Available online at: http://alive.lppm.unand.ac.id/

Andalasian Livestock

ISSN 3063-1912 (Online)

Research Article

Storage Stability of Complete Feed Wafers Containing Mangrove Fruit and Palm Fatty Acid Distillate: Physical Properties and In Vitro Rumen Fermentation

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Article History | Received: August 26, 2025 | Revised: December 18, 2025 | Accepted: January 27, 2026 | Published: January 30, 2026

ABSTRACT

This study aimed to evaluate the effects of storage duration on the physical properties of complete feed wafers supplemented with mangrove fruit as a tannin source and palm fatty acid distillate (PFAD) as an energy source, as well as in vitro rumen fluid characteristics. A completely randomized design was used with four storage duration treatments: 15 days (T1), 30 days (T2), 45 days (T3), and 60 days (T4), with five replications. The feed ingredients consisted of fermented sugarcane tops, *Tithonia diversifolia*, concentrate, mangrove fruit, and PFAD, which were processed into complete feed wafers. The observed parameters included the physical properties of the wafers, namely aroma, texture, color, water absorption, and density, as well as rumen fluid characteristics, namely total volatile fatty acid (VFA), pH, and ammonia (NH_3). The results showed that increasing storage duration tended to decrease total VFA from 123.12 ± 2.28 mM in T1 to 121.10 ± 2.01 mM in T4, although the values remained relatively stable. The rumen fluid pH was also relatively uniform, ranging from 6.82 ± 0.13 to 6.88 ± 0.13. NH_3 concentration decreased with increasing storage duration, from 21.28 ± 0.54 mg/100 mL in T1 to 18.13 ± 1.51 mg/100 mL in T4. Storage duration had no significant effect ($P>0.05$) on the aroma, texture, or color of the wafers, indicating that their physical quality was maintained during storage. Based on these results, it can be concluded that complete feed wafers supplemented with mangrove fruit and PFAD maintained their physical quality and rumen fermentation stability for up to 60 days of storage.

Keywords: complete feed wafer, mangrove fruit, palm fatty acid distillate, rumen fermentation, storage duration

INTRODUCTION

Feed is the main factor determining the success of ruminant farming because it directly affects animal productivity, nutrient utilization efficiency, and production costs. One of the major constraints of feed supply systems is the unstable availability of forage throughout the year, particularly during the dry season. Therefore, feed processing technology is needed to improve the shelf life, facilitate handling, and maintain the nutritional quality of feed ingredients. One potential form of feed processing is a complete feed wafer, as it is compact, practical, easy to store, and more efficient in both transportation and feeding (Ikhlas et al., 2024a; Jamarun et al., 2024).

Complete feed wafers are processed feed products that combine forage and concentrates into a single product with a relatively complete nutrient composition. Processing feed into wafers is intended not only to improve practicality but also to extend feed shelf life (Vinodhini et al., 2025).

DOI: https://doi.org/10.25077/alive.v3.n1.p61-71.2026

However, storage duration may affect the physical and biological quality of wafers, including color, aroma, texture, water absorption, density, and possible changes in nutrient quality, which may ultimately influence rumen fermentability. Therefore, evaluating storage duration is important to determine the extent to which complete feed wafers maintain their quality and function as animal feed.

The use of local feed resources with functional value is essential for the development of complete feed wafers to improve feed efficiency and quality. One potential ingredient is mangrove fruit, which contains tannins. Tannins are bioactive compounds that, at certain levels, may exert positive effects on the rumen fermentation system, such as protecting protein from excessive degradation, suppressing excessive ammonia formation, and improving nitrogen utilization efficiency (Elihasridas et al., 2024; Elihasridas et al., 2025). In addition, tannins have also been reported to have the potential to modulate rumen microbial populations and suppress the activity of certain undesirable microorganisms (Susanto et al., 2024; Pazla et al., 2024). Thus, the inclusion of mangrove fruit as a tannin source in complete feed wafers is expected not only to serve as an alternative local feed ingredient but also to enhance rumen fermentation characteristics and biological value (Pazla et al., 2025a).

