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Quality of King Grass and Gliricidia Mixed Silage Inoculated with Epiphytic Lactic Acid Bacteria Enriched with Water-Soluble Carbohydrates

Kualitas Silase Campuran Rumput Raja dan Gamal yang Diinokulasi dengan Bakteri Asam Laktat Epifit yang Diperkaya Karbohidrat Larut Air

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ABSTRAK

Penelitian ini mengevaluasi pengaruh inokulan bakteri asam laktat (BAL) epifit yang diperkaya sumber karbohidrat larut air (KLA) terhadap karakteristik fisik dan fermentasi silase campuran rumput raja dan gamal. Penelitian menggunakan Rancangan Acak Lengkap dengan enam perlakuan dan empat ulangan. Perlakuan meliputi P1, campuran rumput raja-gamal dengan air mineral 3% (v/b) sebagai kontrol, serta P1 dengan inokulan BAL (3% v/b) yang diperkaya glukosa (P2), molases (P3), gula pasir (P4), air kelapa tua (P5), atau ekstrak sagu (P6). Parameter meliputi kualitas fisik (warna, aroma, tekstur, keberadaan jamur), bahan kering (BK), bahan organik (BO), pH, dan skor Fleigh. Data dianalisis menggunakan analisis ragam dan uji Duncan. Pengayaan KLA tidak memengaruhi karakteristik fisik dan BK (P>0,05), tetapi meningkatkan BO serta memperbaiki pH dan skor Fleigh (P<0,01). Ekstrak sagu menghasilkan pH terendah (3,93) dan skor Fleigh tertinggi (91,5), yang menunjukkan kualitas fermentasi silase terbaik.

Kata kunci: bakteri asam laktat epifit, rumput raja, ekstrak sagu, karbohidrat larut air, kualitas silase rumput dan gamal

ABSTRACT

This study evaluated the effect of epiphytic lactic acid bacteria (LAB) inoculant enriched with water-soluble carbohydrate (WSC) sources on the physical and fermentation characteristics of mixed king grass and gliricidia silage. A completely randomized design with six treatments and four replicates was used. Treatments were P1, a king grass–gliricidia mixture with 3% (v/w) mineral water (control), and P1 with LAB inoculant (3% v/w) enriched with glucose (P2), molasses (P3), granulated sugar (P4), mature coconut water (P5), or sago extract (P6). Parameters included physical quality (color, aroma, texture, fungal presence), dry matter (DM), organic matter (OM), pH, and Fleigh score. Data were analyzed using ANOVA and Duncan's multiple range test. WSC enrichment did not affect physical characteristics or DM (P>0.05) but increased OM and improved pH and Fleigh score (P<0.01). Sago extract produced the lowest pH (3.93) and the highest Fleigh score (91.5), indicating the best silage fermentation quality.

Keywords: epiphytic lactic acid bacteria, king grass, sago extract, water-soluble carbohydrates, grass and gliricidia silage quality

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INTRODUCTION

Silage is a forage preservation technology based on anaerobic fermentation that aims to maintain nutrient composition and ensure a continuous supply of feed throughout the year. The success of the ensiling process largely depends on the activity of lactic acid bacteria (LAB), which ferment water-soluble carbohydrates (WSC) into lactic acid, thereby rapidly reducing silage pH and inhibiting the growth of spoilage microorganisms (Kung et al., 2018). A mixture of king grass (*Pennisetum purpureophoides*) and *Gliricidia* (*Gliricidia sepium*) has considerable potential as a silage material because it provides a balance between biomass production and protein content. However, the high buffering capacity of *Gliricidia* slows the decline in pH during ensiling, which may adversely affect fermentation quality (Kung et al., 2018).

One approach to improving silage fermentation quality is the application of epiphytic LAB inoculants, commonly known as fermented juice of epiphytic lactic acid bacteria (FJLB). Epiphytic LAB are lactic acid bacteria naturally present on plant surfaces that play an important role in silage fermentation by converting water-soluble carbohydrates into organic acids, particularly lactic acid, thereby accelerating pH reduction and promoting silage preservation (Chen et al., 2023). The use of LAB inoculants has been reported to accelerate lactic acid production, reduce silage pH, and improve fermentation quality (Bureenok et al., 2005; Ridwan et al., 2023). However, the effectiveness of LAB inoculants largely depends on the availability of water-soluble carbohydrates (WSC) as an energy source for microbial growth. The natural population of epiphytic LAB on tropical forages is generally low ($<10^5$ CFU/g), resulting in suboptimal fermentation in the absence of an adequate carbon source (Khota et al., 2016).

