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Evaluation of fiber digestibility of complete feed silage based on Sorghum (*Sorghum bicolor (L.) Moench*) with Fortification of Moringa Leaves and Indigofera Leaves

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Abstract

This study aimed to analyze the digestibility of cellulose, hemicellulose, and lignin of complete feed silage based on sorghum with fortification of moringa leaves and Indigofera leaves in beef cattle. This research was conducted for 5 months from January to May 2026 at the CV. AKAS beef cattle farm, Lonuo Village, Tilongkabila District, Bone Bolango Regency. Sample analysis was carried out at the Feed Chemistry Laboratory, Department of Nutrition and Animal Feed, Faculty of Animal Science, Hasanuddin University, Makassar. This study used a completely randomized design (CRD) with several treatments of fortification levels of moringa leaves and Indigofera leaves in sorghum-based complete feed silage. The treatments were: R0 = 75% Sorghum Straw + 25% Concentrate, R1 = 70% Sorghum Straw + 2.5% Indigofera leaves + 2.5% Moringa leaves + 25% Concentrate, R2 = 65% Sorghum Straw + 5% Indigofera leaves + 5% Moringa leaves + 25% Concentrate, R3 = 60% Sorghum Straw + 7.5% Indigofera leaves + 7.5% Moringa leaves + 25% Concentrate. The results showed that the addition of moringa leaves and Indigofera leaves as fortification materials could increase the digestibility values of cellulose, hemicellulose, and lignin, where the highest cellulose digestibility occurred in R3 (56.61%), followed by R2 (55.47%), and R1 (53.83%), and the lowest digestibility in R0 (44.85%); the highest hemicellulose digestibility occurred in treatment R3 (62.36%), followed by R2 (48.00%), R1 (45.63%), and the lowest in R0 (42.81%); the highest lignin digestibility was in treatment R3 (19.81%), followed by R2 (16.34%), R1 (15.46%), and the lowest in R0 (13.10%). Sorghum-based complete feed silage with a combination fortification of 7.5% moringa leaves and 7.5% Indigofera leaves was the most effective treatment in increasing hemicellulose, cellulose, and lignin digestibility.

Keywords: Cellulose Digestibility; Hemicellulose Digestibility; Lignin Digestibility; Silage; Complete Feed; Sorghum; Fortification; Beef Cattle

1. Introduction

Ruminant livestock productivity is highly dependent on the provision of forage as a source of nutrition because most of the production costs in livestock farming are used for feed provision. The continuous availability of quality feed is a major challenge in livestock production systems, especially during the dry season when forage availability decreases. Therefore, efforts are needed to utilize local feed materials that have high potential and can be preserved so that they can be used throughout the year. One technology widely used to maintain feed availability is complete feed silage, a feed preservation technique that combines various feed ingredients in one formulation to achieve better nutrient balance [1].

One local feed material that has great potential as a forage source is sorghum (*Sorghum bicolor*). Sorghum plants have the potential to be used as ruminant feed, especially the forage part (stems and leaves). Sorghum plants contain fairly high nutrients, indicated by crude protein content of 7.82% and crude fiber of 28.94%, making it very suitable as an

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alternative feed source [2]. However, the use of sorghum as the main feed ingredient has limitations because its crude protein content is relatively low and its crude fiber content is quite high, which can affect nutrient digestibility in the rumen if not balanced with other quality nutrient sources [3].

One approach to improve the nutritional quality of sorghum-based feed is through fortification with high-quality forage protein sources. Moringa leaves (**Moringa oleifera**) is one of the leguminous plants that has high crude protein content, ranging from 20–30%, and is rich in vitamins, minerals, and bioactive compounds beneficial for livestock health. In addition to moringa leaves, Indigofera (*Indigofera zollingeriana*) is also a tree legume that has high crude protein content, around 24–31%, and has good palatability for ruminants. Indigofera is also known to have relatively easily digestible fiber content, so it has the potential to improve the efficiency of nutrient utilization in the rumen. Several studies show that the use of *Indigofera zollingeriana* as feed can increase feed consumption and nutrient digestibility in ruminants [4].