In addition to a tannin source, an appropriate energy source is an important factor in complete feed formulation. Palm fatty acid distillate (PFAD) is a by-product of the palm oil industry that is rich in energy and has the potential to be utilized as a livestock feed ingredient (Handojo et al., 2019). Palm Fatty Acid Distillate (PFAD) contains fatty acids that may increase the energy density of the ration, thereby supporting the energy requirements of both rumen microbes and the animal (Pazla et al., 2025b; Pazla et al., 2025c). In complete feed wafer formulation, the inclusion of PFAD may be a strategy to enhance feed energy content by utilizing relatively available local raw materials. However, the use of PFAD should be further evaluated, particularly regarding its effect on wafer quality during storage and rumen fermentation (Ikhlas et al., 2024b; Franzolin et al., 2024).

The combination of mangrove fruit as a tannin source and PFAD as an energy source in complete feed wafers represents an interesting approach that integrates both protective and energy-supplying functions in a single feed product. The interaction between these two ingredients during storage is presumed to affect both the physical quality of the wafers and the characteristics of the rumen fluid when tested in vitro. A storage period that is too short may not adequately reflect product stability, whereas an excessively long storage period may reduce the physical and biological quality of the wafers. Therefore, testing several storage periods is important to determine the optimal storage duration that maintains the quality of the wafers.

Based on the above considerations, research on the effects of storage duration on complete feed wafers containing mangrove fruit as a tannin source and PFAD as an energy source is required. This study is important for evaluating changes in the physical properties of wafers during storage and their effects on rumen fluid characteristics, including pH, VFA, and NH_3. The results of this study are expected to provide scientific information regarding the stability and quality of complete feed wafers during storage, while also supporting the utilization of functional local feed ingredients in a more efficient and sustainable ruminant production system.

MATERIAL AND METHODS

Research Materials

The materials used in this study consisted of sugarcane tops collected from sugarcane plantations in Puncak Lawang, Agam District, West Sumatra, *Tithonia diversifolia* obtained from

Padang Panjang, and *Pleurotus ostreatus* purchased from Bungus, Padang City. Tapioca starch was purchased from Belimbing Market, Kuranji, Padang City. Concentrate ingredients, including corn, rice bran, tofu by-products, and molasses, were obtained from Raya Market, Padang City. PFAD was purchased from PT Sinar Mas Medan. Mangrove fruit are harvested on the southern coast of the Mandeh area. The rumen fluid was collected from a goat slaughterhouse for in vitro analysis. In addition, chemicals and reagents used for physical quality evaluation and in vitro rumen fermentation analysis were prepared.

Research Equipment

The equipment used in this study comprised a wafer press machine, digital and manual balances, a shaker incubator, an oven, a centrifuge, and a complete set of laboratory equipment for in vitro analysis, physical quality evaluation of wafers, and measurement of rumen fluid characteristics.

Experimental Design

This study was conducted using a completely randomized design with four treatments and five replications. The treatments were based on the storage duration of the complete feed wafers: T1 = 15 days, T2 = 30 days, T3 = 45 days, and T4 = 60 days. The nutrient composition of the feed ingredients and the ration formulation used for the production of complete feed wafers are presented in Tables 1 and 2, respectively.

Table 1. Nutrient contents

Nutrient contents	Fermented sugarcane tops	Tithonia	Tofu pulp	Bran	Tapioca flour	Mangrove fruit
Crude protein	8.36	21.88	19.26	11.09	4.40	8.70
Total Digestible Nutrients	49.05	63.15	70.22	74.87	82.00	57.53
Dry matter	92.32	90.89	85.91	87.5	86.13	55.82
Ash	10.57	13.28	5.6	10.56	0.06	5.18
Crude fat	2.90	3.06	2.8	6.28	1.90	1.44
Crude fiber	37.98	18.32	16.8	9.23	4.60	28.76
Nitrogen Free Extract	41.75	43.46	55.54	62.83	89.04	55.92
Neutral Detergent Fiber	80.87	60.72	44.6	48.11	2.1	62.20
Acid Detergent Fiber	52.63	41.78	27.37	23.08	9.64	54.01
Hemicellulose	28.24	18.94	17.28	25.03	7.54	8.19
Cellulose	33.8	35.07	25.67	11.05	1.61	22.61
Lignin	8.79	4.8	5.95	3.78	1.11	23.55
Tannin	-	-	-	-	-	28.34

Parameters Measured

The observed parameters in this study included the physical properties of wafers, such as aroma, texture, color, water absorbency, and density. Rumen fluid characteristics, including total volatile fatty acid (VFA), pH, and ammonia (NH_3) concentration.

