# Effects of Fermentation Additives on Silage Quality, Chemical Composition, and Cyanide Residues of Ensiled Durian Peel as a Roughage Source for Ruminants

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**Abstract**

To assess durian peel as a potential ruminant feed resource, this study investigated the effects of various fermentation additives on silage quality, nutrient composition, and feed safety. The experimental design followed a completely randomized design (CRD) with three treatments: yeast, salt, and sodium nitrate. Each additive was applied at 1% of the fresh matter. The experiment was conducted in triplicate, with each replicate serving as an independent fermentation unit prepared in an individual 20-L plastic container. Fresh durian peel was manually chopped into 2-3 cm pieces, thoroughly mixed with the specified additives, and stored under anaerobic conditions for 21 days. Fermentation quality was assessed based on physical characteristics, pH, and residual hydrocyanic acid concentration. Chemical composition was analyzed using standard proximate and fiber analysis. The results showed that all treatments produced silage of acceptable quality, characterized by a favorable fermented aroma and desirable pH values. Residual hydrocyanic acid levels in across ensiled durian peel treatments remained well within safe limits for ruminant feeding. Yeast supplementation yielded the highest crude protein content and enhanced palatability, whereas salt improved physical characteristics, color stability, and gross energy. Notably, sodium nitrate was the most effective additive for reducing fiber fractions and further minimizing cyanide residues. The results indicate that durian peel can be effectively preserved and its nutritional value enhanced through ensiling with appropriate additives. Overall, yeast supplementation yielded in the highest crude protein content, while salt treatments enhanced silage physical quality and energy value. Conversely, sodium nitrate was most effective in treatment reducing fiber fractions and mitigating cyanide residues. The selection of fermentation additives should be tailored to specific production goals, such as maximizing protein content, ensuring feed safety, and optimizing cost-effectiveness. These findings suggest the potential of ensiled durian peel as a sustainable and low-cost potential roughage source for ruminants in tropical regions.

**Keywords**: Fermented durian peel, chemical composition, ruminant feed, roughage source

## Introduction

Rising feed costs continue to challenge ruminant production systems, particularly among smallholder farmers in tropical regions where access to conventional feed resources is increasingly limited (FAO, 2018). In this context, agricultural by-products have attracted attention as alternative feed resources due to their availability and potential to reduce production costs while supporting sustainable livestock systems. Durian (*Durio zibethinus*) is an economically important fruit crop in Southeast Asia. Due to the structure of the fruit, only about 30-40% of the total mass is edible, while the remaining portion consists of husk or peel, which is typically discarded as waste. Consequently, massive quantities of durian peel are generated as agricultural by-products with potential for value-added utilization (Gamay et al., 2024; Tang & Nguyen, 2025). Durian peel contains considerable amounts of structural carbohydrates, including cellulose and hemicellulose, as well as fermentable components that may support microbial fermentation (Semae et al., 2024). However, the direct use of durian peel as ruminant feed is constrained by its high moisture content and elevated fiber levels. In addition, it contains anti-nutritional compounds, particularly cyanogenic compounds such as hydrocyanic acid (HCN), which may negatively affect feed intake and nutrient digestibility (Semae et al., 2024). Ensiling is a widely adopted preservation technique for high-moisture feed materials that relies on anaerobic fermentation mediated primarily by lactic acid bacteria (LAB). In the ensiling process, water-soluble carbohydrates are converted into organic acids, mainly lactic acid, resulting in a rapid decline in pH and inhibition of undesirable microorganisms (McDonald et al., 1991). Nevertheless, successful ensiling depends on substrate availability and microbial activity. Accordingly, the use of fermentation additives has been widely recommended to improve silage quality and nutrient preservation (Kung et al., 2018).

