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Analysis of the fermentation quality of sorghum-straw-based complete feed with various fortification materials and microorganism sources

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Abstract

The purpose of this study was to analyze the fermentation quality of sorghum-straw-based complete feed with various fortification materials, to analyze the fermentation quality of sorghum-based complete feed with different microorganism sources, and to analyze the interaction between fortification materials and microorganism sources on the fermentation quality of sorghum-based complete feed. This study used a completely randomized design with a 3×2 factorial pattern consisting of factor A (fortification materials: moringa leaves and indigofera leaves) and factor B (types of microorganisms: cattle rumen-content MOL, cattle fecal MOL, and MA-11), resulting in 6 treatment combinations, each replicated 3 times. The variables observed included the physical characteristics of silage, namely color, texture, aroma, and percentage of mold presence. Statistical analysis showed that fortification materials had a significant effect ($P<0.05$) on silage texture, while microorganism sources significantly affected ($P<0.05$) the silage aroma. Furthermore, there was an interaction between fortification materials and microorganism sources, which jointly influenced the texture and aroma of sorghum-based complete feed silage. Based on the results, it can be concluded that the sorghum-based complete feed silage produced using fortification materials and microorganism sources demonstrated good quality. This was indicated by favorable physical characteristics—including color, texture, and aroma—that met the criteria of high-quality silage, as well as a very low percentage of mold contamination (0.00–1.16%).

Kata Kunci : Sorghum; Fermentation; Complete Feed; Fortification; Microorganisms

1. Introduction

The demand for animal protein in Indonesia continues to increase along with population growth. However, this trend is not matched by the country's limited domestic beef production capacity. The imbalance between demand and production has led to a beef deficit, prompting the government to rely on imports as a short-term solution. Unfortunately, this dependence on imports may weaken national food self-sufficiency and threaten food security. To address this issue, the government launched the National Milk and Meat Production Improvement Program (P2SDN) to reduce reliance on imports. One of the main obstacles to the success of this program is the limited availability of high-quality forage.

The availability of feed—especially forage—in terms of quality, quantity, and continuity is a key factor in supporting the success of ruminant livestock production. Feed supply must be accompanied by consistent efforts to ensure year-round availability so that livestock nutritional needs are met. A common problem faced by farmers is the limited availability of feed ingredients, particularly forage, leading to low livestock productivity in Indonesia. Forage availability is highly dependent on the season: abundant during the rainy season but scarce during the dry season. This situation necessitates feed preservation technologies, one of which is the innovation of producing fermented complete feed.

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Complete feed is a promising innovation to ensure a continuous feed supply. It is a mixture of various feed ingredients—both forage and concentrate—formulated to meet livestock nutrient requirements and support optimal rumen function and growth [1]. In addition, the use of complete feed supports environmental sustainability through the utilization of local resources [2].

One local ingredient with strong potential as the main component of complete feed is sorghum. Sorghum is known for several advantages, including drought tolerance, seasonal adaptability, high productivity, and nutrient content suitable for ruminant feed [3]. According to [4], sorghum contains 90.78% dry matter, 90.70% organic matter, and 31.69% crude fiber. Additionally, its low lignin content makes sorghum highly suitable as silage material [5]. However, sorghum's weakness lies in its relatively low crude protein content, around 7–8% [6], whereas beef cattle in the fattening phase require 12–13% crude protein. To meet this requirement, fortification with high-protein ingredients is necessary to ensure the nutritional value of the feed matches livestock needs and produces high-quality complete feed [7]. According to [8], fortification is the process of adding micronutrients to commonly consumed food to improve its nutrient content for the wider population.

Two potential plants for fortifying sorghum-based complete feed are Indigofera and Moringa oleifera. These two legume species are easy to obtain, high in protein, and suitable as feed ingredients. Indigofera contains up to 29.16% crude protein, while moringa leaves contain about 26% protein on a dry matter basis [9]. These values indicate that both plants have strong potential to increase the protein content of livestock feed.

To ensure year-round feed availability, especially during the dry season, feed preservation through fermentation is required. This process not only extends shelf life but also improves nutritional quality by halting enzymatic activity and reducing energy and protein losses in forage [10]. Moreover, lactic acid bacteria that develop during fermentation play an important role in preserving feed materials, preventing pathogenic microbial growth, and improving silage quality [11];[48]. To carry out the fermentation process, microorganisms are needed as starters to break down complex compounds into simpler forms, making them easier for livestock to digest.

2. Material and Methods

This research was conducted from June 2024 to March 2025. Sorghum cultivation was carried out in Tamboo Village, Tilongkabila District, Bone Bolango Regency. The silage production and fermentation processes were carried out at the Ruminant and Non-Ruminant Livestock Laboratory, and the physical characteristics testing was conducted at the Animal Nutrition Laboratory, Faculty of Agriculture, Gorontalo State University. The equipment used included a chopper machine, 5-liter jerry cans, used bottles, containers, hoses, stirrers, scales, measuring cups, glass jars, pipettes, a pH meter, an oven, porcelain crucibles, and stationery. The research materials consisted of components for MOL production (cattle feces, rumen contents, brown sugar, rice-washing water, molasses, and coconut water) and ingredients for fermented complete feed (sorghum biomass, indigofera leaves, moringa leaves, tofu waste, rice bran, corn flour, MA-11, molasses, and distilled water). The treatment ration was formulated with a ratio of 75% forage to 25% concentrate.