 DOI: https://doi.org/10.25077/alive.v3.n1.p61-71.2026

Table 2. Ration composition and ration nutrient content

Feed ingredient	Ration composition (%)
Tapioca starch	10
Fermented sugarcane tops	30
Tithonia	30
Bran	8.55
Tofu dreags	9.95
Mangrove fruit	4
Molases	6
Salt	0.5
lime	0.5
Sulphur	0.5
Total	100
PFAD supplementation	4
Nutrient Content	
Crude protein	12.68
Total digestible nutrients	61.26
Ash	8.96
Dry matter	85.09
Crude fat	2.94
Crude fiber	20.91
Nitrogen free extract	48.08
Neutral detergent fiber	54.06
Acid detergent fiber	36.22
Hemicellulose	19.35
Cellulose	25.09
Lignin	6.04
Tannin	1.13

Research Procedure

Fermentation of sugarcane tops

Fermentation of sugarcane tops was conducted as described by Pazla et al. (2021a). Sugarcane tops were collected from the Puncak Lawang sugarcane plantation in the Agam District, West Sumatra. The collected sugarcane tops were separated from the stems and sun-dried. After drying, the sugarcane tops were chopped using a chopping machine. The chopped material was spread evenly on a tarpaulin and thoroughly mixed with 10% *Pleurotus ostreatus*. The mixture was then packed into plastic bags, compacted under anaerobic conditions, sealed tightly, and incubated for 21 days. After incubation, the fermented sugarcane tops were dried and ground before use.

Preparation of complete feed wafers

Complete feed wafers were prepared using a 50:50 ratio of dried *Tithonia diversifolia* and fermented sugarcane tops. The concentrate portion consisted of rice bran, mangrove fruit, PFAD, tofu by-product, corn, molasses, minerals, and salt, which were weighed according to the formulated ration. All feed ingredients were thoroughly mixed until a homogeneous mixture was

obtained, then processed using a wafer press machine and molded into wafers according to the method described by Ikhlas et al. (2024a). The resulting wafers were stored for 15, 30, 45, or 60 days, depending on the experimental treatment, before further evaluation.

Analysis of physical properties of wafers

Texture, aroma, and color

The evaluation of wafer texture, aroma, and color was conducted according to the method described by Solihin et al. (2015). Color was assessed based on the degree of wafer darkness. Texture was evaluated by touching the wafer surface, while aroma was assessed by smell. The sensory evaluation was carried out by 20 panelists. Observations of physical properties were scored according to the criteria presented in Table 3.

Table 3. Wafer characteristics assessment criteria (Solihin et al., 2015)

Criteria	Characteristic	Score	Desription
Colour	Dark brown	3.0-3.9	Very good
	Light brown	2.0-2.9	Good
	Brownish yellow	1.0-1.9	Fair
Aroma	Smells	3.0-3.9	Very good
	Odourlees	2.0-2.9	Good
	Rancid	1.0-1.9	Fair
Tekstur	Has a firm, dense texture (not easily broken)	3.0-3.9	Very good
	Has a firm texture, easy to break	2.0-2.9	Good
	Has a wet, easily broken, and slimy	1.0-1.9	Fair

Water absorbency

Water absorbency was determined according to the method described by Trisyulianti et al. (2003) by measuring the weight of the wafers before and after soaking in water for 5 min. Water absorbency was calculated using the following formula: WA (%) = ((B2 − B1) / B1) × 100

Where:

WA = water absorbency (%)

B1 = initial weight of wafer (g)

B2 = final weight of wafer after soaking (g)

Wafer density

The wafer density was calculated according to Trisyulianti et al. (2003) using the following formula:

$K = W / (P \times L \times T)$

Where: K = wafer density (g/cm^3); W = sample weight (g); P = sample length (cm); L = sample width (cm); T = sample thickness (cm)

In vitro analysis

Preparation of McDougall's solution

The composition of McDougall's solution used as a buffer is presented in the following table. All components were dissolved in distilled water and prepared one day before in vitro incubation.

 DOI: https://doi.org/10.25077/alive.v3.n1.p61-71.2026

The solution was then placed in a shaker water bath at 39°C and flushed with CO_2 gas for 30–60 s to maintain anaerobic conditions.

Collection of rumen fluid

Rumen fluid was collected in the morning from the slaughterhouse. The rumen contents were squeezed and transferred into a thermos flask maintained at 39°C and continuously flushed with CO_2 to preserve anaerobic conditions and microbial activity. The rumen fluid was then filtered through gauze to the required amount for mixing with McDougall's solution.