The addition of glucose as a source of WSC during inoculum preparation has been shown to increase LAB populations and accelerate the decline in the pH of fermented grass extract (Sheeladevi & Ramanathan, 2011; Ghimire & Raya, 2022). Santoso et al. (2024) reported that glucose supplementation increased the LAB population in king grass extract from 0.7×10^6 to 3.3×10^6 CFU/mL, accompanied by a reduction in pH from 5.39 to 4.11. However, the relatively high cost of glucose limits its practical application at the farm level.

As an alternative, molasses, mature coconut water, and sago extract have considerable potential as WSC sources because they contain simple sugars and other carbohydrates that can be utilized by LAB as fermentation substrates (Hussien et al., 2024; Shi et al., 2025). The use of these locally available materials is expected to produce effective LAB inoculants while reducing production costs compared with glucose. However, information regarding the effectiveness of different locally available WSC sources for enriching epiphytic LAB inoculants prior to their application to king grass–*Gliricidia* mixed silage remains limited, particularly under tropical conditions. Unlike previous studies, which generally added WSC sources directly to the silage material, the present study enriched epiphytic LAB inoculants with locally available WSC sources before their application to the silage.

The effectiveness of LAB inoculants enriched with different WSC sources should be assessed based on both fermentation characteristics and physical quality of silage. While pH and Fleigh score indicate fermentation quality, color, odor, texture, and mold occurrence reflect physical preservation and potential spoilage. Adequate WSC availability supports LAB activity and organic acid production, promoting pH reduction and suppressing undesirable microorganisms (Kung et al., 2018; Carvalho et al., 2020). However, improved fermentation does not necessarily result in significant changes in all physical attributes. Therefore, both aspects should be evaluated to determine the effectiveness of WSC-enriched LAB inoculants in king grass-Gliricidia mixed silage.

Therefore, this study aimed to evaluate the effects of epiphytic LAB inoculants enriched with different WSC sources on the physical quality and fermentation characteristics of king grass-*Gliricidia* mixed silage.

MATERIALS AND METHODS

Research Location

The experiment was conducted at the Laboratory of Animal Nutrition and Feed Science, Faculty of Animal Science, Universitas Papua, Manokwari.

Experimental Design and Treatments

The experiment was arranged in a completely randomized design (CRD) consisting of six treatments with four replications, resulting

Table 1. Organoleptic Evaluation Criteria for Silage

Score	Color	Odor	Texture	Mold Occurance
1	Greenish-brown	Fresh acidic	Non-clumped and non-slimy	None
2	Brown	Acidic	Slightly clumped	Slight
3	Dark brown	Kurang asam	Moderately clumped and slimy	Abundant on the surface
4	Black	Putrid	Heavily clumped and slimy	Abundant throughout the silage

in a total of 24 experimental units. The treatments were as follows:

P1: king grass-*Gliricidia* mixture treated with mineral water (3%, v/w) as a control;

P2: king grass–Gliricidia mixture treated with a glucose-enriched epiphytic LAB inoculant (3%, v/w);

P3: king grass-*Gliricidia* mixture treated with molasses-enriched epiphytic LAB inoculant (3%, v/w);

P4: king grass-*Gliricidia* mixture treated with granulated sugar-enriched epiphytic LAB inoculant (3%, v/w);

P5: king grass-*Gliricidia* mixture treated with mature coconut water-enriched epiphytic LAB inoculant (3%, v/w)

P6: king grass-*Gliricidia* mixture treated with sago extract-enriched epiphytic LAB inoculant (3%, v/w)

In the control treatment, water was added at the same volume as that used in treatments P2–P6, as recommended by Cai et al. (2020) and Souza et al. (2023). The forage mixture consisted of king grass and *Gliricidia* at a ratio of 60:40 on a fresh weight basis.

Preparation of Epiphytic LAB Inoculants

Epiphytic LAB inoculants were prepared according to the method of Bureenok et al. (2006), as modified by Santoso et al. (2024). Fresh king grass (110 g) was blended with 500 mL of mineral water and filtered through two layers of cheesecloth to obtain approximately 800 mL of grass extract. The extract was subsequently enriched with different WSC sources according to the treatments: glucose (6 g/200 mL extract), molasses (10 g/200 mL extract), granulated sugar (10 g/200 mL extract), mature coconut water (120:80 mL), and sago extract (100:100 mL). The sago extract was prepared by mixing 300 g of sago starch with 150 mL of mineral water. The mixture was then filtered through two layers of gauze, and the resulting filtrate was used as a source of WSC. The dosage of WSC sources was based on the recommendation of McDonald et al. (1991). All mixtures were thoroughly homogenized and anaerobically fermented at 30°C for 48 h. The resulting inoculants were subsequently used as silage additives.