This study used a completely randomized design (CRD) with a 2×3 factorial pattern and three replications. The first factor (A) was the fortification material (indigofera leaves and moringa leaves), while the second factor (B) was the type of microorganism (MOL from cattle rumen contents, MOL from cattle feces, and MA-11), resulting in six treatment combinations. The research began with the preparation of MOL by mixing rumen contents or cattle feces (½ kg) with coconut water (500 ml), brown sugar (¼ portion), and rice-washing water (1 L), then fermenting the mixture for 14 days. Next, the forage materials (sorghum, indigofera leaves, and moringa leaves) were chopped (3–5 cm), wilted for 12 hours, and homogenously mixed with concentrate ingredients (fine rice bran, ground corn, tofu waste, and diluted molasses at a 1:10 ratio). The mixed materials were then supplemented with microorganisms at 50 ml/kg of feed, placed into silos, compacted, sealed tightly, and fermented anaerobically for 21 days. Silage samples were then collected for laboratory fermentation quality analysis. The observed variables included physical quality parameters such as color, texture, aroma, and mold presence. The collected data were analyzed using analysis of variance (ANOVA) and further tested with Duncan's Multiple Range Test (DMRT).

3. Results and discussion

3.1. Silage Color

The results of observations on the fermentation quality (silage color) of complete sorghum straw-based feed with various fortification materials and sources of microorganisms are presented in the table below.

Tabel 1 Average Color Value of Complete Feed Silage Based on Sorghum Straw with Various Fortification Materials and Microorganism Sources

Fortification Materials	Source of Microorganisms			Mean ± std
	B1	B2	B3	
A1	2.83 ± 0.11	2.72 ± 0.23	2.87 ± 0.05	2.80 ± 0.16
A2	2.89 ± 0.08	2.87 ± 0.04	2.83 ± 0.50	2.86 ± 0.06
Rataan ± std	2.86 ± 0.10	2.79 ± 0.18	2.85 ± 0.05	

Description: A1 = Indigofera Leaves; A2 = Moringa Leaves; B1 = Rumen Content Mol; B2 = Cow Feces Mol; B3 = MA-11; different superscripts in the columns indicate significant differences (P<0.05) ; Color value assumptions: 1: Black approaching the color of compost, 2: blackish brown, 3: brownish yellow.

Analysis of variance showed no significant difference (P>0.05) in the silage color. The average color values of silage fortified with Indigofera leaves (A1 = 2.80 ± 0.16) and Moringa leaves (A2 = 2.86 ± 0.06) both fell into the category of "yellowish brown," which is close to their original color. These results are consistent with the findings of [12], which reported that sorghum silage combined with Indigofera produced a yellowish-green color similar to the original forage. However, the results of this study were slightly lower than those reported by [29], where agricultural-waste silage supplemented with 10% Moringa leaves reached an average of 3.42. Differences in color scores between the two fortification materials may be influenced by their natural pigments and nutrient composition, where Indigofera leaves contain indigo pigments, while Moringa leaves are rich in chlorophyll and carotenoids that may degrade during fermentation. A yellowish-brown color indicates a good fermentation process and optimal physical quality of the silage. High-quality silage generally retains a color close to that of the original forage [12].

The analysis of variance also indicated that the use of different microorganism sources did not significantly affect (P>0.05) silage color. The mean color values based on microorganism sources were B1 = 2.86 ± 0.10, B3 = 2.85 ± 0.05, and B2 = 2.79 ± 0.18, all falling within the yellowish-brown category. Differences among treatments were likely influenced by variations in microbial composition, enzymatic activity, and substrate availability during fermentation. The microorganism source from rumen-content MOL (B1) is rich in lactic acid bacteria such as *Lactobacillus* sp., which promotes more stable fermentation [13], while MA-11 (B3) has more controlled enzymatic activity compared to fecal MOL (B2), which contains a more heterogeneous microbial population [14]. The results show that all treatments produced "yellowish brown" silage with good quality. The rumen-content inoculant (B1) yielded a brighter color due to anaerobic conditions that suppress mold growth [15]. The MA-11 treatment (B3) showed similar results because MA-11 contains cellulolytic, proteolytic, and amylolytic bacteria sourced from cattle rumen [16]. The slightly lower value in fecal MOL (B2) may be due to the lower microbial population compared to rumen liquor [17]. The silage color values obtained in this study were higher than those in [45], where silages using various starters had color scores ranging from 1.20 to 1.43, categorized from black to dark brown. Overall, all three microorganism sources were suitable for use, though B1 and B3 more consistently produced stable color quality.