The use of complete feed silage technology combined with fortification of moringa and Indigofera leaves is expected to improve the nutritional quality of sorghum-based feed, especially in increasing protein availability and improving fiber digestibility in the rumen. Fiber digestibility is one of the important indicators in assessing the quality of ruminant feed because fiber fractions such as cellulose and hemicellulose are the main energy sources for rumen microbes, which in turn produce volatile fatty acids as an energy source for livestock [5].

Feed digestibility evaluation can be carried out through *in vivo* methods that provide a real picture of the animal's ability to digest and utilize feed nutrients. This method is considered more accurate because it involves direct interaction between feed, rumen microbes, and the animal's digestive system as a whole [6]. Therefore, research on *in vivo* fiber digestibility evaluation of sorghum-based complete feed silage with fortification of moringa and Indigofera leaves needs to be conducted to determine the extent to which the combination of these feed ingredients can improve the efficiency of fiber utilization by ruminants.

2. Material and methods

This research was conducted for five months from January to May 2026, located at the CV. AKAS beef cattle farm, Lonuo Village, Tilongkabila District, Bone Bolango Regency. Sample analysis was carried out at the Feed Chemistry Laboratory, Department of Nutrition and Animal Feed, Faculty of Animal Science, Hasanuddin University, Makassar.

The equipment used from feed preparation included a forage chopper machine, plastic drums or silos, shovels, platform scales, measuring cups, buckets, animal scales, drinking water containers, and sample collection equipment including sample bags, markers, buckets, shovels, drying ovens, and fiber analysis equipment. The materials used were 12 experimental animals (male Bali cattle aged 1.5–2 years), deworming medication, vitamin B-complex injection, forage (sorghum straw, moringa leaves, Indigofera leaves), concentrate (tofu waste, rice bran, corn flour, molasses, and MA-11 (*Microbacter alfalfa*)). The cages used were individual cages made of bricks and cement with twelve pens measuring 1x2 meters equipped with feeding and drinking water facilities.

This study used a Completely Randomized Design (CRD) with several treatments of fortification levels of moringa and Indigofera leaves. The treatments were as follows:

- R0 = 75% Sorghum Straw + 25% Concentrate
- R1 = 70% Sorghum Straw + 2.5% Indigofera leaves + 2.5% Moringa leaves + 25% Concentrate
- R2 = 65% Sorghum Straw + 5% Indigofera leaves + 5% Moringa leaves + 25% Concentrate
- R3 = 60% Sorghum Straw + 7.5% Indigofera leaves + 7.5% Moringa leaves + 25% Concentrate

The parameters observed in this study included: cellulose digestibility, hemicellulose digestibility, and lignin digestibility. Data collection was carried out through direct observation of experimental animals, measurement of feed consumption, total fecal collection, and laboratory analysis of feed and fecal samples. This technique aimed to obtain accurate data regarding feed consumption and fiber digestibility *in vivo* in ruminants.

Tabel 1 Ration Formulation and Nutrient Content of Each Treatment

Feed Ingredients	R0	R1	R2	R3
Sorgum Straw	70	70	65	60
Indigofera	0	2,5	5	7,5
Moringa	0	2,5	5	7,5
Tofu Waste	8,5	8,5	8,5	8,5
Rice Bran	11	11	11	11
Corn Flour	2,5	2,5	2,5	2,5
Molasses	3	3	3	3
Total	100	100	100	100
Dry Matter %	83,54	76,64	76,49	76,63
Crude Protein %	12,79	14,18	14,29	14,40
Crude Fiber %	21,86	21,80	21,35	20,90
Crude Fat %	3,87	3,80	40,1	4,01
Ash %	10,21	9,83	9,77	9,70
NFE %	52,68	51,75	52,71	51,67
TDN %	60,70	61,48	62,48	63,47

The data obtained were analyzed using analysis of variance to determine the effect of treatments. If the treatment had a significant effect on the measured parameters, it was continued with Duncan's multiple range test to determine differences between treatments [7].

3. Results and discussion

3.1. Cellulose Digestibility

The mean values of cellulose, hemicellulose, and lignin digestibility of sorghum-based feed with fortification of moringa and Indigofera leaves are presented in the table below.

