Research Article

Fortification of Complete Feed Silage Based on Sorghum Straw with Indigofera and Moringa as an Effort to Improve Performance and Reduce Cholesterol in Balinese Beef

Syamsul Bahri[1*], Muhammad Mukhtar[1], Sri Suryaningsih Djunu[1], Haris Singgili[2]

[1]Animal Husbandry Study Program, State University of Gorontalo, Gorontalo, Indonesia; [2]Agribusiness Study Program, State University of Gorontalo, Gorontalo, Indonesia.

Abstract | Ruminant productivity is highly dependent on the availability of high-quality feed. Gorontalo Province has great potential for sorghum cultivation due to the availability of extensive dry land. Sorghum is a nutrient-rich crop that plays an important role in improving the productivity of Bali cattle, which are also one of the region's leading commodities. The availability of sustainable, continuous, and highly nutritious feed is a primary requirement in efforts to develop Bali cattle production. One approach to meeting this need is through feed processing technology, namely fermented complete feed (silage). Complete feed silage based on sorghum straw is modified by the addition of fortified ingredients to enhance its nutritional value. This study aimed to evaluate the effects of feeding complete feed silage based on sorghum straw with fortified ingredients on growth performance, digestibility, and carcass quality of Bali cattle. A Randomized Block Design (RBD) was used with four treatments and three body-weight groups as blocks. Parameters observed included feed intake, body weight gain, feed conversion ratio, feed digestibility, carcass percentage, and meat cholesterol content. Data were analyzed using analysis of variance at the 1% significance level, and when significant differences were detected, Duncan's multiple range test was applied. The results showed that the fortified silage significantly increased ($P<0.05$) feed intake, average daily gain, and crude protein digestibility, while improving the feed conversion ratio, carcass percentage, and meat cholesterol content. In conclusion, fortifying complete feed silage with *Indigofera* and *Moringa* can improve growth performance, feed digestibility, and carcass percentage, while reducing meat cholesterol levels in Bali cattle.

Keywords | Fortification, Complete feed, Sorghum, Performance, Cholesterol, Balinese beef

Received | December 15, 2025; **Accepted** | January 20, 2026; **Published** | February 06, 2026
***Correspondence** | Syamsul Bahri, Animal Husbandry Study Program, State University of Gorontalo, Gorontalo, Indonesia; **Email:** syamsul.bahri@ung.ac.id
Citation | Bahri S, Mukhtar M, Djunu SS, Singgili H (2026). Fortification of complete feed silage based on sorghum straw with Indigofera and moringa as an effort to improve performance and reduce cholesterol in Balinese beef. Adv. Anim. Vet. Sci., 14(2):425-434.
DOI | https://dx.doi.org/10.17582/journal.aavs/2026/14.2.425.434
ISSN (Online) | 2307-8316