Silage Preparation

King grass and *Gliricidia* were collected from SP IV, Prafi District, Manokwari Regency, Indonesia. The forages were wilted for 24 h, chopped into 1–2 cm lengths, and mixed at a ratio of 60:40 on a fresh weight basis. Each experimental unit consisted of 1 kg of fresh forage supplemented with 3% (v/w) epiphytic LAB inoculant according to the respective treatment. The forage mixture was packed into plastic silos, manually compacted to expel trapped air, sealed, and stored under anaerobic conditions for 30 days, following the ensiling duration reported by Zhang et al. (2019) and Souza et al. (2023).

At the end of the fermentation period, the silos were opened, and the entire silage sample was transferred to a container and thoroughly mixed. A representative subsample equivalent to 25% of the total sample was then collected for fermentation quality analysis. Silage extracts were prepared by mixing 20 g of fresh silage with 70 mL of mineral water, followed by storage at 4°C for 24 h before filtration for pH determination according to Bureenok et al. (2006). The remaining silage samples were dried in a forced-air oven at 60°C for 48 h, ground to pass through a 1-mm screen, and analyzed for dry matter (DM) and organic matter (OM).

Variables Measured

1. Physical Characteristics of Silage

The physical characteristics of the silage, including color, odor, texture, and mold occurrence, were evaluated organoleptically

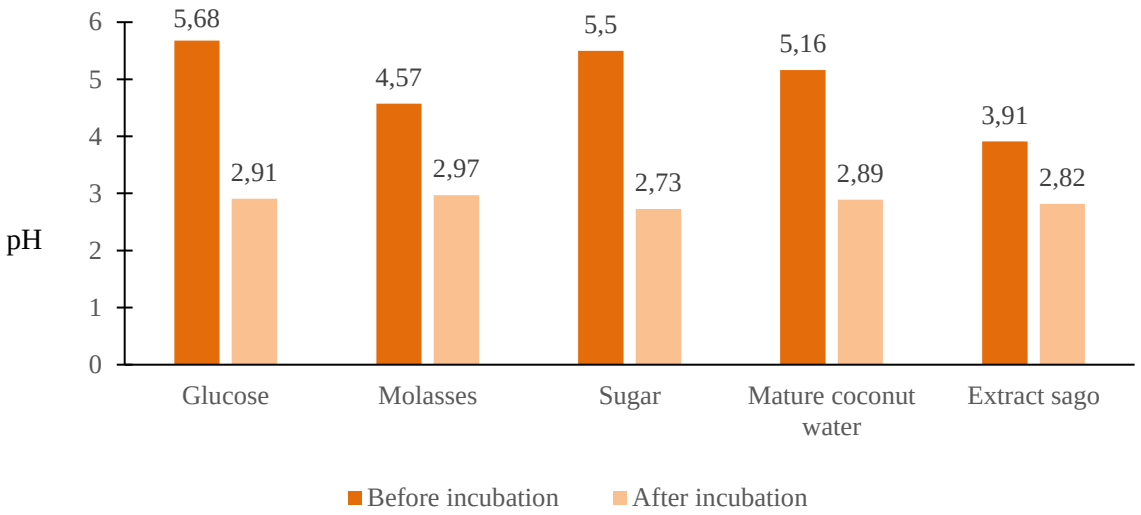


Figure 1. Changes in the pH of Fermented King Grass Extract Before and After Incubation

according to the method of Zakariah et al. (2015), as presented in Table 1. The evaluation was conducted by five trained panelists.

2. Dry Matter and Organic Matter Contents

Dry matter and OM contents were determined according to the methods of AOAC (2023). Dry matter content was determined by drying the silage samples in a forced-air oven at 60°C for 72 h or until a constant weight was achieved. The dried samples were then ground to pass through a 1-mm screen and subsequently dried at 105°C for 24 h for DM determination. Ash content was determined by incineration in a muffle furnace at 550°C for 4 h, whereas OM content was calculated as the difference between DM and ash content.