Tabel 2 Mean Values of Cellulose Digestibility, Hemicellulose Digestibility, and Lignin Digestibility

Parameter	Treatment			
	R0	R1	R2	R3
Cellulose Digestibility	$44,85^{a} \pm 5,68$	$53,83^{b} \pm 4,10$	$55,47^{b} \pm 3,80$	$56,61^{b} \pm 4,61$
Hemicellulose Digestibility	$42,81^{a} \pm 1,36$	$45,63^{a} \pm 1,98$	$48,00^{a} \pm 7,96$	$62,36^{b} \pm 5,93$
Lignin Digestibility	$13,10^{a} \pm 0,98$	$15,46^{b} \pm 0,52$	$16,34^{b} \pm 1,11$	$19,81^{c} \pm 1,90$

Note: Different superscripts in the table indicate significant differences (P<0.05). R0 = 75% Sorghum + 25% Concentrate; R1 = 70% Sorghum + 2.5% Indigofera Leaves + 2.5% Moringa Leaves + 25% Concentrate; R2 = 65% Sorghum + 5% Indigofera Leaves + 5% Moringa Leaves + 25% Concentrate; R3 = 60% Sorghum + 7.5% Indigofera Leaves + 7.5% Moringa Leaves + 25% Concentrate.

The results of analysis of variance showed that sorghum-based complete feed silage with fortification of moringa leaves and Indigofera leaves had a significant effect (P<0.05) on cellulose digestibility. The average cellulose digestibility obtained for each treatment was R0 at 44.85%, R1 at 53.83%, R2 at 55.47%, and R3 at 56.61%. The further test results showed that the cellulose digestibility of sorghum-based complete feed silage that received additional fortification materials of moringa leaves and Indigofera leaves at 15% (7.5% moringa leaves and 7.5% Indigofera leaves) was significantly higher compared to other treatments, where cellulose digestibility increased along with the addition of

moringa and Indigofera fortification. This indicates that the combination of these two fortification materials was able to improve rumen fermentation conditions so that the activity of cellulose-degrading microorganisms increased. Cellulose is the main component of plant cell walls whose absorption is highly dependent on the activity of cellulolytic bacteria such as *Ruminococcus albus*, *Ruminococcus flavefaciens*, and *Fibrobacter succinogenes*. The growth of these microbes requires the availability of nitrogen, energy, minerals, and optimal rumen environmental conditions [8].

The high cellulose digestibility in the combination treatment of moringa and Indigofera leaves is thought to be caused by the high crude protein content in both materials. Moringa leaves and Indigofera leaves are known to have crude protein content above 20%, so they can increase the availability of nitrogen for rumen microbial protein synthesis. Sufficient nitrogen availability will stimulate the growth of cellulolytic bacteria and increase the production of cellulase enzymes that function to hydrolyze β-1,4-glycosidic bonds in cellulose into simple sugars that are easily fermented [9]. In addition, the combination of moringa and Indigofera leaves is also thought to provide better nutrient balance compared to single use. Moringa leaves are rich in vitamins, minerals, and antioxidant compounds, while Indigofera leaves have good protein quality and high digestibility. The combination of these two materials can increase the efficiency of rumen microbial metabolism so that the cellulose degradation process takes place more optimally. [10] reported that the use of *Indigofera zollingeriana* produced high in vitro digestibility values because its nutrient content supports rumen microbial activity.

The increase in cellulose digestibility is also related to the relatively low lignin content in moringa and Indigofera leaves. Lignin is the main limiting factor in fiber degradation because it forms complex bonds with cellulose and hemicellulose. The lower the lignin content in the ration, the easier it is for cellulase enzymes to access the cellulose substrate. Therefore, fortification with moringa and Indigofera leaves is thought to increase the accessibility of cellulose to microbial enzymes, resulting in higher cellulose digestibility values. The presence of bioactive compounds such as saponins and flavonoids in moringa and Indigofera leaves is also important because they can contribute to increased cellulose digestibility. Saponins at appropriate concentrations can reduce the population of rumen protozoa so that the number of cellulolytic bacteria increases. The increase in bacterial population causes fiber degradation activity to become more efficient. According to [11], saponin compounds can improve rumen fermentation through modification of microbial communities and increase the utilization of feed fiber components.

The results of this study are in line with research [12] which reported that increasing the proportion of *Indigofera zollingeriana* in the ration could increase in vitro digestibility and improve rumen fermentation conditions. The study showed that the high protein content in Indigofera contributes to increased fibrolytic microbial activity that plays a role in the degradation of fiber fractions, including cellulose. Thus, the high cellulose digestibility value in the combination treatment of moringa and Indigofera leaves in this study reinforces the finding that high-quality legumes can improve fiber utilization by ruminants.