INTRODUCTION

The demand for animal protein, particularly beef, has risen significantly, yet domestic production has been insufficient to meet it. Various government programs have been launched to boost national production, one of which is the current national program implemented by the central government, namely the National Milk and Meat Production Improvement Program (P2SDN). For the Government of Gorontalo Province, the high demand for beef and the prospects for beef cattle development present both challenges and opportunities in developing beef cattle commodities, particularly Bali cattle. A primary challenge is that cattle management remains predominantly grass-based, with limited availability of supplementary concentrates. To support increased productivity of beef cattle, complete feed represents an innovation to ensure year-round availability of livestock feed. Complete feed is a mixture of various feed ingredients consisting of forage and concentrate to meet livestock nutritional requirements in order to optimize rumen function and animal growth (Hoy *et al*., 2023). In addition, it aims to ensure the continuous availability of high-quality feed throughout the year and to provide benefits for environmental sustainability (Bahri and Purnomo, 2020; Syamsu, 2011). Plants suitable as basic ingredients for complete feed production are those that possess advantages, including containing nutrients required by livestock. Sorghum is a cultivated crop widely developed on dry land (Nurmi *et al*., 2023). Sorghum is a multipurpose crop with several advantages, including drought resistance, adaptability to seasonal conditions, high productivity, and nutrient content suitable for use as forage for ruminant livestock. The nutritional content of sorghum includes dry matter 90.78%, organic matter 90.70%, and crude fiber 31.69% (Purwantari, 2008). In addition, its low lignin content and high water-soluble carbohydrate (WSC) levels make sorghum suitable as a raw material for silage production (Kurniawan *et al*., 2017). However, a limitation of sorghum is its relatively low crude protein content, which ranges only between 7–8% (Kurniawan, 2014). Considering that the crude protein content of sorghum alone is insufficient for livestock requirements (12-14% of dry matter (Periambawe and Sutrisna, 2016), fortification has been explored to enhance its nutritional value in order to increase feed nutritional value according to the needs of beef cattle and to produce a high-nutrient complete feed (Bahri *et al*., 2023). Indigofera and Moringa are two plants with high potential for feed fortification. The crude protein content of indigofera and moringa plants is 27.97% and 25.70%, respectively (Akbarillah and Kaharuddin, 2002). To ensure continuous feed availability and extend shelf-life, preservation methods such as fermentation are necessary. Fermentation plays a role in stopping enzymatic reactions and minimizing nutrient losses in forage so that nutrients remain in forms that can be efficiently utilized by livestock (Rusdy, 2017; Mukhtar *et al*., 2023). The inclusion of sorghum straw up to a level of 70% in complete feed has been shown to increase body weight gain in Kacang goats, along with high feed nutrient utilization at this level (Sayuti *et al*., 2024). Body weight gain in livestock reflects the extent to which the provided feed benefits the animals (Bahri and Amirudin, 2025). Based on the description above, the problem formulation of this study is as follows: (a) what are the levels of feed intake, average daily gain, feed conversion ratio, and nutrient digestibility in cattle fed complete feed silage based on sorghum straw with fortified ingredients, and (b) what are the carcass percentage and meat cholesterol levels of beef cattle fed complete feed silage based on sorghum straw with fortified ingredients.

MATERIALS AND METHODS

Place and time of research

This research was conducted at a community livestock farm in Tilongkabila District, Bone Bolango Regency from June to October 2025. Sample analysis was carried out at the Animal Husbandry Department Laboratory, Faculty of Agriculture, Gorontalo State University and the Animal Nutrition and Feed Laboratory, Faculty of Animal Husbandry, Hasanuddin University, Makassar.

Tools and materials

Bali cattle were placed in individual metabolic pens measuring 1.25 x 2 m equipped with feeders and water troughs.

The following equipment was used:

- Chopper for grass chopping, bucket for concentrate, plastic barrel (silo) for complete feed, mixer for mixing feed ingredients, shovel, tarpaulin
- Salter brand hanging scales with a capacity of 25 kg with an accuracy of 0.1 kg, Thang Long brand scales with a capacity of 10 kg with a sensitivity of 0.05 kg, Sartorius brand analytical scales with a capacity of 100 gr with a sensitivity of 0.0001 g, Rudweigh brand digital scales with a capacity of 1000 kg with a sensitivity of 0.5 kg.

The following materials were used:

- Sorghum straw harvested at 90 days of age
- Legumes (indigofera leaves and moringa leaves) for fortification.
- Concentrate (tofu pulp, fine corn, bran, molasses and MA-11)
- All feed provided is prepared according to the needs of growing cattle with the assumption of daily weight gain of 0.5 – 1.0 kg, namely 64% TDN and 12% crude protein. The composition of forage and concentrate used in the complete feed for each treatment is presented in Table 1.

Table 1: Composition of forage and concentrate in complete feed.