The combination of fortification materials and microorganism sources did not show a significant interaction (P>0.05) on the color of the complete feed silage. The A1B1 combination (Indigofera leaves with rumen-content MOL) resulted in a bright dark-brown color (2.83 ± 0.11), indicating optimal fermentation due to high lactic acid bacteria populations that rapidly lowered pH and prevented overheating. Indigofera leaves, with their high protein and pigment content, also accelerated silage stabilization [18]. The A1B2 combination (Indigofera leaves with fecal MOL) had the lowest value (2.72 ± 0.23), producing a darker color likely caused by the heterogeneous microbial population and possible oxidation due to facultative bacteria and mild Maillard reactions [19]. Meanwhile, A1B3 (Indigofera leaves with MA-11) produced a bright yellowish-brown color (2.87 ± 0.05), indicating efficient fermentation because MA-11 contains homofermentative microbes that suppress spoilage microorganisms. This combination suggests that inoculants with high fermentative activity are able to maintain stable silage color.

The A2B1 interaction (Moringa leaves with rumen-content MOL) produced the highest color value (2.89 ± 0.08) with a bright yellowish-brown color, indicating optimal fermentation. The synergy between stable plant pigments in Moringa leaves and the cellulolytic microbes in rumen-content MOL kept the color uniform [20]. The A2B2 combination (Moringa leaves with fecal MOL) had a value of 2.87 ± 0.04 with a golden-brown color; natural antioxidants in Moringa leaves such as vitamin C and flavonoids helped prevent pigment degradation despite the heterogeneity of fecal inoculants. The A2B3 treatment (Moringa leaves with MA-11) resulted in a bright brown color (2.83 ± 0.50), attributed to homofermentative microbes that accelerate lactic acid formation and Moringa's antioxidants that enhance color stability. Overall, all combinations showed good fermentation without signs of oxidation or spoilage.

3.2. Silage Texture

The results of observations on the texture of complete feed silage based on sorghum straw with various fortification materials and sources of microorganisms are presented in the table below.

Table 2 Average Texture Value of Complete Feed Silage Based on Sorghum Straw with Various Fortification Materials and Microorganism Sources

Fortification Materials	Source of Microorganisms			Mean ± std
	B1	B2	B3	
A1	2.87^{ab} ± 0.07	2.84^{a} ± 0.03	2.99^{c} ± 0.02	2.90 ± 0.08^{a}
A2	2.97^{c} ± 0.04	2.99^{c} ± 0.02	2.93^{bc} ± 0.09	2.96 ± 0.06^{b}
Mean ± std	2.92 ± 0.08	2.91 ± 0.08	2.96 ± 0.07	

Description: A1 = Indigofera Leaves; A2 = Moringa Leaves; B1 = Rumen Content Mol; B2 = Cow Feces Mol; B3 = MA-11; different superscripts in the columns indicate significant differences (P<0.05) ; Assumption of texture value: 1: wet (lumpy, slimy and watery), 2: slightly wet (slightly lumpy), 3: slightly dry (not lumpy, not slimy and crumbly).

Analysis of variance showed a significant difference (P<0.05) in the silage texture between Indigofera leaves (A1 = 2.90 ± 0.08) and Moringa leaves (A2 = 2.96 ± 0.06). Further tests indicated that A2 produced a drier and more crumbly texture than A1. However, both treatments resulted in a slightly dry texture, approaching a score of 3, which indicates crumbly silage that is not clumped and not slimy. The drier texture produced by Moringa leaf fortification (A2) is presumably influenced by its polyphenol and flavonoid content, which enhances microbial activity during fermentation, as well as the moisture level of the material prior to fermentation, which affects silage compactness [21]. The texture values in this study were higher than those reported in [46], where sorghum-based silages at different levels produced texture values of 2.4–2.5.

The analysis of variance also showed that different microorganism sources had no significant effect (P>0.05) on the silage texture. The average texture values indicated a slightly dry silage texture, with scores of B1 (2.92 ± 0.08), B2 (2.91 ± 0.08), and B3 (2.96 ± 0.07). All treatments exhibited good physical quality—non-clumped and crumbly. The highest value in B3 is thought to be due to MA-11 containing lignocellulolytic microbes and lactic acid bacteria that accelerate fermentation and soften fiber [22]. Meanwhile, B1 and B2 were also effective although more variable because the natural microbial composition depends on the donor animal's conditions. Silages using various types of starters produced texture values similar to those in this study, with averages ranging from 2.80 to 2.97 [45].

The combination of fortification materials and microorganism sources showed a significant interaction (P<0.05) on the texture of sorghum-based complete feed silage. Duncan's test placed combinations A2B1 (2.97), A2B2 (2.99), and A1B3 (2.99) in the best group, producing the driest texture. The A1B3 treatment indicated that Indigofera leaves could match the quality of A2B3. The A2B3 treatment (2.93) was in a slightly lower group, suggesting that MA-11 was less optimal when combined with Moringa leaves. A1B1 (2.87) fell into the intermediate group, while A1B2 (2.84) was the lowest combination. Overall, selecting the appropriate fortification material and microorganism source greatly influences silage texture quality.