The results of research [13] show that *Indigofera zollingeriana* has good nutrient content and high in vitro digestibility values. The researchers reported that increasing the nutrient quality of forage is closely related to the increased ability of rumen microbes to degrade structural fiber components. These results support the findings of this study that the addition of Indigofera together with moringa leaves can significantly increase cellulose digestibility. In terms of moringa leaf use, the results of this study are also supported by [14] who stated that moringa leaf supplementation in ruminant feed can improve rumen fermentation efficiency and nutrient utilization. The protein, mineral, and secondary metabolite content in moringa leaves can create a more conducive rumen environment for the growth of fiber-digesting microbes. Thus, the combination of moringa and Indigofera leaves is thought to produce a greater synergistic effect compared to using either ingredient alone.

3.2. Hemicellulose Digestibility

The results of analysis of variance showed that sorghum-based complete feed silage with fortification of moringa leaves and Indigofera leaves had a significant effect ($P<0.05$) on hemicellulose digestibility. The average hemicellulose digestibility obtained for each treatment was R0 at 42.81%, R1 at 45.63%, R2 at 48.00%, and R3 at 62.36%. The further test results showed that the hemicellulose digestibility of sorghum-based complete feed silage that received additional fortification materials of moringa leaves and Indigofera leaves at 15% (7.5% moringa leaves and 7.5% Indigofera leaves) was significantly higher compared to other treatments, where hemicellulose digestibility increased along with the addition of moringa and Indigofera fortification. These results indicate that the combination of the two fortification materials was able to create more optimal fermentation conditions for rumen microorganisms in degrading hemicellulose components. Hemicellulose is a structural polysaccharide that is more easily degraded compared to cellulose and lignin, so that increased fibrolytic microbial activity will directly increase its digestibility.

The high hemicellulose digestibility in the combination treatment of moringa and Indigofera leaves is thought to be caused by the high crude protein content of both materials which can increase nitrogen availability for rumen microbes. Sufficient nitrogen will increase the growth of fibrolytic bacteria so that hemicellulase enzyme production increases and hemicellulose degradation takes place more effectively. In addition, there is a synergistic effect between these two materials. Moringa leaves are known to have high crude protein, vitamin, and mineral content, while Indigofera leaves have good protein quality and relatively easily digestible fiber content. The combination of both is thought to create a more conducive rumen environment for the growth of fiber-degrading microbes. Sufficient nitrogen availability will increase microbial protein synthesis so that the population of fiber-digesting bacteria increases and the hemicellulose degradation process takes place more intensively [13].

The increase in hemicellulose digestibility in the treatment combination of 7.5% moringa leaves and 7.5% Indigofera leaves is thought to be related to the relatively lower lignin content compared to other fibrous feed ingredients. The low lignin content causes the bonds between lignin and hemicellulose to be more easily broken during the silage fermentation process and rumen fermentation. As a result, hemicellulose becomes more easily accessible to microbial enzymes so that its degradation rate increases. In addition, the presence of bioactive compounds such as saponins and flavonoids contained in moringa and Indigofera leaves is also thought to contribute to increased hemicellulose digestibility. At the right concentration, saponins can suppress the population of rumen protozoa without inhibiting fibrolytic bacterial activity. The decrease in protozoan population causes predation of bacteria to decrease so that the number of fiber-digesting bacteria increases. [11] reported that saponins can improve rumen fermentation efficiency through modulation of microbial populations, which ultimately improves the utilization of feed fiber components.

The results of this study are in line with research [12] which reported that increasing the proportion of *Indigofera zollingeriana* in the ration could increase in vitro dry matter and organic matter digestibility. This increase was associated with the high protein content and low indigestible fiber content in Indigofera which supports rumen microbial activity. The increase in microbial activity contributes to the degradation of fiber fractions, including hemicellulose. Research [9] also showed that the use of *Indigofera zollingeriana* in sheep feed increased rumen fermentability and in vitro nutrient digestibility. The researchers explained that the high protein content and nutrient quality of Indigofera increased microbial protein synthesis which plays a role in the degradation of plant cell wall fiber components. These findings support the results of this study which showed that the addition of Indigofera in combination with moringa leaves could significantly increase hemicellulose digestibility.