Ingredient	Treatment			
	R0	R1	R2	R3
Sorghum Straw	75	70	65	60
Indigofera Leaves	0	2.5	5	7.5
Moringa Leaves	0	2.5	5	7.5
Tofu Waste	8.5	8.5	8.5	8.5
Fine Bran	11	11	11	11
Cornmeal	2.5	2.5	2.5	2.5
Molasses	3	3	3	3
Total	100	100	100	100

Research implementation

Nutrient Digestibility

Nutrient digestibility is measured using the following equation:

$$\text{Dry Matter Intake} = \frac{\text{Fresh consumption (kg)} \times \text{DM Content (\%)}}{100}$$

$$\text{Consumption} = \frac{\text{DM intake (kg)} \times \text{nutrient content (\%)}}{100}$$

$$Consumption = \frac{DM\ intake\ (kg)\ x\ nutrient\ content\ (\%)}{100}$$

$$Digestibility = \frac{Consumption - Feces \times 100\,\%}{\text{Consumption}}$$

Daily weight gain, body weight is measured every two weeks to determine daily weight gain, which is calculated from the difference between the final and initial body weight at the end of the observation period divided by the observation period (Sudono *et al*., 2003). Feed conversion is the ratio of feed intake to daily weight gain, which indicates the amount of feed required to produce a certain amount of weight gain.

Digestibility determination

Digestibility was determined using the total collection method Natsir (2012), which was divided into two periods: A seven-day adaptation period to the cage and feed, and a seven-day data collection period covering feed intake, feed residues and faeces excreted.

Procedure for making complete fermented feed

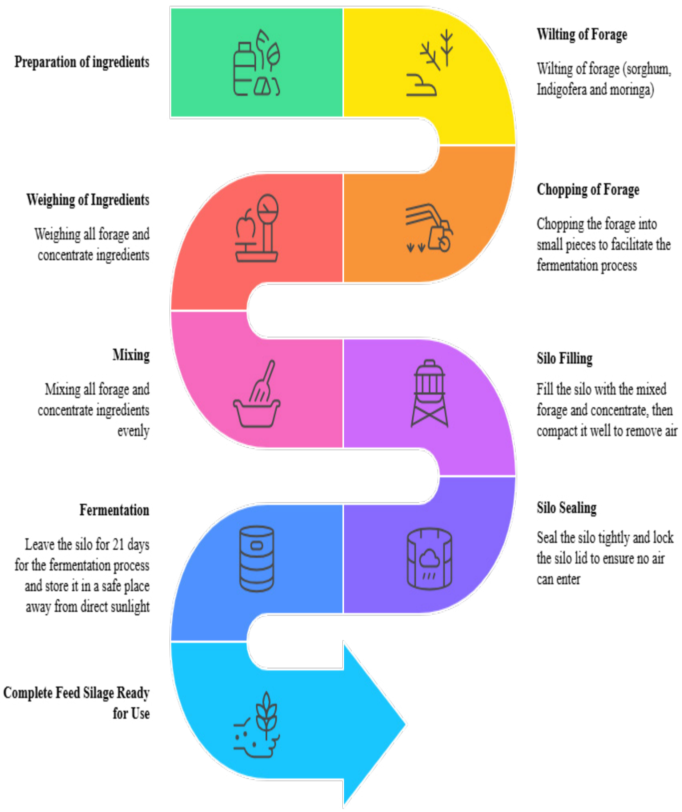

Figure 1: Procedure for making complete fermented feed.

Feed digestibility measurement procedure

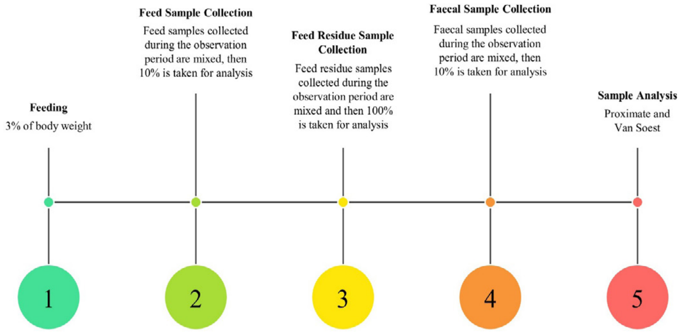

Figure 2: Feed digestibility measurement procedure.