3. Silage Fermentation Quality

Silage fermentation quality was evaluated based on pH and Fleigh score. The pH of the silage extract was measured using a digital pH meter, whereas the Fleigh score was calculated according to Ozturk et al. (2006) using the following equation:

Fleigh score = 220 + (2 × DM − 15) − (40 × pH)

According to Ozturk et al. (2006), silage quality based on the Fleigh score was classified as very good (85–100), good (60–80), moderate (55–60), poor (25–40), and very poor (<20).

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using a completely randomized design (CRD). When the ANOVA indicated significant differences among treatments (**P**<0.05), mean separation was performed using Duncan's Multiple Range Test. Ordinal data on the physical characteristics of silage were analyzed using the Kruskal-Wallis test to determine differences among treatments. All statistical analyses were conducted using R version 4.5.1.

RESULTS AND DISCUSSION

Characteristics of Fermented Grass Extract

The pH values of all fermented king grass extracts decreased after incubation at 30°C for 48 h, as shown in Figure 1.

The decline in pH observed in all fermented king grass extracts indicates that the fermentation process proceeded effectively. This reduction occurred because LAB utilized WSC as substrates for lactic acid production. The accumulation of lactic acid during fermentation increased the acidity of the medium, resulting in a progressive decline in pH. After 48 h of incubation, the pH values of all treatments were relatively similar, ranging from 2.73 to 2.97. These results indicate that alternative WSC sources, including molasses, granulated sugar, mature coconut water, and sago extract, were as effective as glucose in supporting LAB growth and lactic acid production. The comparable pH values among WSC sources suggest that all substrates supplied sufficient fermentable carbohydrates to support LAB metabolism, resulting in similar rates of lactic acid production.

The decrease in pH observed in the present study is consistent with the findings of Santoso et al. (2024) and Santoso et al. (2025), who reported

Table 2. Physical Characteristics of King Grass-*Gliricidia* Mixed Silage Treated with LAB Inoculants

Variables	Treatments						SEM	*P*
	P1	P2	P3	P4	P5	P6		
Color	1,05	1.45	1.45	1.75	1.15	1.35	0.24	NS
Odor	1.90	2.10	2.15	1.50	2.40	2.15	0.32	NS
Texture	1.70	1.55	1.35	1.45	2.05	1.80	0.20	NS
Mold Occurance	1.45	1.50	1.40	1.90	1.80	1.90	0.24	NS

NS: not significant (P>0.05); SEM: standard error of the mean; P: significance level.

that the pH of fermented king grass extract decreased from 5.39 to 4.11 and from 5.78 to 4.17, respectively. Similar results were also reported by Kambu et al. (2026), who observed a decline in pH from 6.13 to 3.65 after 48 h of incubation. The reduction in pH reflects the ability of LAB to utilize water-soluble carbohydrates (WSC) as fermentation substrates for lactic acid production, thereby creating an increasingly acidic environment that favors LAB proliferation throughout the fermentation process. These findings are in similar with Bureenok et al. (2006), who reported that enriching fermented juice of epiphytic lactic acid bacteria (FJLB) with carbon sources enhanced LAB growth and lactic acid production, thereby accelerating pH reduction and improving fermentation quality. Therefore, the consistently low pH values obtained across all treatments indicate that each WSC source evaluated in this study effectively supported the fermentation of king grass extract.

Physical Characteristics of Silage

The physical characteristics of king grass-*Gliricidia* mixed silage, including color, odor, texture, and mold occurrence, are presented in Table 2.

As shown in Table 2, the application of epiphytic LAB inoculants enriched with different WSC sources had no significant effect (P>0.05) on the physical characteristics of king grass-*Gliricidia* mixed silage, including color, odor, texture, and mold occurrence. These findings indicate that all WSC sources effectively supported the fermentation process, resulting in silage with comparable physical quality. Silage color ranged from greenish-brown to brown (scores of 1.05–1.75), the odor was predominantly fresh acidic (scores of 1.50–2.40), the texture was compact, non-slimy, and slightly clumped (scores of 1.35–2.05), whereas mold occurrence remained very low (scores of 1.40–1.90). These characteristics indicate that fermentation proceeded successfully under anaerobic conditions, allowing LAB to dominate the fermentation process, produce lactic acid, reduce pH, and inhibit the growth of spoilage microorganisms and molds.