Previous studies have shown that different additives can modify fermentation dynamics and the chemical composition of silage. Yeast may stimulate microbial activity and fermentation efficiency (Dawson et al., 1990), whereas salt can inhibit spoilage microorganisms and improve silage stability (Weinberg & Muck, 1996). Sodium nitrate has also been explored as a nitrogen source and microbial modulator during ensiling, although potential nitrate and nitrite residues require careful consideration of feed safety (Leng, 2008). Despite increasing interest in durian peel as a ruminant feed resource, comparative information on the effects of different fermentation additives on fermentation quality, nutrient composition, and cyanide reduction in ensiled durian peel remains limited. It was hypothesized that different fermentation additives would differentially affect fermentation quality, nutrient composition, and cyanide reduction in ensiled durian peel. Therefore, this study aimed to evaluate the effects of yeast, salt, and sodium nitrate as fermentation additives on the fermentation characteristics, chemical composition, and cyanide residues of ensiled durian peel.

## Materials and Methods

### Experimental Design

The experiment was conducted using a completely randomized design (CRD), evaluating the effects of three different fermentation additive treatments: yeast, salt, and sodium nitrate. Each additive was applied at a level of 1% on a fresh matter basis, with three replicates per treatment. The inclusion level of 1% was selected based on previous studies reporting that additive levels around 1% are effective in improving the fermentation quality of silage (Kung et al., 2018). Each replicate represented an independent fermentation unit prepared in a separate 20-L plastic container.

### Preparation of Durian Peel and Ensiling Procedure

Fresh durian peel was collected and manually chopped into pieces approximately 2.0-3.0 cm in length to increase surface area and facilitate packing into fermentation containers. The prepared durian peel was thoroughly mixed with the respective additives according to the experimental treatments presented in Table 1.

**Table 1** Ingredient formulation of ensiled durian peel with different fermentation additives

| Ingredients | Additives (%) | | |
|---|---|---|---|
| | Yeast | Salt | Sodium nitrate |
| Durian peel | 87 | 87 | 87 |
| Yeast | 1 | 0 | 0 |
| Salt | 0 | 1 | 0 |
| Sodium nitrate | 0 | 0 | 1 |
| Molasses | 3 | 3 | 3 |
| Brown sugar | 3 | 3 | 3 |
| Urea | 1 | 1 | 1 |
| Water | 5 | 5 | 5 |
| Total | 100 | 100 | 100 |
| Ensiling cost (THB/kg) | 3.36 | 1.45 | 2.65 |

The mixtures were packed into 20 L plastic containers, compacted to minimize trapped air, and tightly sealed to ensure anaerobic conditions. The ensiling process was conducted at ambient temperature for 21 days, as this duration is sufficient for lactic acid fermentation to stabilize and for silage to reach acceptable preservation quality (McDonald et al., 1991; Kung et al., 2018). During this period, the containers remained unopened. The fermentation process depended on the activity of lactic acid bacteria, leading to a reduction in pH and the suppression of undesirable microorganisms.

**Evaluation of Fermentation Quality**

After 21 days of ensiling, the containers were opened. The color of the ensiled durian peel was measured using a colorimeter (CR-400, Konica Minolta, Japan), and the results were expressed as L* (lightness), a* (redness-greenness), and b* (yellowness-blueness) values according to the CIELAB color system. For pH determination, a representative 25 g sample of ensiled durian peel was randomly collected from each replicate and soaked in 100 mL of distilled water. The mixture was thoroughly stirred for 10 minutes, after which the pH was measured using a digital pH meter.

**Cyanide Residue Analysis**

Ensiled durian peel samples were randomly collected from each replicate and analyzed for residual cyanide content using the Continuous Flow Analysis (CFA) method following AOAC (2016). Briefly, samples were homogenized and subjected to acid hydrolysis to release cyanide, which was subsequently determined calorimetrically through the formation of a colored complex measured by an automated continuous flow analyzer.

**Chemical Composition Analysis**

For chemical analysis, ensiled durian peel samples were collected at 500 g per replicate. Samples were oven-dried at 75 °C until constant weight was achieved, then ground using a laboratory mill to pass through a 1-mm sieve. The ground samples were analyzed for dry matter (DM), crude protein (CP), and ash using proximate analysis, following the standard procedures outlined by the AOAC (2016). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined following the detergent fiber procedures described by Van Soest et al. (1991). Organic matter (OM) content was calculated using the equation: OM (%) = DM (%) − ash (%).