Research procedures and methods

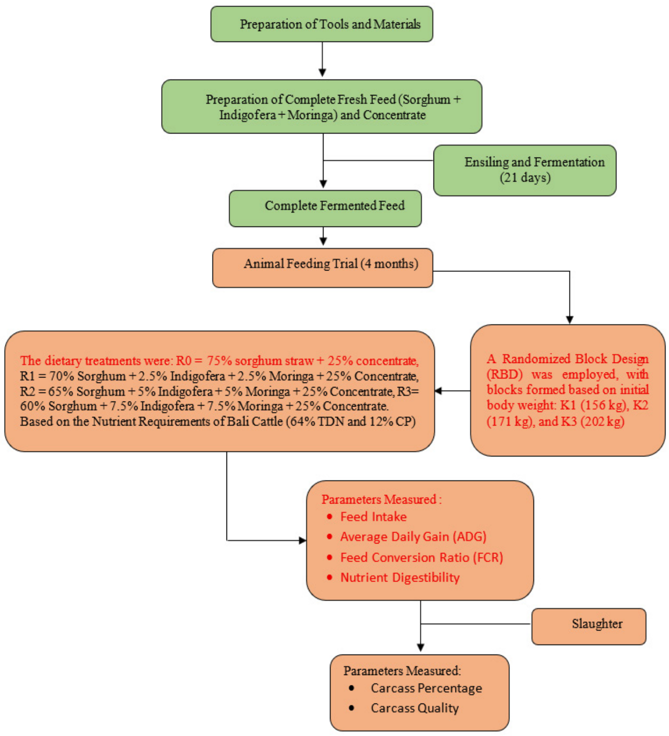

Figure 3: Schematic diagram of the research procedures and experimental design

RESULTS AND DISCUSSION

Bali cattle performance with complete feed silage treatment based on sorghum straw and fortified materials

Feed consumption

Dietary treatment had a significant effect ($P<0.01$) on feed intake (kg/head/day). The highest average feed consumption was found in treatment R3 (11.85 ± 0.83 kg/head/day), followed by R2 (9.97 ± 1.01 kg/head/day), R1 (9.20 ± 0.60 kg/head/day), and the lowest in R0 (8.02 ± 1.32 kg/head/day).

The increase in feed intake corresponding with higher levels of Indigofera and Moringa suggests that these ingredients improved diet palatability. The R0 treatment, which only used sorghum straw and concentrate, had the lowest feed consumption, possibly because sorghum straw has a relatively high crude fiber content and lower palatability compared to the ration supplemented with legumes.

Table 2: Performance of bali cattle fed sorghum straw-based silage with different fortification levels.

Variable	Treatment			
	R0	R1	R2	**R3**
Feed Intake (kg DM/day)	8.02[d] ± 1.32	9.20[c] ± 0.60	9.97[b] ± 1.01	11.85[a] ± 0.83
ADG (kg/day)	0.25[b] ± 0.03	0.33[b] ± 0.02	0.65[b] ± 0.02	0.88[a] ± 0.02
Conversion	33.52[a] ± 1.94	27.62[b] ± 1.71	15.39[c] ± 1.18	13.50[c] ± 0.70

Information: ADG = Average Daily Gain. Values are presented as mean ± SD. Means in the same row with different superscripts differ significantly (P < 0.05), 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.

In treatments R1 to R3, reducing the proportion of sorghum straw and increasing the levels of indigofera and moringa leaves contributed to improved ration nutritional quality, particularly crude protein content. Indigofera and moringa leaves are known to be good sources of vegetable protein, thus stimulating rumen microbial activity and increasing feed degradation rates. This encourages livestock to consume larger amounts of feed.