The findings are consistent with those reported by Kambu et al. (2026), who found that silage prepared from elephant grass-*Gliricidia* mixtures supplemented with different WSC sources exhibited a greenish-brown color, a fresh acidic odor, an intact and non-slimy texture, and minimal mold growth. Similar observations were reported by Rasuli et al. (2022), who stated that a greenish-brown color, acidic odor, and texture closely resembling the original forage are indicative of high-quality silage. Furthermore, Kung et al. (2018), Carvalho et al. (2020), and Wiguna et al. (2024) explained that the dominance of LAB during fermentation promotes lactic acid production, resulting in a rapid decline in pH, improved silage stability, and suppression of molds and other spoilage microorganisms. Therefore, the use of different WSC sources for enriching epiphytic LAB inoculants produced silages with comparable physical quality, indicating that all evaluated carbon sources have the potential to be used for the preparation of LAB inoculants for silage production.

Dry Matter and Organic Matter Contents of Silage

The DM and OM contents of king grass-*Gliricidia* mixed silage treated with epiphytic LAB inoculants are presented in Table 3.

Dry matter content is an important indicator for evaluating silage quality because it reflects the balance between nutrient losses during fermentation and the moisture content of the forage after ensiling. Analysis of variance showed that enriching epiphytic LAB inoculants with different WSC sources had no significant effect (P>0.05) on the DM content of the silage. Across all treatments, DM content ranged from 214.2 to 232.6 g/kg, indicating that inoculant

Table 3. Dry Matter and Organic Matter Contents of King Grass-*Gliricidia* Mixed Silage Treated with Epiphytic LAB Inoculants

Variables	Treatment						SEM	*P*
	P1	P2	P3	P4	P5	P6		
Dry matter (g/kg)	214.2	227.5	232.6	218.5	222.5	218.6	4.40	NS
Organic matter (g/kg)	896.1^{b}	891.9^{b}	895.2^{b}	901.1^{a}	893.9^{b}	893.9^{b}	1.65	*

SEM = standard error of the mean; ** = highly significant (P<0.05); NS = not significant; Means within the same row followed by different superscript letters differ significantly (P<0.05).

enrichment did not substantially alter the DM content of the silage.

The absence of significant differences among treatments was likely attributable to the uniformity of the forage materials and ensiling conditions. All treatments used the same king grass-*Gliricidia* mixture (60:40, fresh weight basis) and were subjected to identical wilting, chopping, inoculation, and fermentation procedures. Consequently, moisture loss and organic matter degradation during fermentation occurred at similar rates, resulting in comparable final DM contents. According to McDonald et al. (1991), the DM content of silage is influenced primarily by the initial moisture content of the forage, the degree of wilting, and the extent of respiratory and fermentative losses during ensiling rather than by the type of additive applied.

Furthermore, the WSC sources used in this study primarily served as fermentation substrates for LAB rather than as components that directly increased silage DM content. Water-soluble carbohydrates were metabolized by LAB to produce lactic acid, thereby accelerating the decline in pH, whereas the associated changes in DM content were relatively small. Therefore, although enrichment of the epiphytic LAB inoculants improved fermentation characteristics, its effect on silage DM content was insufficient to produce significant differences among treatments.

These findings are consistent with Khota et al. (2016), who reported that LAB inoculation improved silage fermentation by accelerating lactic acid production without significantly affecting DM content. Similarly, Afandi et al. (2021) found that the use of additives in sorghum-*Calopo* silage did not significantly alter DM content because their primary role was to optimize fermentation rather than increase the dry matter fraction. Lin et al. (2023) also reported that successful fermentation, as indicated by a reduction in pH, is not necessarily accompanied by changes in DM content when the forage materials and ensiling conditions are comparable. Overall, these findings suggest that enriching epiphytic LAB inoculants with different WSC sources contributes more to improving fermentation efficiency than to altering the DM composition of silage.

Analysis of variance revealed that the treatments had a highly significant effect (P<0.01) on the OM content of the silage. Duncan's Multiple Range Test showed that P4 (granulated sugar) produced the highest OM content (90.1%), which was significantly higher (P<0.05) than those of the other treatments, which ranged from 89.2 to 89.6%. Although the differences among treatments were relatively small, these results indicate that the type of WSC source used to enrich the epiphytic LAB inoculants influenced the preservation of the organic fraction during ensiling.