3.3. Lignin Digestibility

The results showed that the administration of sorghum-based complete feed silage fortified with moringa leaves (*Moringa oleifera*) and Indigofera leaves (*Indigofera zollingeriana*) had a significant effect ($P<0.05$) on lignin digestibility in beef cattle. The lignin digestibility values in treatments R0, R1, R2, and R3 were respectively 13.10 ± 0.98%, 15.46 ± 0.52%, 16.34 ± 1.11%, and 19.81 ± 1.90%. The further test results showed that each increase in fortification level resulted in a significantly different increase in lignin digestibility, where R3 had the highest value, followed by R2, R1, and R0. This gradual increase shows that the combination of moringa and Indigofera leaves can improve the utilization of the most difficult-to-digest fiber fraction through improved rumen fermentation conditions and increased microbial access to the lignocellulose complex.

Lignin is a complex phenolic polymer that functions to strengthen plant cell walls and binds tightly to cellulose and hemicellulose. Lignin-carbohydrate complexes limit the access of microbial enzymes to structural carbohydrates, so lignin is known as the most resistant fiber fraction to degradation in the rumen. Therefore, lignin digestibility values in ruminants are generally much lower than cellulose and hemicellulose digestibility. According to Van Soest (1994), an increase in lignin content in forage will decrease cell wall digestibility because lignin cannot be hydrolyzed by enzymes produced by rumen microorganisms. Although lignin is basically difficult to degrade, the results of this study show that fortification with moringa and Indigofera leaves can increase lignin digestibility values from 13.10% in R0 to 19.81% in R3, or an increase of about 51.2% compared to the control. This increase is likely not caused by direct lignin degradation, but rather by increased rumen microbial activity that is able to utilize the loosely bound fraction of lignin with structural carbohydrates and increase the release of cellulose and hemicellulose fractions from the lignocellulose complex.

The results of this study are in line with [16] which reported that the addition of *Indigofera zollingeriana* to sorghum silage increased nutrient digestibility and improved rumen fermentation characteristics, marked by increased NH_3 and VFA production. These conditions reflect increased rumen microbial activity which also contributes to more efficient utilization of fiber fractions. Research by Holik et al. (2019) also showed that the addition of *Indigofera zollingeriana* to sorghum silage increased crude protein content and improved fermentation quality so that nutrient digestibility increased. Although the study did not specifically evaluate lignin digestibility, the improvement in fermentation quality

and cell wall degradation supports the results of this study that legume fortification can improve the utilization of complex fiber fractions.

The results of this study are also in line with research [15] which explained that increased degradation of lignocellulose fractions causes lignin to be more easily released from the lignin-carbohydrate complex. The study emphasized that changes in plant cell wall structure can increase lignin digestibility values even though lignin itself remains a component that is highly resistant to biological degradation. The findings of this study are also supported by [9] which reported that the use of *Indigofera zollingeriana* in sheep feed increased fermentability and in vitro nutrient digestibility. Although the study emphasized more on dry matter and organic matter digestibility, the increase in fibrolytic microbial activity reported indicates the potential for more intensive cell wall structure breakdown, including the release of lignin from lignocellulose bonds. In addition, research [10] also showed that *Indigofera zollingeriana* has good nutrient quality and high in vitro digestibility. Good nutrient quality allows optimal rumen microbial growth so that fiber fraction degradation increases. These results support the findings of this study that the combination of moringa and Indigofera leaves can increase the utilization of complex fiber fractions, including the lignin fraction bound to plant cell walls..

4. Conclusion

Based on the results and discussion, it can be concluded that sorghum-based complete feed silage with a combination fortification of 7.5% moringa leaves and 7.5% Indigofera leaves was the most effective treatment in increasing hemicellulose, cellulose, and lignin digestibility. This increase occurred through improvement of feed nutrient quality, increased fiber-degrading microbial activity, optimization of rumen fermentation, increased accessibility of hemicellulose to fiber-degrading enzymes, and the availability of protein, minerals, and bioactive compounds that support the growth of cellulolytic microbes as well as increased accessibility of cellulose to fiber-digesting enzymes.

Compliance with ethical standards

Disclosure of conflict of interest

No conflicts of interest to declare.

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