**Statistical Analysis**

All data were subjected to statistical analysis to determine differences among treatments according to the experimental design. Data were analyzed using analysis of variance (ANOVA). Before analysis, the assumptions of normality and homogeneity of variance were checked. Treatment means were compared using Duncan's Multiple Range Test, with statistical significance declared at $P < 0.05$. Data were analyzed using SAS software (Version 6.12, SAS Institute Inc., Cary, NC, USA).

## Results

### Physical appearance and color characteristics of ensiled durian peel

The physical appearance of fresh and ensiled durian peel after 21 days of fermentation is illustrated in Fig. 1, while the color parameters are presented in Table 2. After ensiling, all treatments exhibited characteristics of well-preserved silage, including a pleasant fermented odor and acceptable visual quality, by sensory observation and visual inspection. Ensiled durian peel supplemented with yeast, salt, and sodium nitrate differed in physical appearance compared with fresh durian peel. The yeast-treated silage appeared softer and slightly more compacted, whereas the salt- and sodium nitrate-treated silages maintained a firmer structure. No visible signs of spoilage, such as mold growth or discoloration, were observed in any treatments during visual inspection.

(1) (2) (3) (4)

**Figure 1** Physical appearance of durian peel before and after ensiling (1) Fresh durian peel (2) Ensiled durian peel supplemented with yeast; (3) Ensiled durian peel supplemented with salt; (4) Ensiled durian peel supplemented with sodium nitrate

Colorimetric analysis (Table 2) indicated that the type of fermentation additive significantly influenced the color characteristics of ensiled durian peel. Among the treatments, the silage treated with salt exhibited the highest lightness value (L* = 35.85), which was significantly greater ($P<0.05$) than the values observed in the yeast (27.63) and sodium nitrate (23.12) treatments. This higher L* value indicates a brighter, slightly yellowish appearance, which is commonly associated with good-quality silage. Redness values (a*) did not differ significantly among treatments, indicating that the fermentation additives had no clear effect on the red-green color characteristics of the ensiled durian peel. In contrast, yellowness values (b*) were significantly higher ($P<0.05$) in the salt-treated silage (18.65) than in the yeast treatment (12.85). The sodium nitrate treatment showed intermediate b* values (16.23) and did not differ significantly from either treatment.

**Table 2** Color parameters of fermented durian peel after 21 days

| Color parameters | Additive | | | SEM |
|---|---|---|---|---|
| | Yeast | Salt | Sodium nitrate | |
| L* | $27.63^b$ | $35.85^a$ | $23.12^b$ | 4.76 |
| a* | 11.81 | 11.67 | 11.24 | 1.91 |
| b* | $12.85^b$ | $18.65^a$ | $16.23^{ab}$ | 3.26 |

Means within the same row with different superscript letters (a, b) differ significantly ($P < 0.05$). SEM = standard error of the mean.

Overall, the visual observations presented in Fig. 3 were consistent with the instrumental color measurements shown in Table 4, demonstrating that salt supplementation resulted in a more desirable color profile of ensiled durian peel compared with yeast and sodium nitrate supplementation.

**Chemical composition of fresh and ensiled durian peel**

Table 3 shows the chemical composition of fresh durian peel and fermented durian peel prepared with different fermentation additives. Across treatments, pH values ranged from 3.59 to 5.97, indicating successful fermentation. Silage treated with salt and sodium nitrate exhibited a lower pH than that treated with yeast, indicating a greater extent of acidification during the ensiling process. Residual hydrocyanic acid concentrations in all fermented durian peel treatments were low, ranging from 0.33 to 0.47 mg%. Ensiling markedly altered the chemical composition of durian peel. Organic matter (OM) content decreased after ensiling compared with fresh durian peel, particularly in the sodium nitrate treatment. Dry matter (DM) content of ensiled durian peel ranged from 79.25 to 79.74%, showing only minor variation among treatments.