In vitro incubation

Samples of complete feed wafers from each storage treatment were subjected to in vitro incubation using rumen fluid and McDougall's buffer solution. Incubation was conducted under anaerobic conditions at 39°C. At the end of the incubation period, rumen fluid characteristics, including total VFA, pH, and NH_3 concentration, were measured.

RESULTS AND DISCUSSION

Physical Properties of the Wafer

The results showed that the storage duration of the complete feed wafers supplemented with mangrove fruit and PFAD had no significant effect (P>0.05) on wafer physical quality, including aroma, texture, and color. The aroma scores for treatments T1, T2, T3, and T4 were 3.32 ± 0.61, 3.28 ± 0.54, 3.29 ± 0.51, and 3.28 ± 0.64, respectively (Table 4), with a P-value of 0.872. These values indicate that the wafer aroma remained relatively stable throughout the storage period.

Table 4. Physical quality of the wafer

Physical properties (score)	Treatment			
	T1	T2	T3	T4
Aroma	3.32±0.61	3.28±0.54	3.29±0.51	3.28±0.64
Texture	3.12±0.52	3.16±0.50	3.15±0.62	3.13±0.54
Color	3.27±0.71	3.27±0.57	3.26±0.63	3.24±0.52

Notes: T1 = Storage period: 15 days, T2 = Storage period: 30 days, T3 = Storage period: 45 days, T4 = Storage period: 60 days

The texture scores in treatments T1, T2, T3, and T4 were 3.12 ± 0.52, 3.16 ± 0.50, 3.15 ± 0.62, and 3.13 ± 0.54, respectively (P = 0.843). These results indicate that the storage duration did not cause any significant change in wafer texture. Similarly, for the color parameter, the values obtained in treatments T1, T2, T3, and T4 were 3.27 ± 0.71, 3.27 ± 0.57, 3.26 ± 0.63, and 3.24 ± 0.52, respectively, with a P-value of 0.750. This indicates that the wafer color remained relatively uniform during storage. These results suggest that complete feed wafers supplemented with mangrove fruit and PFAD maintained their physical quality throughout the storage period.

The absence of a significant effect of storage duration on wafer aroma indicates that, during storage, the product maintained the stability of the volatile compounds responsible for odor. Aroma is an important indicator of the physical quality of feed because it relates to the acceptability of the material to animals (Tumbal et al., 2025). The relatively similar aroma values across all treatments indicate that storage until the end of the observation period did not produce

rancid, sour, or other abnormal odors (Koesmara et al., 2024). This suggests that the wafers remained in good condition and had not undergone substantial physical deterioration.

The lack of a significant difference for the texture parameter indicates that the physical structure of the wafers remained stable during storage. Wafer texture is generally influenced by material density, moisture content, interparticle binding capacity, and the molding process (Claudia et al., 2023). The stable texture values across all treatments indicate that the wafers remained compact and did not break easily during storage. This condition suggests that the wafer processing technology used produced a sufficiently stable feed form, thereby maintaining resistance during storage (Vidya et al., 2021).

The wafer color, which did not differ significantly among treatments, indicates that storage did not cause any meaningful change in appearance. Color is a visual parameter that is easily observed and is often used as an early indicator of changes in feed quality. The relatively similar color values across all treatments indicate that oxidation, browning, or pigment changes during storage were minimal or insufficient to affect wafer color scores (Wereńska et al., 2021). This suggests that the visual quality of the wafers remained well maintained.

Overall, the stability of aroma, texture, and color during storage indicates that complete feed wafers supplemented with mangrove fruit and PFAD had good physical shelf stability. This condition is advantageous because maintaining feed physical quality supports handling, storage, and potential acceptability by animals. Therefore, the use of mangrove fruit and PFAD in complete feed wafers did not degrade the physical quality of the product during the tested storage period.

Rumen Fluid Characteristics

The results showed that the storage duration of complete feed wafers supplemented with mangrove fruit and PFAD tended to influence rumen fermentation characteristics, particularly the descriptively NH_3 concentration. The total VFA values in treatments T1, T2, T3, and T4 were 123.12 ± 2.28, 122.45 ± 1.12, 121.40 ± 2.23, and 121.10 ± 2.01 mM (Table 5), respectively. These data indicate that a longer storage period tended to slightly decrease total VFA, although the decline was relatively small.

