^{b}	31.8^{c}	32.6^{c}	33.5^{c}	1.82
ADF (%)	17.5^{a}	21.5^{b}	24.3^{c}	24.9^{c}	24.9^{c}	1.14
Hemicellulose (%)	22.7^{a}	23.9^{b}	30.9^{c}	30.8^{c}	34.3^{d}	1.22

P-values marked by different superscript in the same row differ significantly (P<0.05) due to dietary treatment; no superscript = not significantly difference (P>0.05). NDF – neutral detergent fiber; ADF – acid detergent fiber

Neutral Detergent Fibre digestibility

Based on Table 2, the analysis results indicate that the treatments significantly affect ($P<0.05$) in vitro NDF digestibility. Duncan's range test reveals that NDF digestibility in treatment T0 differs significantly from T1, T2, T3, and T4. Treatment T1 also shows significant differences from T2, T3, and T4. However, treatments T2, T3, and T4 do not differ significantly from each other. These differences are likely due to the varying levels of ammoniated oil palm fronds used in each treatment, as each feed ingredient has a unique material structure and fiber composition. Furthermore, ammoniation with urea improves cell wall digestibility in the treated material (oil palm fronds).

Differences in material structure and the enhanced cell wall digestibility following ammoniation contribute to increased NDF digestibility across treatments. This improvement in NDF digestibility is attributed to the effect of urea used in the ammoniation process. Urea treatment helps to loosen lignocellulosic and lignohemicellulosic bonds in the oil palm fronds, which enhances cell wall digestibility and subsequently increases NDF digestibility. This is consistent with Adesogan et al. (2019) findings, which state that urea ammoniation of fibrous feeds not only facilitates the breakdown of lignocellulosic bonds for easier digestion by rumen bacteria but also boosts the crude protein content of the feed to meet the nitrogen needs for rumen bacterial growth.

The ammonia treatment of palm frond fiber enhances its degradation, making it more susceptible to digestion by livestock enzymes while also increasing its protein content.Furthermore, Mudgal et al. (2018) notes that urea ammoniation enhances the nutritional value of fibrous feeds. Andayani (2009) highlights that urea treatment affects corn husks by causing absorbed NH3 to alter cell wall composition and structure, breaking bonds between lignin, cellulose, and hemicellulose, which changes the fiber component structures. Adams et al. (2022) reported a significant increase in NDF digestibility of ammoniated bagasse, rising from 23.5% to 52.7%.

Acid Detergent Fibre digestibility

Based on Table 3, the variance analysis results indicate that the treatments significantly affect ($P<0.05$) in vitro ADF digestibility. Duncan's range test reveals that ADF digestibility in treatment T0 differs significantly from T1, T2, T3, and T4. Treatment T1 also significantly differs from T2, T3, and T4. However, treatments T2, T3, and T4 do not differ significantly from each other. These differences are likely due to the varying levels of ammoniated oil palm fronds used in each treatment, as each feed ingredient has a unique material structure and fiber composition. Furthermore, urea ammoniation can enhance the digestibility of the cell walls in the treated material.

The variations in material structure and the improved cell wall digestibility following ammoniation contribute to increased ADF digestibility in each treatment. This enhancement in ADF digestibility is likely due to the urea used in the ammoniation process. Urea treatment helps to loosen lignocellulosic and lignohemicellulosic bonds in the oil palm fronds, improving cell wall digestibility and thereby increasing ADF digestibility. This is consistent with Mohammadi et al. (2024), who assert that urea ammoniation of fibrous feeds not only facilitates the breakdown of lignocellulosic bonds for easier digestion by rumen bacteria but also boosts the crude protein content of the feed to support the nitrogen needs for bacterial growth.

Adesogan et al. (2019) highlights that the process of urea ammoniation improves the nutritional quality of fibrous feeds. Andayani (2009) observes that urea treatment affects corn husks by causing absorbed NH_3 to modify cell wall composition and structure, breaking the bonds between lignin, cellulose, and hemicellulose, which consequently alters the fiber component structures. These changes in cell wall composition and structure improve the digestibility of fibrous feeds, making them more efficient for ruminant animals. The increased breakdown of lignin, cellulose, and hemicellulose enhances the availability of nutrients, thereby improving feed efficiency and animal performance.

Hemicellulose digestibility

Based on Table 3, the analysis results indicate that the treatments significantly affect ($P<0.05$) in vitro hemicellulose digestibility. Duncan's advanced range test reveals that hemicellulose digestibility in treatment T0 differs significantly from T1, T2, T3, and T4. Treatment T1 also shows significant differences from T2, T3, and T4. However, treatment T2 does not differ significantly from T3 but does differ from T4, while T3 significantly differs from T4. These variations are likely due to the differing levels of ammoniated oil palm fronds used in each treatment. Additionally, urea ammoniation can improve the digestibility of the cell walls in the treated material.