The higher OM content in P4 may be associated with the availability of sucrose as a fermentable substrate during inoculant preparation. However, this explanation remains a hypothesis. Zi et al. (2022) reported that adding sucrose, glucose, or molasses directly

to stylo silage increased lactic acid concentration, propionic and butyric acids were not detected in those supplemented treatments. Qiu et al. (2024) also found that sucrose addition lowered the final pH of mixed king grass and rice straw silage. These findings support the general role of fermentable carbohydrates in silage acidification, but they do not directly explain the higher OM concentration in P4. In both studies, the additives were applied directly to the forage, whereas the present study used carbohydrate-enriched LAB inoculants.

The mechanism underlying the higher OM content in P4 remains uncertain. Notably, P4 did not have the lowest final pH: its pH was 4.29, compared with 3.93 in P6. Thus, the OM response cannot be explained solely by differences in final acidity. The LAB populations, residual sugars, fermentation products, and OM recovery were not measured,

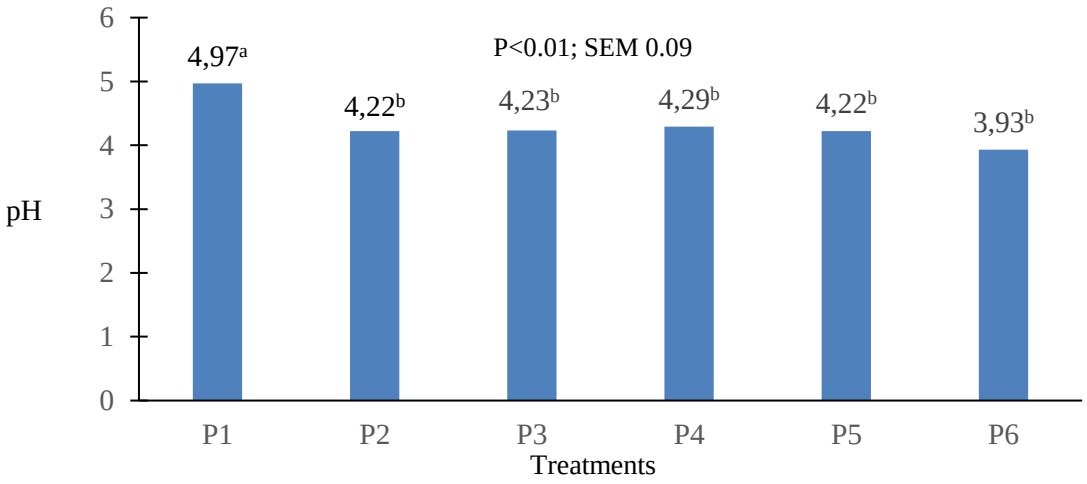


Figure 2. pH Values of King Grass-*Gliricidia* Mixed Silage Treated with Epiphytic Lactic Acid Bacteria Inoculants

and the enrichment substrates differed in composition and inclusion level. The result should therefore be interpreted as an association between the granulated sugar-enriched inoculant and the highest final OM content under the conditions tested, rather than as evidence of superior OM preservation.

Under these conditions, LAB likely established dominance during the early stage of fermentation, allowing most WSC to be converted into lactic acid. Rapid lactic acid production accelerated the decline in pH, thereby suppressing the activity of enterobacteria, *Clostridium*, yeasts, and other microorganisms responsible for secondary fermentation. Consequently, the degradation of organic matter into volatile fatty acids (VFAs), particularly acetic, propionic, and butyric acids, was reduced, thereby minimizing nutrient losses during fermentation. According to Kung et al. (2018), ideal silage fermentation is dominated by homofermentative LAB, which convert WSC into lactic acid with greater dry matter and energy recovery. In contrast, increased production of secondary fermentation products, such as VFAs and alcohols, reflects less efficient fermentation and is associated with greater losses of dry matter and energy.

Therefore, the higher OM content observed in P4 indicates that less OM was converted into VFAs than in the other treatments. This finding suggests that fermentation proceeded more efficiently, organic matter losses were minimized, and overall silage quality was improved. The results further indicate that the use of mature coconut water as an enrichment medium for epiphytic LAB inoculants not only supplied nutrients to support bacterial growth but also promoted a fermentation pattern characterized by enhanced lactic acid production, resulting in greater OM retention during ensiling.

Silage Fermentation Characteristics

Silage pH is one of the primary indicators of silage quality because it reflects the success of anaerobic fermentation and the production of organic acids, particularly lactic acid (Oliveira et al., 2017). A decline in pH indicates the activity of LAB in utilizing WSC as substrates for lactic acid production. The resulting acidic environment suppresses the growth of spoilage microorganisms, including undesirable bacteria, molds, and yeasts, thereby stabilizing the fermentation process and minimizing nutrient losses during storage.