**Table 3** Chemical composition of fresh and ensiled durian peel with different fermentation additives (DM basis)

| Chemical composition | Fresh durian peel | Additive | | | SEM |
|---|---|---|---|---|---|
| | | Yeast | Salt | Sodium nitrate | |
| pH | nd- | 5.97 | 3.59 | 3.76 | 0.16 |
| Hydrocyanic acid (mg/kg DM) | nd- | 3.50 | 4.70 | 3.30 | 0.06 |
| Organic matter (%) | 78.12 | 68.45 | 68.20 | 64.12 | 1.84 |
| Dry matter (%) | 83.24 | 79.36 | 79.74 | 79.25 | 0.66 |
| Crude protein (%) | 4.67 | 22.28[a] | 18.22[b] | 15.32[c] | 0.73 |
| Ether extract (%) | 0.29 | 1.27[c] | 2.85[b] | 5.01[a] | 0.99 |
| Ash (%) | 5.13 | 10.90 | 11.54 | 15.12 | 1.28 |
| Neutral detergent fiber (%) | 60.67 | 53.49[a] | 46.40[b] | 38.73[c] | 3.50 |
| Acid detergent fiber (%) | 45.22 | 39.97[a] | 33.40[b] | 35.73[b] | 1.16 |
| Gross energy (kcal/kg) | 5003.86 | 3449.7[b] | 3781.8[a] | 3307.7[b] | 5.72 |

Means within the same row with different superscript letters (a–c) differ significantly ($P < 0.05$). SEM = standard error of the mean. nd = not detected. All chemical composition data are expressed on a dry matter (DM) basis.

Crude protein (CP) content was significantly affected by the type of fermentation additive ($P < 0.05$). The highest CP content was observed in the yeast treatment (22.28%), followed by the salt (18.22%) and sodium nitrate (15.32%) treatments. In contrast, the ether extract (EE) content was highest in the sodium nitrate treatment (5.01%), whereas the yeast treatment had the lowest EE content (1.27%). Ash content increased in all treatments compared with fresh durian peel, with the highest concentration in the sodium nitrate treatment. Fermentation additives also affected the fiber fraction. Neutral detergent fiber (NDF) content was significantly lower in the sodium nitrate treatment (38.73%) compared with the yeast (53.49%) and salt (46.40%) treatments ($P<0.05$). Acid detergent fiber (ADF) content was lowest in the salt treatment, while the highest ADF concentration among the ensiled treatments was observed in the yeast treatment. Gross energy content differed significantly among treatments ($P<0.05$). The salt treatment exhibited the highest gross energy (3,781.8 kcal/kg), whereas lower energy values were observed on the yeast and sodium nitrate treatments.

## Discussion

Differences in fermentation quality, physical characteristics, chemical composition, and safety were observed among the fermentation additives evaluated in this study. Despite these differences, all treatments produced silage with acceptable quality, suggesting that durian peel can be effectively preserved when appropriate additives are applied. Comparable outcomes have also been reported for other high-moisture agricultural by-products used as ruminant feed resources (McDonald et al., 1991; Kung et al., 2018).

**Fermentation characteristics and physical quality**

Across treatments, the detection of a sour fermented aroma indicates that lactic acid fermentation was achieved and that acceptable silage preservation occurred. Compared with the yeast treatment, lower pH values were observed in the salt and sodium nitrate treatment, suggesting a more effective acidification process that may contribute to limiting the growth of undesirable microorganisms during ensiling (Muck et al., 2018; Kung et al., 2018; Wilkinson & Rinne, 2018). The high pH observed in the yeast-treated silage may indicate less efficient acidification during fermentation. This could be due to competition between yeast and lactic acid bacteria, which may reduce lactic acid production and slow the decline in pH. In general, silage with pH values above 5 is considered suboptimal for preservation, as it may allow the growth of undesirable microorganisms (McDonald et al., 1991; Kung et al., 2018). Differences in texture among treatments reflect variations in microbial activity during fermentation. The salt and sodium nitrate treatment tended to exhibit a firmer texture, which may be linked to the antimicrobial properties of these additives that restrict extensive microbial degradation of plant tissues and contribute to maintaining structural integrity (Li et al., 2020; Sun et al., 2021). By contrast, the yeast treatment showed a softer and slightly slimy texture, which was generally observed across replicates, possibly due to enhanced microbial activity and increased degradation of structural carbohydrates during fermentation (Filya et al., 2004; Zhao et al., 2022). Nevertheless, all silages satisfied the physical quality criteria for good silage according to the Department of Livestock Development (2004).