The increase in hemicellulose digestibility is likely due to ammoniation. The process of ammoniating with urea loosens the lignocellulosic and lignohemicellulosic bonds in the oil palm fronds, thereby enhancing hemicellulose digestibility. This finding is consistent with McDonald et al. (2022), who assert that urea ammoniation not only facilitates the breakdown of lignocellulosic and lignohemicellulosic bonds for easier digestion by rumen bacteria but also boosts the crude protein content of the feed, supporting bacterial growth. Additionally, Zhang et al. (2023) notes that urea ammoniation improves the nutritional value of fibrous feeds.

Additionally, hemicellulose digestibility is influenced by the contents of NDF and ADF, as hemicellulose is derived from the difference between these two components. The digestibility of hemicellulose also relies on rumen microbes. This is consistent with Nofrizal et al. (2019), who explain that hemicellulose content increases with higher cellulose levels because hemicellulose is dependent on the availability of NDF and ADF. Furthermore, Sharkeret al. (2023) highlight that rumen microbes producing high levels of hemicellulase enzymes are crucial for optimizing hemicellulose digestion, as these enzymes play a key role in hydrolyzing feed and providing energy.

Conclusions

This study concludes that the ammoniation process improves the quality of oil palm fronds, enhancing their digestibility in livestock feed. As a result, ammoniated oil palm fronds can fully replace forage in cattle diets, as ammoniation facilitates fiber breakdown by disrupting lignocellulosic bonds, leading to better NDF, ADF, and hemicellulose digestibility. Continuous evaluation of its effectiveness and cost considerations is essential for optimal feed management.

Acknowledgement

This study was fully funded by the Non-Tax State Revenue, Universitas Jambi.

References

Adams, K.A and E.K. McGuire. 2022. Student Study Guide With IBM® SPSS® Workbook for Research Methods, Statistics, and Applications: Edition 3. SAGE Publications Inc. India.

Adesogan, A.T., K.G. Arriola., Y. Jiang., A. Oyebade., E.M. Paula., A.A. Pech-Cervantes., J.J. Romero., L.F. Ferraretto, and D. Vyas. 2019. Symposium review: Technologies for improving fiber utilization. *Journal of Dairy Science*, Volume 102, Issue 6, Pages 5726-5755, ISSN 0022-0302, https://doi.org/10.3168/jds.2018-15334.

Andayani, J., A. Yani, dan Akmal. 2005. Kecernaan Bahan Kering, Bahan Organik, dan NDF Kulit Buah Jagung Amoniasi Secara In Sacco. *Laporan Penelitian*, Fakultas Peternakan Universitas Jambi, Jambi.

Andayani, J. 2008. Evaluasi Kecernaan In Sacco Beberapa Pakan Serat yang Berasal dari Limbah

Pertanian dengan Amoniasi. *Jurnal Ilmiah Ilmu-Ilmu Peternakan*, 11(2): 88-92.

Andayani, J. 2009. Kecernaan In Vitro Komponen Serat Ransum Ternak Sapi yang Menggunakan Kulit Buah Jagung Amoniasi. *Jurnal Ilmiah Ilmu-Ilmu Peternakan*. 12(3): 129-136.

Andayani, J. 2010. Evaluasi Kecernaan In Vitro Bahan Kering, Bahan Organik, dan Protein Kasar Penggunaan Kulit Buah Jagung Amoniasi dalam Ransum Ternak Sapi. *Jurnal Ilmiah Ilmu -Ilmu Peternakan*, 13(5): 252-259.

Andrade, A.P., M.P. de Figueiredo., D.G. de Quadros., J.Q. Ferreira., T.R. Whitney., Y.S. Luz., H.R.O. Santos, and M.N.S. Souza. 2020. Chemical and biological treatment of cotton gin trash for fattening Santa Ines lambs. *Livestock Science*, Volume 240, 104146, ISSN 1871-1413, https://doi.org/10.1016/j.livsci.2020.104146.

Battelli, M., Colombini, S., Parma, P., Galassi, G., Crovetto, G.M., Spanghero, M., Pravettoni, D., Zanzani, S.A., Manfredi, M.T, and Rapetti, L. 2023. In vitro effects of different levels of quebracho and chestnut tannins on rumen methane production, fermentation parameters, and microbiota. Front. Vet. Sci. 10:1178288. https://doi.org/10.3389/fvets.2023.1178288.