The A1B1 combination produced a score of 2.87 ± 0.07, indicating moderate fermentation because the high lignin content limits fiber degradation [23]. A1B2 had the lowest score (2.84 ± 0.03), likely due to tannins inhibiting microbial activity [24]. The best combination was A1B3, with the highest value (2.99 ± 0.02), as MA-11 can reduce antinutritional factors, accelerate lactic acid production, and produce dry, stable silage texture [25]. The A2B2 combination produced the highest texture score (2.99 ± 0.02), followed by A2B1 with 2.97 ± 0.04, and A2B3 with 2.93 ± 0.09. The optimal performance of Moringa leaves with natural microbes (B1 and B2) is due to their high protein content (23–30% DM),

mineral levels, and balanced C/N ratio that support rumen microbial growth [26]. Microbes such as Fibrobacter succinogenes and Ruminococcus flavefaciens assist in fiber degradation and produce acetic acid and sugars that improve silage texture [27]. The A2B3 combination (Moringa leaves + MA-11) had a slightly lower score (2.93 ± 0.09), likely due to suboptimal adaptation of MA-11 microbes to Moringa's antinutritional compounds, such as tannins, phytates, and saponins [28]. Overall, Moringa leaves are most compatible with natural microbes from rumen and cattle feces, producing dry and stable silage texture..

3.3. Silage Aroma

The results of observations on the aroma of complete silage feed based on sorghum straw with various fortification materials and sources of microorganisms are presented in the table below.

Table 3 Average Aroma Value of Complete Feed Silage Based on Sorghum Straw with Various Fortification Materials and Microorganism Sources

Fortification Materials	Source of Microorganisms			Mean ± std
	B1	B2	B3	
A1	3.00 ± 0.00[b]	2.71 ± 0.19[a]	3.00 ± 0.00[b]	2.90 ± 0.18
A2	2.99 ± 0.02[b]	3.00 ± 0.00[b]	2.97 ± 0.04[b]	2.99 ± 0.03
Mean ± std	2.99 ± 0.01[b]	2.85 ± 0.20[a]	2.99 ± 0.03[b]	

Description: A1 = Indigofera Leaves; A2 = Moringa Leaves; B1 = Rumen Content Mol; B2 = Cow Feces Mol; B3 = MA-11; different superscripts in the column indicate significant differences (P<0.05)); Assumption of aroma value: 1: not typical of silage (not pleasant/rotten), 2: somewhat typical of silage (sour/somewhat typical) tape, 3: typical of silage (tape/sour)

Analysis of variance showed that the use of fortification materials did not have a significant effect (P>0.05) on silage aroma. Based on the mean values, silage fortified with moringa leaves (A2) had a higher aroma score (2.99 ± 0.03) compared to Indigofera leaves (A1) (2.90 ± 0.18), with both falling into the category of "typical silage aroma." The stronger aroma in the moringa leaf fortification (A2) is presumably influenced by phytochemical and volatile compounds that support lactic acid bacteria activity [29]. Greater aroma variability in the Indigofera leaf fortification (A1) is caused by differences in protein, fiber, and anti-nutritional contents that generate a more varied aroma. Meanwhile, moringa leaves produce a more consistent aroma due to antioxidant compounds that suppress spoilage microbes and maintain fermentation stability [30]. The results of this study are similar to those of [12], where sorghum combined with Indigofera leaves produced silage with a typical silage/sour aroma. Likewise, rice straw silage with 10% moringa leaves resulted in a mean aroma score of 2.82, which is lower than in this study [29].

Analysis of variance showed that the source of microorganisms had a significant effect (P<0,05) on silage aroma. The post hoc test showed that B1 and B3 produced a more distinct silage aroma compared to B2. Based on the mean values, rumen liquor MOL (B1) and MA-11 (B3) produced the highest and most stable aroma scores (2.99 ± 0.01–0.03), while the microorganism source from cattle feces MOL (B2) had a lower value (2.85 ± 0.20). This indicates that B1 and B3 are more effective in producing a consistent silage aroma than B2. Differences in aroma among microorganism sources are caused by variations in microbial composition and activity. B1 contains various lactic acid bacteria such as L. plantarum, L. rhamnosus, and S. bovis, which produce lactic acid, lower pH, and create a distinctive silage aroma [31];[32]. B3 is also effective because it contains lactic acid bacteria and selected microbes that accelerate fermentation and suppress spoilage [33]. Conversely, B2 has a lower aroma score due to possible dominance of Clostridium, which produces butyric acid responsible for unpleasant odors [14]. The high variability (±0.20) in B2 reflects microbial instability in feces, which is influenced by the diet and condition of donor animals. Study [45] reported that agricultural waste silage using various inoculants produced aroma scores between 2.37 and 2.77, indicating that the results of this study are higher.

Analysis of variance showed that the combination of fortification materials and microorganism sources had a significant interaction effect (P<0.05) on silage aroma. The Duncan test indicated that A1B1, A1B3, A2B1, A2B2, and A2B3 all produced high aroma values ranging from 2.97 to 3.00, categorized as "very typical silage aroma." This demonstrates that fermentation in these combinations proceeded optimally, producing a strong and stable fermented/sour aroma. Treatments A1B1 and A1B3 produced very good aroma scores with no difference between them, showing that both microbial types can adapt and ferment Indigofera efficiently. Conversely, the combination A1B2 had the lowest aroma score (2.71), indicating a significant reduction compared to the other five treatments. This suggests that using feces-based MOL on Indigofera does not produce optimal silage aroma, likely due to the low soluble sugar content in Indigofera, which is insufficient to support the more heterogeneous microbial community present in feces-based MOL

The combinations A1B1 and A1B3 showed the best aroma scores (3.00 ± 0.00), whereas A1B2 was lower (2.71 ± 0.19). The optimal performance of A1B1 and A1B3 is attributed to the ability of microbes in B1 (rumen liquor) and B3 (MA-11) to degrade condensed tannins in Indigofera through the activity of lactic acid bacteria such as Lactobacillus plantarum and Pediococcus acidilactici [34]. Meanwhile, the low aroma score in A1B2 is likely due to the dominance of Clostridium sporogenes and Pseudomonas, which produce unpleasant odors through protein degradation, as well as the limited ability of feces-derived bacteria to degrade tannins effectively [35].