The application of epiphytic LAB inoculants enriched with different WSC sources had a highly significant effect ($P<0.01$) on silage pH. Duncan's Multiple Range Test showed that the control treatment (P1) had the highest pH value (4.97), which was significantly higher ($P<0.01$) than those of treatments P2, P3, P4, P5, and P6. The pH values of inoculated treatments ranged from 3.93 to 4.22, which fall within the range considered indicative of good-quality silage according to Chamberlain and Wilkinson (1996). The lower pH values observed in the inoculated silages indicate that enriching epiphytic LAB inoculants with different WSC sources enhanced fermentation activity and promoted more rapid lactic acid production. The accumulation of lactic acid accelerated the establishment of stable anaerobic conditions,

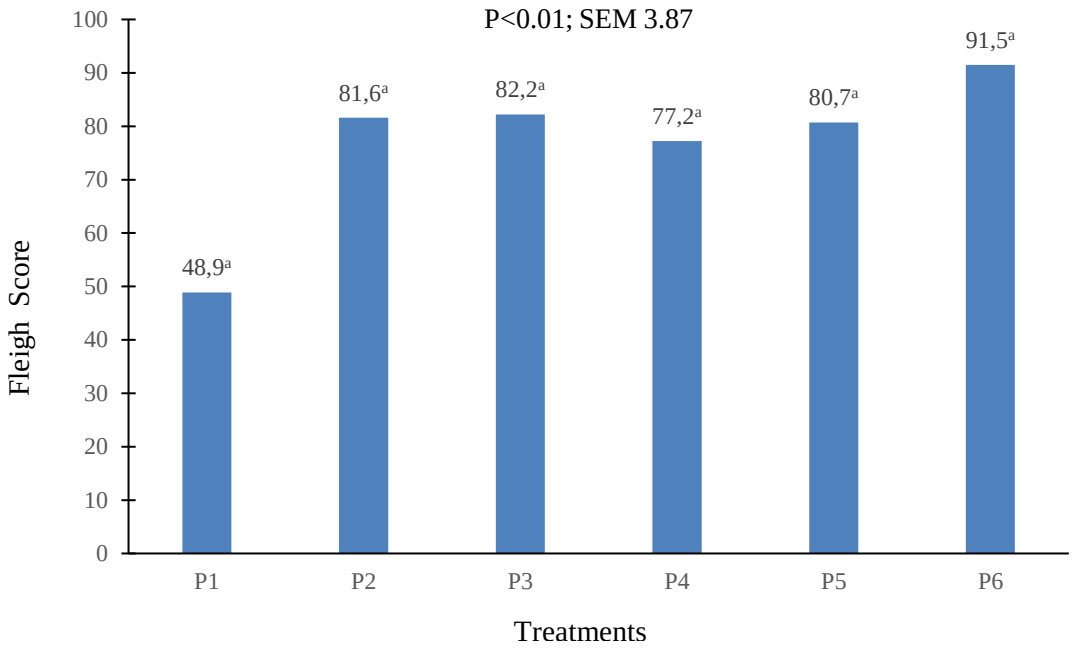


Figure 3. Fleigh Scores of King Grass-*Gliricidia* Mixed Silage Treated with Epiphytic Lactic Acid Bacteria Inoculants

inhibited undesirable microorganisms, and supported efficient silage fermentation. These findings agree with the mechanism described by Wang et al. (2009), who reported that the addition of fermented grass extract increased lactic acid production and accelerated the decline in pH during fermentation. Similar results were reported by Santoso et al. (2015), who found that supplementation of king grass silage with glucose-enriched epiphytic LAB inoculants at 30 mL/kg significantly reduced silage pH compared with uninoculated silage. Likewise, Hussien and Saeed (2023) demonstrated that LAB inoculants enriched with glucose, sugarcane molasses, and date molasses significantly improved the fermentation efficiency of wheat straw silage, as reflected by lower pH values.