Belanche, A., A.I. Martin-García., E. Jiménez., N.N. Jonsson, and Yáñez-Ruíz. 2021. A novel ammoniation treatment of barley as a strategy to optimize rumen pH, feed degradability, and microbial protein synthesis in sheep. *Journal of the Science of Food and Agriculture*, 101(13): 5541–5549. https://doi.org/10.1002/jsfa.11205.

Cavallini, D., E. Raffrenato., L.M.E. Mammi., A. Palmonari., G. Canestrari., A. Costa., G. Visentin, and A. Formigoni. 2023. Predicting fibre digestibility in Holstein dairy cows fed dry-hay-based rations through machine learning. *Animal*, Volume 17, Supplement 5, 101000, ISSN 1751-7311, https://doi.org/10.1016/j.animal.2023.101000.

Chen, Y., Xing J., Chin, C.K, and Ho, C.T. 2020. Effect of urea on volatile generation from Maillard reaction of cysteine and ribose. *Journal of Agricultural and Food Chemistry*, 48 (8), pp. 3512 - 3516, Cited 31 times. https://doi.org/10.1021/jf9910761.

Dinas Perkebunan Daerah TK I. Provinsi Jambi. 2021. *Statistik Perkebunan Provinsi Jambi*. 2005. Pemerintah Daerah TK I. Provinsi Jambi. Jambi.

Fakhri, S., Suryani, H., Kaswari, T., Pane, M., Hariyati, N., Limbong, D.R., Jayanegara, A., Komwihangilo, D. 2024. Improving the Nutritional Value and Rumen Fermentation Profile of Oil Palm Fronds by Autoclaving and Ammoniation with Different Levels of Urea. *Advances in Animal and Veterinary Sciences*, 12 (10), pp. 2051-2061. https://doi.org/10.17582/journal.aavs/2024/12.10.2051.2061.

Fitria, R., S.A.C. Luthfi, and N. Hindratiningrum. 2023. Nutritional Quality of Amofer (Ammonia Fermentation) Corn Straw Using EM4 and M21 Decomposer. *Jurnal Sains dan Teknologi Peternakan*, 5(1): 18–24. https://doi.org/10.31605/jstp.v5i1.3160

Julianti, E., R.P. Harahap, dan Y. Rohayeti. 2024. Evaluasi Komposisi Serat Kasar dan Kecernaan Rumen In Vitro Tandan Kosong Kelapa Sawit Teknologi Amoniasi Fermentasi dengan EM-4 dan Cairan Rumen Sapi. *Jurnal Nukleus Peternakan*, 11(1): 6–14.

Katoch, R. 2023. *Techniques in Forage Quality Analysis*. Springer. Singapore.

Liang, J., Zhang, R., Chang, J., Chen, L., Nabi, M., Zhang, H., Zhang, G, and Zhang, P. 2024. Rumen microbes, enzymes, metabolisms, and application in lignocellulosic waste conversion - A comprehensive review. *Biotechnology Advances*. Volume 71, 108308, ISSN 0734-9750, https://doi.org/10.1016/j.biotechadv.2024.108308.

McDonald, P., R.A. Edwards., J.F.D. Greenhalgh., C.A. Morgan., L.A. Sinclair, and R.G. Wilkinson. 2022. *Animal Nutrition 8th* Edn. Pearson. Singapore.

Mohammadi, M., M. Alian., B. Dale., B. Ubanwa, and V. Balan. 2024. Multifaced application of AFEX-pretreated biomass in producing second-generation biofuels, ruminant animal feed, and value-added bioproducts. *Biotechnology Advances*, Volume 72, 108341, ISSN 0734-9750, https://doi.org/10.1016/j.biotechadv.2024.108341.

Mor, P., B. Bals., A.K. Tyagi., F. Teymouri., N. Tyagi., S. Kumar., V. Bringi, and M. VandeHaar. 2018. Effect of ammonia fiber expansion on the available energy content of wheat straw fed to lactating cattle and buffalo in India. *Journal of Dairy Science*, Volume 101, Issue 9, Pages 7990-8003, ISSN 0022-0302, https://doi.org/10.3168/jds.2018-14584.

Morais, L.F de., Almeida, J.C de C., Nepomuceno, D de D., Freitas, R.S.X de., Melo, B.M.G de, and Silva J.F M. 2020. Nutritive value of elephant grass hay ammoniated by urea. *Bioscience Journal*, 36(5): 1-13. https://doi.org/10.14393/bj-v36n5a2020v36n5a2020-41135.