The combinations A2B1 (2.99 ± 0.02) and A2B3 (2.97 ± 0.04) showed near-perfect aroma with low variability, while A2B2 (3.00 ± 0.00) consistently achieved the maximum value. These findings indicate synergistic adaptation between moringa leaf nutrients and the microbial ecology of various inoculants. The high protein content of moringa leaves supports the growth of lactic acid bacteria (LAB), which produce protease enzymes to break down proteins into amino acids, which are later utilized by microbes for growth and production of aromatic compounds characteristic of silage [36]. LAB dominance such as Lactobacillus plantarum in B1 and B3 contributes to a stable lactic acid profile that creates the typical sour aroma. The A2B2 combination, which achieved a perfect aroma score (3.00 ± 0.00), is supported by the presence of LAB in the feces of healthy cattle such as L. reuteri, L. gasseri, and L. salivarius, which have adapted to the bioactive compounds in moringa leaves [37], enabling optimal fermentation and production of aroma-forming acids. The slight decrease in A2B3 (2.97 ± 0.04) is presumably due to competitive inhibition between MA-11 microbes and indigenous microbes [38], although the low variability suggests that the fermentation process remained well-controlled.

3.4. Percentage of Fungal Presence in Silage

The results of observations on the percentage of fungal presence in complete feed silage based on sorghum straw with various fortification materials and sources of microorganisms are presented in the table below.

Table 4 Average Value of Fungal Presence in Complete Silaage Feed Based on Sorghum Straw wit Various fortification materials and sources of microorganisms

Fortification Materials	Source of Microorganisms			Mean ± std
	B1	B2	B3	
A1	0.99 ± 0.74	0.00 ± 0.00	0.55 ± 0.78	0.51 ± 0.74
A2	0.01 ± 0.02	0.00 ± 0.00	1.16 ± 1.40	0.39 ± 0.97
Mean ± std	0.50 ± 0.71	0.00 ± 0.00	0.86 ± 1.17	

Description: A1 = Indigofera Leaves; A2 = Moringa Leaves; B1 = Rumen Content Mol; B2 = Cow Feces Mol; B3 = MA-11; different superscripts in the columns indicate significant differences (P<0.05)

Analysis of variance showed that the use of fortification materials did not have a significant effect (P>0.05) on the percentage of mold presence in the silage. The mean percentage of mold presence in Indigofera leaf silage (A1 = 0.51 ± 0.74) and moringa leaf silage (A2 = 0.39 ± 0.97) was low; however, the high standard deviation indicates substantial variability in mold growth due to differences in fermentation conditions and environmental factors. Moringa leaves were more effective in suppressing mold growth due to their bioactive compounds such as flavonoids, terpenoids, alkaloids, tannins, saponins, and phenols, which possess antifungal activity [39];[40]. Meanwhile, Indigofera leaves were less effective despite containing tannins, likely due to their higher moisture content, which creates a humid environment that supports mold growth [41]. Nevertheless, mold growth of <5% is still considered acceptable in the ensiling process [42]. Mold contamination in this study was very low compared to the study in [12], where sorghum silage supplemented with Indigofera leaves showed mold contamination ranging from 2.3–6.5%. Mold contamination in silage using various microorganism sources in this study was also lower than that reported in pakchong grass silage using SOC in study [47], which showed mold contamination ranging from 8.54–8.84%.

Analysis of variance indicated that different microorganism sources did not significantly affect (P>0.05) mold percentage. Cattle feces MOL (B2) showed the best results with no mold growth (0.00% ± 0.00), likely due to ecological competition from microbes such as Lactobacillus reuteri, L. gasseri, and L. salivarius, which suppress mold through lactic acid production and pH reduction [43]. Rumen liquor MOL (B1) exhibited 0.50% ± 0.71 mold contamination, influenced by variations in the donor animal's diet that affect rumen microbial composition. Meanwhile, MA-11 (B3) showed the highest contamination (0.86% ± 1.17), possibly due to suboptimal anaerobic conditions, higher pH, or technical errors during the ensiling process.

Analysis of variance also showed that the combination of fortification materials and microorganism sources did not produce a significant interaction (P>0.05) on mold percentage. The mean percentage of mold presence in each combination included A1B1 (0.99 ± 0.74), A1B2 (0.00 ± 0.00), A1B3 (0.55 ± 0.78), A2B1 (0.01 ± 0.02), A2B2 (0.00 ± 0.00), and A2B3 (0.86 ± 1.17). The A2B1 combination resulted in only 0.01% mold, far lower than A1B1 (0.99%), likely due to the flavonoid and polyphenol contents in moringa leaves, which have antibacterial and antifungal properties [38]. The A1B2 and A2B2 combinations showed the best results with no mold contamination (0%), supported by optimal anaerobic conditions and rapid lactic acid production by lactic acid bacteria (LAB) [44]. Conversely, A1B3 was more effective (0.55%) compared to A2B3 (1.16%), possibly due to lower raw material quality, inadequate compaction, or suboptimal performance of the inoculant.