Table 5. VFA content, NH_3, and pH

Treatment	VFA (mM)	pH	NH_3 (mg/100 ml)
T1	123.12±2.28	6.84±0.10	21.28±0.54
T2	120.45±1.12	6.82±0.13	19.94±0.59
T3	122.40±2.23	6.88±0.13	18.23±0.34
T4	123.10±2.01	6.83±0.03	18.23±1.51

Notes: T1 = Storage period: 15 days, T2 = Storage period: 30 days, T3 = Storage period: 45 days, T4 = Storage period: 60 days

The rumen fluid pH values across all treatments were nearly identical, ranging from 6.82 ± 0.13 to 6.88 ± 0.13. This condition indicates that storage of complete feed wafers for up to 60 days still maintains the stability of rumen fermentation pH. Meanwhile, NH_3 concentration decreased with increasing storage duration, from 21.28 ± 0.54 mg/100 mL in T1 to 19.94 ± 0.59 mg/100 mL in T2, then further decreasing to 18.23 ± 0.34 mg/100 mL in T3 and 18.13 ± 1.51 mg/100 mL in T4. These results indicate that longer storage duration tended to reduce NH_3 concentration in rumen fermentation.

 DOI: https://doi.org/10.25077/alive.v3.n1.p61-71.2026

The total VFA values in all treatments remained within a relatively similar range. This indicates that storage for up to 60 days of complete feed wafers containing mangrove fruit and PFAD did not cause major changes in the ability of the substrate to be fermented by rumen microbes. Although there was a decreasing trend in the VFA from T1 to T4, the difference was relatively small. Biologically, this suggests that the quality of fermentable carbohydrates is still sufficiently maintained during the storage period (Arya et al., 2024). Thus, storage did not substantially reduce the availability of organic matter as a source of volatile fatty acids.

pH values ranging from 6.82 to 6.88 indicate stable rumen fermentation conditions that support microbial activity, particularly cellulolytic bacteria (Guo et al., 2024). This pH range suggests that complete feed wafers stored for up to 60 days maintained a normal fermentation environment. The stable pH was also in accordance with the VFA values, which showed no marked changes, indicating that the accumulation of fermentation acids remained within the range tolerated by the rumen buffering system (Tunkala et al., 2023).

The decrease in NH_3 concentration with increasing storage duration suggests changes in protein degradation or nitrogen utilization during rumen fermentation. The higher NH_3 value at T1 suggests that the protein fraction or non-protein nitrogen in wafers stored for a shorter period was more readily degraded in the rumen. In contrast, the lower NH_3 concentrations in T3 and T4 may indicate that during longer storage periods, physical or chemical changes occurred in the feed material, resulting in slower protein degradation.

In addition, the inclusion of mangrove fruit was presumed to contribute to the reduction in NH_3 concentration. Mangrove fruit contains bioactive compounds, such as tannins, which can bind to proteins and form tannin–protein complexes (Bersharati et al., 2022). These complexes tend to be more resistant to microbial degradation in the rumen, thereby reducing the amount of protein deaminated into ammonia (Chamadia et al., 2020). Therefore, the decrease in NH_3 at longer storage durations may be associated not only with the effect of storage itself, but also with the increasingly stable interaction between feed components, including bioactive compounds in mangrove fruit, and the protein fraction in the wafers (Dentinho & Bessa, 2016).

PFAD, as a dense energy source, was presumed to contribute to maintaining fermentation stability, particularly because pH and VFA values remained within the normal range. This indicates that the combination of mangrove fruit and PFAD in complete feed wafers preserved the fermentability of the ration during storage (Franzolin et al., 2010). In general, the results of this study show that complete feed wafers stored for up to 60 days remained suitable for use, as they did not cause a sharp decline in VFA or pH and instead showed a decreasing trend in NH_3, which may indicate more efficient nitrogen utilization.

CONCLUSION

Storage of complete feed wafers containing mangrove fruit as a tannin source and PFAD as an energy source for up to 60 days maintained the physical quality of the wafers and the stability of the rumen fluid characteristics in vitro. Storage did not cause meaningful changes in wafer aroma, texture, or color, indicating that the product maintained good physical quality throughout the storage period. In terms of rumen fluid characteristics, the total VFA, pH, and NH_3 values remained within the normal range and were relatively stable.

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