Morales, A.G., R.E. Vibart., M.M. Li., A. Jonker., D. Pacheco, and M.D. Hanigan. 2021. Evaluation of Molly model predictions of ruminal fermentation, nutrient digestion, and performance by dairy cows consuming ryegrass-based diets. *Journal of Dairy Science*, Volume 104, Issue 9, Pages 9676-9702, ISSN 0022-0302, https://doi.org/10.3168/jds.2020-19740.

Mudgal, V., M.K. Mehta, and A.S. Rane. 2018. Lentil straw (Lens culinaris): An alternative and nutritious feed resource for kids. *Animal Nutrition*, Volume 4, Issue 4, Pages 417-421, ISSN 2405-6545, https://doi.org/10.1016/j.aninu.2018.04.009.

Nofrizal, S., Mulyani, dan Syafrizal. 2019. Pengaruh Penggunaan Beberapa Macam Feses Ternak pada Lahan Bera terhadap Kualitas Fraksi Serat (NDF, ADF, Selulosa, Hemiselulosa, dan Lignin) Rumput Lapangan. *Jurnal Embrio*, 11(1): 48-58.

Obada, D.O., M.O. Kekung., T. Levonyan, and G.W. Norval. 2023. Palm Oil Mill Derived Empty Palm Fruit Bunches as a Feed Stock for Renewable Energy Applications in Nigeria: A Review. *Bioresource Technology Reports*, 24(3): 1-7.

Sadarman., Febrina, D., Rinaldi, S.T., Hendri, M.I., Ilyazar, Weno, Alfian, A., Nurfitriani, R.A., Qomariyah, N., Sukmara, A., Koswara, E., Prihambodo, T.R., Gholib, and Azmi, A.F.M. 2023. The Quality of Organic Waste Market Ensiled Using Rejected Commercial Syrup as An Alternative Ruminant Livestock Feed. *Animal Production: Indonesian Journal of Animal Production*, 25(3): 186-198. doi: 10.20884/1.jap.2023.25.3.257.

Sadarman., D. Febrina., E. Saleh., Mhd. Fazly., A.B. Prastyo., N. Qomariyah, dan A.F.M. Azmi. Transformasi Proses Pembuatan Silase: Peningkatan Kualitas dengan Penambahan Sirup Komersial Afkir pada Silase Berbahan Rumput Odot dan Dedak Padi Halus. *Jurnal Ilmiah Peternakan Terpadu*, 12(2): 155-171. https://dx.doi.org/10.23960/jipt.

Saha, S.K and N.N. Pathak. 2021. *Fundamentals of Animal Nutrition, 1st Edn*. Springer Nature. Singapore.

Sharker, B., Md.A. Islam., Md.Al.A Hossain., I. Ahmad., A.Al. Mamun., S. Ghosh., A. Rahman., Md.S. Hossain., Md.A. Ashik., Md.R. Hoque., Md.K. Hossain., M.Al. Mamun., Md.A. Haque., H. Patel., Md.Y. Prodhan., P. Bhattacharya, and Md.A. Haque. 2023. Characterization of lignin and hemicellulose degrading bacteria isolated from cow rumen and forest soil: Unveiling a novel enzymatic model for rice straw deconstruction. *Science of The Total Environment*, Volume 904, 166704, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2023.166704.

Theodorou, M.K and A.E. Brook. 1990. *Evaluation of a New Laboratory Procedure for Estimating the Fermentation Kinetic of Tropical Feeds*. Annual Report AFRC Institute, Hurley, Maidenhead, London.

Van Soest, P.J. 1965. Symposium on Factors Influencing Voluntary Intake of Herbage by ruminant: Volunter Intake in Relation to Chemical Composition and digestibility. *J. Animal sci*. 24: 834.

Wahyono, T., E. Jatmiko, Firsoni, S.N.W. Hardani, dan E. Yunita. 2019. Evaluasi Nutrien dan Kecernaan In Vitro Beberapa Spesies Rumput Lapangan Tropis di Indonesia. *Jurnal Sains Peternakan*, 17(2): 17-23.

Zhang, X.M., W.X. Chen., Q.X. Yan., C. Wang., B. Lin., S.Y. Yi., R. Wang., Z.Y. Ma., Q.S. Li., A. Jonker., X.Z. Sun., S. Wittayakun., Z.L. Tan, and M. Wang. 2023. Low-Protein Diet Promotes Nitrogen Retention Efficiency Via Enhanced Renal Urea Reabsorption and Microbial Hydrogen Incorporation in the Rumen of Goats. *Animal Feed Science and Technology*, 305(2023): 115762.