4. Conclusion

The use of fortification materials and various types of microorganism sources can produce complete feed silage based on sorghum straw with good physical quality. Moringa leaves provide more stable performance in color, texture, aroma, and mold suppression compared to indigofera leaves. Microorganism sources MOL rumen contents and MA-11 produce good fermentation quality, characterized by a brownish yellow color, a slightly dry texture, a distinctive silage aroma, and low fungal contamination. MOL cow feces is also effective, especially in suppressing fungal growth, although the aroma is more varied. The combination of fortification and microorganism sources shows a positive interaction, especially in the combination of A2B1, A2B2, and A1B3 which is the best treatment in producing silage with optimal physical quality.

Compliance with ethical standards

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Disclosure of conflict of interest

There are no conflicts of interest to disclose.

References

[1] Hoy, C.P.E., Hartati, E. and Lestari, G.A.Y., 2023. Pengaruh Silase Pakan Komplit Berbasis Sorgum Clitoria Ternatea dengan Penambahan Berbagai Level Konsentrat Mengandung ZnSO4 dan ZnCu Isoleusinat terhadap Fermentasi Rumen In Vitro. *Animal Agricultura*, 1(2), pp.79-89.

[2] Bahri, S. and Purnomo, S.H., 2020. Produksi Biji Dan Biomas Jagung Pakan Ternak Yang Diberi Pupuk Organik Dan Kepadatan Awal Tanam Berbeda Pada Lahan Kering. *Journal TABARO Agriculture Science*, 4(2), pp.496-501.

[3] Nurmi, N., Syamsul Bahri, Yundriyani, Yunnita Rahim, & Mohamad Arief Azis. (2025). Growth And Yield of Two Varieties of Sorghum (Sorghum bicolour L. Moench) Through Rice Husk Organic Fertilizer Application. *International Journal of Technology and Education Research*, *3*(04), 282-293.

[4] Purwantari, T., 2008. Fermentabilitas In Vitro dan Produksi Biomassa Mikroba Ransum Komplit yang Mengandung Jerami Sorgum, Konsentrat dengan Penambahan Suplemen Pakan. *Skripsi*. Fakultas Peternakan, IPB.

[5] Kurniawan, W., H. Has, Rahman. 2017. Early evaluation of 65th days after sowing bmr sorghum productivity gown on swamp soil applied with different levels of biochar. *Proceedings of International Conference on Sustainable Animal Agiculture for Developing Countries*. 161-164. Malang.

[6] Kurniawan, W., 2014. Potensi Sorgum Numbu, CTY-33, dan BMR sebagai Pakan pada Beberapa Level Pupuk Kandang di Tanah Sedimentasi Ultisol. *Tesis*. Sekolah Pascasarjana, Institut Pertanian Bogor.

[7] Bahri, S., Hasan, S., Natsir, A. and Sirajuddin, S.N., Rismawati, N. (Ed). 2023. *Integrated Farming System Sistem Integrasi SIJAGAL (Sapi-Jagung-Gamal).* 1st edn.

[8] Soekatra, M., 2005. *Pertimbangan Nilai Hayati Gizi Fortifikan pada Makanan Anak yang Difortifikasi*. Bogor: Institut Pertanian Bogor.

[9] Abdullah, L., 2014. Prospektif Agonomi Dan Ekofisiologi Indigofera Zollingeriana Sebagai Tanaman Penghasil Hijauan Pakan Berkualitas Tinggi. *Pastura*, 3, pp.79-83.

[10] Rusdy, M., 2017. *Pengawetan Hijauan Pakan*. Makassar: Politik Sosial.

[11] Sudarmanto, A.Y., 2020. Kualitas Fermentasi Ransum Komplit Sapi Potong Dengan Penambahan Bawang Putih. *Doctoral dissertation*. Universitas Hasanuddin.

[12] Holik, Y.L.A., Abdullah, L. and Karti, P.D.M.H., 2019. Evaluasi Nutrisi Silase Kultivar Baru Tanaman Sorgum (Sorghum bicolor) dengan Penambahan Legum Indigofera sp. Pada Taraf Berbeda. *Jurnal Ilmu Nutrisi Dan Teknologi Pakan*, 17(2), pp.38-46.

[13] Rejeki, F.S., 2004. Bakteri Selulolitik Anaerob Sebagai Inokulum Silase Kulit Buah Coklat (Theobroma cacao). *Doctoral dissertation*. Universitas Airlangga.

[14] Dowd, S.E., Callaway, T.R., Wolcott, R.D., Sun, Y., McKechan, T., Hagevoort, R.G. and Edrington, T.S., 2008. Evaluation of the Bacterial Diversity in the Feces of Cattle Using 16S rDNA Bacterial Tag-Encoded FLX Amplicon Pyrosequencing (bTEFAP). *BMC Microbiology*, 8(1), p.125.