**Color characteristics of ensiled durian peel**

Color measurements showed that silage treated with salt exhibited higher lightness ($L^*$) and yellowness ($b^*$) values than those treated with yeast or sodium nitrate. These color attributes are generally linked to acceptable silage quality and indicate limited oxidative deterioration during the ensiling process (Borreani et al., 2018; Zhao et al., 2020). The agreement between visual assessment (Fig.1) and instrumental color data (Table 2) suggests that salt supplementation helps maintain color stability, potentially by reducing enzymatic browning reactions and restricting microbial spoilage. Similar effects have been observed in mineral-treated silages, where salt application contributed to reduced oxidative processes and microbial degradation during fermentation (Li et al., 2020; Sun et al., 2021).

**Chemical composition and nutrient modification**

Ensiling altered the chemical composition of durian peel relative to the fresh material. An increase in CP content was observed in all ensiled treatments, which may be associated with nitrogen supplementation and microbial protein synthesis during the fermentation process (Muck et al., 2018; Kung et al., 2018). The yeast-treated silage exhibited the highest CP content, suggesting a greater extent of microbial growth and nitrogen incorporation into microbial biomass. Comparable responses have been described in silages supplemented with microbial inoculants or yeast cultures, where enhanced microbial activity during ensiling contributes to increased

CP concentration (Filya et al., 2004; Zhao et al., 2022). It should also be noted that the increase in CP may partly reflect the contribution of non-protein nitrogen (NPN) from urea supplementation. Because crude protein is calculated based on total nitrogen content, the reported CP values may include NPN and therefore may not represent true protein alone. In contrast, EE content was highest in the sodium nitrate treatment. This response may be associated with compositional changes during the fermentation process. The partial degradation of structural carbohydrates during ensiling may increase the relative proportion of lipids in the remaining dry matter (Kung et al., 2018; Borreani et al., 2018). In addition, microbial activity during fermentation may contribute to the accumulation of lipid-containing microbial biomass, which may further increase the measured EE content. Ash content increased in all ensiled treatments compared with fresh durian peel, with the greatest values observed in the sodium nitrate group, likely reflecting the direct contribution of mineral additives. Comparable trends have been reported in silages supplemented with inorganic salts (Wilkinson & Rinne, 2018; Li et al., 2020).

Fermentation additives also affected fiber fractions. Notably, NDF was reduced, particularly in the sodium nitrate treatment, suggesting partial degradation of cell wall components during ensiling. However, this reduction may also partly reflect a dilution effect resulting from the inclusion of fermentation additives, which contain negligible fiber and may reduce the relative proportion of structural carbohydrates in the ensiled material (McDonald et al., 1991; Kung et al., 2018). Such reductions in fiber fractions may suggest potential improvements in ruminal degradability, as reported in previous studies (Borreani et al., 2018; Khan et al., 2021), although digestibility and feed intake were not evaluated in the present study. In contrast, ADF content showed little variation among treatments, indicating that cellulose fractions were largely preserved during the ensiling period.

**Energy content and feeding implications**

Gross energy content varied among treatments, reflecting changes in chemical composition associated with the use of different fermentation additives. The salt treatment exhibited higher gross energy values, which may be attributed to improved preservation of fermentable carbohydrates and reduced dry matter and nutrient losses during the ensiling process, resulting in greater retention of energy-yielding substrates (Kung et al., 2018; Borreani et al., 2018). Lower gross energy values were observed in the yeast- and sodium nitrate-treated silages, possibly due to increased microbial utilization of soluble carbohydrates and other readily fermentable substrates. This process may result in compositional changes and partial energy losses through microbial metabolism and gas production during fermentation (Muck et al., 2018; Zhao et al., 2022).