The epiphytic LAB inoculant enriched with sago extract (P6) produced the lowest pH (3.93), indicating more intensive fermentation than the other treatments. This superior performance was likely associated with the characteristics of sago extract, which is rich in readily biodegradable organic compounds. Niju et al. (2025) reported that sago extract contains 2,300–3,500 mg/L carbohydrates, 0.65–1.18% sugars, and 1,500–2,600 mg/L starch, with a BOD/COD ratio of 0.40–0.57, indicating high biodegradability. These carbohydrates and sugars provide readily available energy sources for LAB during inoculant enrichment, thereby enhancing bacterial viability and metabolic activity before inoculation into the silage. As a result, LAB were able to dominate the early stage of ensiling, produce greater amounts of lactic acid, and accelerate pH reduction to levels that effectively inhibited spoilage microorganisms. These findings suggest that sago extract has considerable potential not only as an alternative WSC source but also as an effective enrichment medium for LAB inoculants to improve silage fermentation. The mean pH values of king grass-*Gliricidia* mixed silage treated with epiphytic LAB inoculants are presented in Figure 2.

The Fleigh score is a widely used indicator for evaluating silage fermentation quality based on the combined effects of dry matter content and pH. Higher Fleigh scores indicate superior fermentation quality (Ozturk et al., 2006). Analysis of variance revealed that epiphytic LAB inoculants enriched with different WSC sources significantly affected ($P<0.01$) the Fleigh score of the silage (Figure 3). Silages receiving enriched LAB inoculants (P2-P6) exhibited significantly higher ($P<0.01$) Fleigh scores than the control (P1), indicating that inoculant enrichment improved silage fermentation quality.

According to the Fleigh classification, scores of 85-100 indicate very good fermentation quality, whereas scores of 60-80 indicate good fermentation quality. Accordingly, treatments P2,

P3, P4, and P5 produced silages of good fermentation quality, whereas P6 produced silage of very good fermentation quality. Although the Fleigh scores of P3 (82.2) and P5 (80.7) slightly exceeded the upper limit of the "good" category, these treatments were still considered to produce good-quality silage because their scores did not clearly reach the threshold for the "very good" category (85-100). In contrast, the control (P1) had the lowest Fleigh score (48.9), indicating inferior fermentation quality compared with all inoculated treatments.

The increase in Fleigh score observed in this study was closely associated with the reduction in silage pH following inoculation. Treatment P6 produced both the lowest pH (3.93) and the highest Fleigh score (91.5), whereas the control (P1) had the highest pH (4.97) and the lowest Fleigh score (48.9). These results demonstrate that a more rapid decline in pH during fermentation resulted in higher Fleigh scores. This relationship indicates that enrichment of epiphytic LAB inoculants with different WSC sources provided sufficient substrates to support LAB growth, thereby increasing lactic acid production, accelerating pH reduction, and improving fermentation efficiency. Consequently, these improvements in fermentation were reflected in higher Fleigh scores in the inoculated silages. The results of this study indicate that although the DM content of silage in treatments P1-P6 did not differ significantly ($P > 0.05$), the significant differences in pH values ($P < 0.01$) may contribute to differences in Fleigh Scores among treatments.

The findings are consistent with those of Kambu et al. (2026), who reported that supplementation of elephant grass-*Gliricidia sepium* silage with glucose, molasses, or tapioca flour significantly reduced pH and increased Fleigh scores compared with silage without WSC supplementation. According to Kambu et al. (2026), greater carbohydrate availability enhanced LAB activity and lactic acid production, thereby accelerating pH reduction and improving silage fermentation.

However, this present study differs from that of Kambu et al. (2026) in its experimental approach. In their study, carbohydrate sources were added directly to the silage material, whereas in the present study they were used to enrich epiphytic LAB inoculants before application to the forage. This strategy proved effective in improving fermentation quality, as evidenced by lower pH values and higher Fleigh scores, particularly in treatment P6. These findings demonstrate that enriching epiphytic LAB inoculants is a promising strategy for optimizing the ensiling process by enhancing the initial activity of LAB and may serve as an alternative technology for producing high-quality silage.

CONCLUSION

The use of epiphytic LAB inoculants enriched with different WSC sources improved the fermentation quality of king grass-*Gliricidia* mixed silage. Inoculant enrichment had no effect on the physical characteristics or dry matter content of the silage but increased its organic matter content and enhanced fermentation characteristics, as indicated by lower pH values and higher Fleigh scores. The LAB inoculant enriched with sago extract produced the best fermentation quality, as evidenced by the lowest pH value (3.93) and the highest Fleigh score (91.5). Therefore, sago extract has considerable potential as an effective locally available carbohydrate source for enriching LAB inoculants to produce high-quality silage.

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