[15] Ton, J.W., Lawa, E.D.W., Hilakore, M.A. and Lazarus, E.J., 2023. The Effect Of Time Fermentation On The Physical Quality Of Cow's Rumen Content Silage. *Jurnal Ilmiah Peternakan Terpadu*, 11(3), pp.176-189.

[16] Iskandar, M.J., Ningsih, D.H., Prasetyowati, R.E. and Ahmadi, R., 2022. Pelatihan Pembuatan Pupuk Organik Dengan Dekomposer Microbacter Alfaafa-11 (Ma11) Di Desa Gapuk Kecamatan Suralaga. *Journal of Agri Rinjani: Social Agricultural Economics - Faculty of Agriculture, UGR*, 2(1), pp.30-37.

[17] Afdal, M. and Yurleni, Y., 2015. Pengaruh Modifikasi Inokulum Feses sebagai Pengganti Cairan Rumen pada Teknik In Vitro: Estimasi Kecernaan NDF, ADF dan Protein Kasar Rumput Lapangan. *Jurnal Ilmiah Ilmu-Ilmu Peternakan*, 18(2), pp.83-88.

[18] Alifah, N.N., Yanza, Y.R., Susilawati, I., Saefulhadjar, D. and Setiawan, M.A., 2025. Kualitas Fisik Dan Nilai pH Silase Arachis Pintoi Dengan Campuran Bahan Pakan Yang Berbeda. *Jurnal Nutrisi Ternak Tropis dan Ilmu Pakan*, 7(1), pp.11-22.

[19] Hynd, P.I., 2019. *Animal Nutrition: From Theory to Practice*. CSIRO Publishing.

[20] Pratiwi, A., 2023. Suplementasi Tepung Daun Kelor (Moringa oleifera) Sebagai Sumber Karotenoid Terhadap Tingkat Kecerahan Warna, Laju Pertumbuhan, dan Sintasan Benih Ikan Koi. *Journal Galung Tropika*, 12(2), pp.241-251.

[21] Ermawati, N., Yanza, Y.R., Susilawati, I., Saefulhadjar, D. and Setiawan, M.A., 2025. Karakteristik Fisik dan pH Silase Pueraria montana var. Lobata dengan Penambahan Tebon Jagung, Ampas Tahu dan Akselerator. *Composite: Jurnal Ilmu Pertanian*, 7(1), pp.10-19.

[22] Prabowo, R.J. and Sukaryani, S., 2025. The Difference Between Using MA-11 and EM-4 in Corn Slamper Fermentation to Increase Dry Matter and Organic Matter Digestibility. *Jurnal Biologi Tropis*, 25(2), pp.2115-2122.

[23] Megawati, M., 2024. Kandungan Selulosa, Hemiselulosa, dan Lignin Rumput Gajah Unggul Hasil Mutasi Genetik (Biograss, Biovitas, Bionutris, dan Gama Umami) yang Ditanam di Lahan Pastura.

[24] Akbar, M., 2021. Pengaruh Penambahan Asam Miristat dan Tepung Daun Kaliandra (Calliandra calothyrsus) Sebagai Sumber Tanin Pada Pakan Lengkap Berbasis Jerami Jagung Terhadap Produk Fermentasi di Dalam Rumen Secara In Vitro. *Doctoral dissertation*. Universitas Brawijaya.

[25] Herlika, S.R. and Mual, C.D., 2020. Pengaruh Formula Pupuk Organik Padat Berbasis Microbacter Alfaafa-11 (MA-11) terhadap Pertumbuhan Tanaman Padi (Oryza sativa L.) Di Kampung Prafi Mulya Distrik Prafi Kabupaten Manokwari. In: *Prosiding Seminar Nasional Pembangunan dan Pendidikan Vokasi Pertanian*. Vol. 1, No. 1, pp.204-213.

[26] Makkar, H.P.S. and Becker, K., 1996. Nutritional Value and Antinutritional Components of Whole and Ethanol Extracted Moringa oleifera Leaves. *Animal Feed Science and Technology*, 63(1-4), pp.211-228.

[27] Weimer, P.J., 2022. Degradation of Cellulose and Hemicellulose by Ruminal Microorganisms. *Microorganisms*, 10(12), p.2345.

[28] Ogbe, A.O. and Affiku, J.P., 2011. Proximate Study, Mineral and Anti-Nutrient Composition of Moringa oleifera Leaves Harvested from Lafia, Nigeria: Potential Benefits in Poultry Nutrition and Health. *Journal of Microbiology, Biotechnology and Food Sciences*, 1(3), pp.296-308.

[29] Wijaya, A.I., Tullah, N., Lena, M., Aditama, R.S., Prasetia, M.A., Anggriani, R. and Risfani, R., 2024. Analisis Pengaruh Penambahan Daun Kelor pada Kualitas Fisik dan Kimia Silase Limbah Pertanian. *Jurnal Agroristek*, 7(2), pp.53-62.

[30] Aulyani, T.L. and Sangkek, M.M., 2024. Physical And Chemical Quality Of Corn Silage With The Addition Of Liquid Smoke. *Buletin Veteriner Udayana*, pp.1745-1750.