The highest feed consumption in treatment R3 indicated that the addition of indigofera leaves and moringa leaves at 7.5% each to the ration provided optimal nutritional balance without compromising palatability. This indicates that partial substitution of sorghum straw with high-quality forages may be an effective strategy for increasing feed intake.

Daily weight gain

The results of the analysis of variance showed that the treatment of complete feed based on sorghum straw and fortification materials had an effect (P<0.01) on body weight gain. The average daily body weight gain achieved in beef cattle maintenance was R0 (0.25 kg/head/day), R1 (0.33 kg/head/day), R2 (0.65 kg/head/day), and R3 (0.88 kg/head/day)" to match Table 2.

Further tests showed that the daily weight gain of beef cattle fed the R3 ration was significantly (P<0.05) higher than the R1, R2, and control rations. The highest daily weight gain of male Bali cattle was in the R3 treatment, at 0.88 kg/head/day, and the lowest was in the R0 treatment, at 0.25 kg/head/day.

The significant effect of the treatment was caused by the addition of fortification materials up to 15% (7.5% Indigofera and 7.5% Moringa) causing the availability of protein for livestock to be fulfilled compared to other treatments and also supported by higher PK consumption in R3, so that the excess protein can be used by livestock for weight gain. Complete feed with fortification materials is able to provide the protein needed by the livestock's body to build and repair body tissues, such as muscles, bones, and skin (Armayanti *et al*., 2024). In addition, quality feed will help improve the balance of microbes in the livestock's digestive tract, so that more nutrients are absorbed and can be used to increase body weight (Ahmadi and Kurniawati, 2012). Adequate protein will help improve the growth and development of livestock. Rukmana (2005) stated that the increase in body weight of Bali cattle with good feed reaches 0.7 kg/day in bulls. This opinion is supported by Wahyuni and Amin (2020), who stated that fattening requires adequate feed, both in terms of quality and continuity. Providing quality feed affects cattle weight gain, as a good feed formula will accelerate the growth rate and fattening of cattle.

This study produced an average daily weight gain of 0.88 kg/head/day, almost the same as the results of research conducted by Amien (2013) which produced a daily weight gain of 0.84 kg/head/day and a maximum of 1.25 kg/head/day, and higher than the results of research conducted by Bahri (2009) with complete feed silage (a combination of corn straw and peanuts) on Bali cattle, which produced a daily weight gain of 0.76 kg/head/day.

Feed conversion

The feed conversion values for the different treatment rations showed significant differences (P<0.05). Table 2 shows that the lowest feed conversion value was found in the R3 treatment at 13.50 and the highest in the control treatment at 33.52. This means that if the cows consumed the R3 treatment ration, they would produce a more efficient feed conversion compared to cows fed the R0, R1, and R2 treatments.

The feed conversion ratio indicates that the higher the feed conversion ratio, the less efficient the ration is in increasing body weight gain. This is because a lower feed conversion ratio indicates greater feed efficiency, as less feed is required to produce one kilogram of body weight gain.

The feed conversion of R3 showed better results compared to other treatments, which means that the amount of feed used to increase each kg of body weight is not too much. The less feed to increase each kg of body weight means the better the quality of the feed. According to Sukarne and

Nursan (2022), by providing good quality feed, livestock will grow faster and the conversion rate will also be better. The use of indigofera leaves and moringa leaves in complete feed has a high nutritional content, such as protein, vitamins, and minerals, can help improve the efficiency of feed digestion, so that nutrients will be absorbed more and can be used to increase livestock production, can help improve the microbial balance in the livestock digestive tract, so that nutrients will be absorbed more and can be used to increase livestock production and have antioxidant properties that can help reduce oxidative stress in livestock, thereby increasing feed conversion (Sitanggang, 2019).

Feed digestibility

Table 3: Apparent digestibility of nutrients in Bali cattle fed sorghum straw-based silage with different fortification levels.