**Safety aspects and practical applicability**

Residual HCN concentrations in all ensiled durian peel treatments were low (3.30-4.70 mg/kgDM) and remained well below the safety threshold for ruminant feeding. Cyanide concentrations below approximately 50 mg/kg dry matter are generally considered safe due to the detoxification capacity of rumen microorganisms (McDonald et al., 1991; Bureenok et al., 2012). It should also be noted that the use of urea in combination with sodium nitrate may increase the level of non-protein nitrogen in silage. NPN serves as a valuable nitrogen source for ruminal microbes; however, excessive levels may result in ammonia toxicity if the rate of release is not carefully controlled (McDonald et al., 2011; NASEM, 2016). These results indicate that the ensiling process facilitated the degradation of cyanogenic compounds originally present in the raw material (Fauzi, 2021). Similar reductions in cyanogenic glycosides during ensiling have been reported for tropical feed resources and are commonly attributed to enzymatic hydrolysis and microbial activity under anaerobic conditions (FAO, 2018; Gupta, 2018). These observations highlight the role of ensiling not only as a preservation method but also as a practical approach to improving feed safety through detoxification. Findings from the preliminary palatability assessment further support the practical use of ensiled durian peel, as goats readily accepted all treatments, with a tendency toward greater acceptance of the yeast-treated silage. Aroma, fermentation quality, and crude protein content are known to influence voluntary feed intake in ruminants (Wilkinson & Rinne, 2018; Khan et al., 2021), which may help explain the preference observed in this study.

## Conclusion and Suggestions

The results of this study suggest that ensiling may serve as a potential method for improving the preservation, nutritional value, and safety of durian peel as a ruminant feed resource. All fermentation additives evaluated, yeast, salt, and sodium nitrate, were able to support the ensiling process, as reflected by acceptable pH values, suitable physical characteristics, reduced cyanide residues, and changes in chemical composition relative to fresh durian peel. Among the additives, yeast supplementation was associated with higher CP content and improved palatability, suggesting enhanced microbial protein synthesis and feed acceptance. In contrast, salt treatment showed better physical quality and higher gross energy values, whereas sodium nitrate was more effective in reducing fiber fractions and cyanide residues. These findings highlight the trade-offs among additives depending on the desired nutritional and safety objectives. Salt supplementation enhanced the physical attributes and color stability of the silage while increasing gross energy content, reflecting superior nutrient preservation throughout the fermentation process. Sodium nitrate supplementation was linked to reductions in fiber fractions and cyanide residues, which may support improved digestibility and feed safety. Overall, these results suggest that durian peel can be utilized as a safe and nutritionally improved feed resource when appropriate ensiling strategies are applied. Specific production objectives should therefore guide the selection of fermentation additives. Yeast supplementation was most effective for enhancing crude protein content, salt treatment improved silage physical quality, and energy value. In contrast, sodium nitrate treatment was more effective in reducing fiber fractions and cyanide residues.

**Practical Recommendations**

Based on the findings of this study, fermented durian peel prepared with appropriate fermentation additives can be effectively utilized as a roughage source for goats and other ruminants, particularly during periods of feed scarcity. Yeast supplementation is recommended when the primary objective is to enhance CP content and improve palatability. Salt supplementation offers a cost-effective strategy for smallholder farmers to enhance the physical quality, color stability, and energy retention of silage. Conversely, sodium nitrate should be prioritized when the primary objectives are the reduction of fiber fractions and the mitigation of cyanide residues. However, careful control of inclusion levels is necessary to ensure feed safety. Further *in vivo* feeding trials are recommended to provide a more comprehensive evaluation of fermented durian peel. Such studies should assess feed intake, nutrient digestibility, growth performance, and rumen fermentation characteristics under practical farm conditions.

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## Author Contributions

Author 1: Sareena Semae was responsible for the study concept and methodological design. She carried out the experimental work, managed data curation, and conducted the formal data analysis. She also prepared the initial manuscript draft, revised the manuscript, and oversaw supervision and project administration.

Author 2: Rusnee Umar contributed to the study methodology and investigation. She assisted with data curation and formal analysis and participated in reviewing and editing the manuscript.

Author 3: Masitoh Bindolah contributed to the investigation and data curation. She was responsible for validating the results and also participated in reviewing and editing the manuscript.

## Conflict of Interests

All authors declare that they have no conflicts of interest.

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## Declaration of Generative AI and AI-assisted Technologies

In the preparation of this manuscript, the authors utilized generative artificial intelligence and AI-assisted technologies, specifically ChatGPT (OpenAI), solely to support language editing, sentence refinement, and the improvement of academic clarity. Following such use, the authors carefully reviewed, revised, and evaluated all content and hereby affirm that they bear full responsibility for the accuracy, originality, and completeness of the final version of the manuscript.

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