[31] Ahyanur, M.R., 2023. Kualitas Fisik dan Mikrobiologi Silase Limbah Sayur Kol dan Sawi dengan Penambahan Berbagai Aditif Berbeda. *Doctoral dissertation*. Universitas Islam Negeri Sultan Syarif Kasim Riau.

[32] Zhang, R., Dong, X., Zhou, M., Tu, Y., Zhang, N., Deng, K. and Diao, Q., 2017. Oral Administration of Lactobacillus plantarum and Bacillus subtilis on Rumen Fermentation and the Bacterial Community in Calves. *Animal Science Journal*, 88(5), pp.755-762.

[33] Muck, R.E., 2013. Recent Advances in Silage Microbiology. *Agricultural and Food Science*, 22(1), pp.3-15.

[34] McSweeney, C.S., Palmer, B., McNeill, D.M. and Krause, D.O., 2001. Microbial Interactions with Tannins: Nutritional Consequences for Ruminants. *Animal Feed Science and Technology*, 91(1-2), pp.83-93.

[35] Liu, Y., Chen, H., Van Treuren, W., Hou, B.H., Higginbottom, S.K. and Dodd, D., 2022. Clostridium sporogenes Uses Reductive Stickland Metabolism in the Gut to Generate ATP and Produce Circulating Metabolites. *Nature Microbiology*, 7(5), pp.695-706.

[36] Baharuddin, Z.K., 2022. Kandungan Protein Kasar dan Serat Kasar Silase Rumput Gajah (Pennisetum purpureum) Menggunakan Inokulan Bakteri Asam Laktat Asal Cairan Rumen pada Lama Fermentasi Berbeda. *Doctoral dissertation*. Universitas Hasanuddin.

[37] Lin, W.C., Ptak, C.P., Chang, C.Y., Ian, M.K., Chia, M.Y., Chen, T.H. and Kuo, C.J., 2020. Autochthonous Lactic Acid Bacteria Isolated from Dairy Cow Feces Exhibiting Promising Probiotic Properties and In Vitro Antibacterial Activity Against Foodborne Pathogens in Cattle. *Frontiers in Veterinary Science*, 7, p.239.

[38] Kursia, S., Aksa, R. and Nolo, M.M., 2018. Potensi Antibakteri Isolat Jamur Endofit dari Daun Kelor (Moringa oleifera Lam.). *Pharmauho*, 4(1), pp.30-33.

[39] Patel, P., Patel, N., Patel, D., Desai, S. and Meshram, D., 2014. Phytochemical Analysis and Antifungal Activity of Moringa oleifera. *International Journal of Pharmacy and Pharmaceutical Sciences*, 6(5), pp.144-147.

[40] Widiani, P.I. and Pinatih, K.J.P., 2020. Uji Daya Hambat Ekstrak Etanol Daun Kelor (Moringa oleifera) terhadap Pertumbuhan Bakteri Methicillin Resistant Staphylococcus Aureus (MRSA). *Medika Udayana*, 9(3), pp.22-28.

[41] Resi, I.Y., 2024. Kualitas Fisik Silase Rumput Lapang Dan Indigofera Sp Dengan Penambahan Sirup Komersial. *Doctoral dissertation*. Universitas Islam Kuantan Singingi.

[42] McDonald, P., R.A. Edwards, J.F.D. Geenhalgh, C.A. Morgan, L.A. Sinclair, and R.G. Wilkinson. 2022. *In: Animal Nutrition.* 8 th Eds. Pearson. Singapore.

[43] Wachidan, M.W., Nainggolan, N.I.V. and Setyadi, T., 2024. Pelatihan Pembuatan Silase Rumput Gajah dan Tebon Jagung dalam Peningkatan Ketersediaan Pakan Ternak di Musim Kemarau Desa Kemiri Kabupaten Pasuruan. *Bhakti Nagori: Jurnal Pengabdian kepada Masyarakat*, 4(2), pp.160-169.

[44] Queiroz, O.C.M., Ogunade, I.M., Weinberg, Z. and Adesogan, A.T., 2018. Silage Review: Foodborne Pathogens In Silage And Their Mitigation By Silage Additives. *Journal of Dairy Science*, 101(5), pp.4132-4142.

[45] Kurniawan, D., Erwanto, E., & Fathul, F. (2015). Pengaruh penambahan berbagai starter pada pembuatan silase terhadap kualitas fisik dan pH silase ransum berbasis limbah pertanian. *Jurnal Ilmiah Peternakan Terpadu*, *3*(4), 191-195.

[46] Syahruddin, S. (2023). Kualitas fisik silase pakan komplit berbahan dasar jerami sorgum (Sorghum bicolor (L) moench) dengan taraf yang berbeda. *Gorontalo Journal of Equatorial Animals*, *2*(2).

[47] Rahmawati, I., Widjaja, N., Nurjannah, S., Suryanah, S., & Permana, H. (2024). Uji organoleptik, jamur, dan pH silase rumput pakchong yang diberi suplemen organik cair herbal. *Composite: Jurnal Ilmu Pertanian*, *6*(2), 112-119.

[48] Bahri, I. S., & Amirudin, S. P. (2025). *Integrated Farming System Sijaka (Sapi-Jagung-Kacang Tanah)*. PT Penerbit Qriset Indonesia.