Variable	Treatment			
	R0	R1	R2	R3
CP digestibility (%)	55.64[a] ± 1.16	66.09[b] ± 2.30	66.82[b] ± 1.20	72.96[c] ± 0.97
CF digestibility (%)	37.50[c] ± 1.55	54.07[c] ± 1.33	54.98[b] ± 0.55	56.76[a] ± 0.75
EE digestibility (%)	52,04 ± 0.79	52.63 ± 2.81	56.63 ± 1.56	69.00 ± 0.88

Information: Values are presented as mean ± SD. Means in the same row with different superscripts differ significantly ($P < 0.05$); 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.

Crude protein digestibility

Crude protein (CP) digestibility differed significantly ($P < 0.05$) among treatments. The Duncan's multiple range test results presented in Table 3 showed that treatment R0 (55.64 ± 1.16%) had the lowest digestibility value and was significantly different from all other treatments. The addition of Indigofera leaves and Moringa leaves to treatments R1 (66.09 ± 2.30%) and R2 (66.82 ± 1.20%) significantly increased the crude protein digestibility value compared to R0, but both were not significantly different from each other. The highest value was achieved in treatment R3 (72.96 ± 0.97%), which was significantly different from the other three treatments. The increase in the digestibility crude protein value in treatments with Indigofera and Moringa leaf fortification was due to the high crude protein content and protein quality of both ingredients. *Indigofera zollingeriana* contains 23–28% protein, while *Moringa oleifera* leaves are rich in protein and essential amino acids that are easily digested by ruminants (Suharlina *et al*., 2019; Nisa *et al*., 2018). Furthermore, the bioactive compounds such as flavonoids and saponins in both leaves also play a role in inhibiting protein degradation by proteolytic rumen microbes, resulting in a higher protein fraction available for post-rumen digestion. The highest digestibility crude protein value at R3 indicates that the fortification level of 7.5% Indigofera and 7.5% Moringa is the optimal combination for increasing crude protein digestibility. This is likely related to a better balance of nutrients, especially protein and energy, as well as improved feed fermentability in the rumen. Thus, high levels of fortification can increase the efficiency of protein utilization, which in turn supports improved growth performance of beef cattle.

Crude fiber digestibility

The average digestibility of beef cattle fed sorghum straw-based rations showed a significant difference ($P<0.01$) in crude fiber digestibility. Treatment R0 produced the lowest digestibility crude fiber value (37.50%) compared to treatments R1, R2, and R3. The low digestibility of crude fiber in R0 is caused by limited degradation of structural fiber due to the high proportion of unfortified sorghum straw with quality forage, which generally has a relatively high lignin content, thus limiting rumen microbial access to the cellulose and hemicellulose fractions. The increase in digestibility crude fiber values in treatments R1 to R3 indicates that ration fortification with indigofera leaves and moringa plays a role in increasing the efficiency of fiber fermentation in the rumen. Both materials are known to have higher protein and mineral content than straw, thus supporting the growth and activity of rumen microorganisms that play a role in fiber degradation. The increased availability of nitrogen and microbial growth factors contributes to increased degradation of the fiber fraction, which is reflected in higher crude fiber digestibility values. The improved CF digestibility with Indigofera and Moringa fortification is likely attributable to their higher protein and mineral content, which supports fibrolytic microbial activity in the rumen, rather than to direct enzymatic action from the leaves themselves, so that it can be more easily digested by livestock as well as high protein content and secondary metabolite compounds such as saponins and flavonoids that play a role in suppressing the population of methanogenic rumen microbes, thereby increasing the efficiency of fiber fermentation. In addition, the increase in crude fiber digestibility is also influenced by the availability of sufficient protein to support the growth of the cellulolytic microbial population, which plays a major role in degrading feed fiber, can help improve the balance of microbes in the digestive tract of livestock, so that existing microbes can be more effective in breaking down crude fiber and help increase the production of fatty acids that can help break down crude fiber into simpler components (Putri *et al*., 2025). The digestibility crude fiber value in the R3 treatment (56.76%) was the highest numerically, although not significantly different from R1 and R2. This indicates that the fortification level of 7.5%

Indigofera and 7.5% Moringa is quite optimal in increasing the utilization of feed fiber fractions.

Crude fat digestibility

Analysis of variance showed that the provision of fermented complete feed based on sorghum straw and legume leaves had a very significant effect (P<0.01) on crude fat digestibility. The average results of the study showed variations in crude fat digestibility in fermented complete feed based on sorghum straw and fortification materials. Treatment R3 provided the highest crude fat digestibility value of 69.00%, followed by treatment R2 with an average crude fat digestibility value (56.63%), higher than R0 (52.04%) and R1 (52.63%). The low crude fat digestibility values in R0 to R2 indicate that the relatively high proportion of sorghum straw still limits the efficiency of fat utilization. Sorghum straw has a high structural fiber content, which can inhibit the interaction between feed fat and rumen microbes, so that the lipolysis process and fatty acid utilization are not optimal. This condition causes some fat fractions to be inefficiently digested and excreted in the feces. However, in R3, the addition of Indigofera and Moringa leaves in higher amounts significantly increased the protein content and quality of the ration, allowing rumen microbes to adapt and function more optimally. This adaptation reduces the negative effects of anti-nutritional compounds and improves the livestock's ability to digest fat, resulting in higher crude fat digestibility in R3 compared to other treatments. Higher protein content can increase rumen microbial activity, especially lipolytic microbes, so that the fat hydrolysis process occurs more optimally (Saputri *et al*., 2025). Furthermore, indigofera and Moringa leaves contain bioactive compounds that have the potential to increase the efficiency of digestion and absorption of nutrients, including fat.

The increase in crude fat digestibility is also influenced by the enhanced supply of nitrogen and minerals from indigofera and moringa leaves, which leads to an increase in the population and activity of cellulolytic rumen microorganisms (Amelia *et al*., 2025). In addition, it also has emulsification properties that can help break down crude fat into smaller particles and help improve the microbial balance in the livestock's digestive tract, so that the existing microbes can be more effective in breaking down crude fat and help increase the production of bile acids that can help break down crude fat into simpler components so that it can be more easily digested by livestock. Conversely, in treatments R1 and R2, lower levels of fortification were not able to increase crude fat digestibility. This indicates that the addition of indigofera and moringa leaves at low to moderate levels is not enough to significantly increase fat digestion activity.

Carcass percentage and meat cholesterol content

Carcass percentage

Carcass weight is a primary metric in carcass evaluation, carcass percentage is the ratio between carcass weight and live weight multiplied by 100%. The average carcass percentage of male Bali cattle fed a complete silage ration based on sorghum straw with fortified materials is shown in Table 4.

Table 4: Average carcass percentage and cholesterol content of beef beef given a ration based on sorghum straw and fortified materials.

Variable	Treatment			
	R0	R1	R2	R3
% Carcass	49.31[c] ± 1.25	54.68[b] ± 0.89	55.16[b] ± 0.66	58.46[a] ± 1.96
Infraspinatus (IF)	23.19[a] ± 1.12	18.11[ab]± 0.32	14.80[bc]± 1.77	10.44[c] ±0.46
Semitendino-sus(ST)	43.20[a] ±3.81	39.10[a] ± 0.77	21.59[b] ± 0.56	19.27[b] ±1.42
Longisimus (LD)	26.21± 0.89	23.82± 4.53	15.26± 0.31	15.47± 0.52

Description: Values are presented as mean ± SD. Means in the same row with different superscripts differ significantly (P < 0.05); 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 of the analysis of variance showed that the provision of complete ration silage with different compositions to male Bali cattle had a significant effect (P<0.05) on the carcass percentage. The carcass percentage of Bali cattle fed complete silage based on sorghum straw with fortified materials using different compositions obtained the highest carcass percentage value in the R3 treatment, namely 58.46% with a feed composition of 60% sorghum straw + 7.5% moringa leaves + 7.5% indigofera leaves + 25% concentrate and the lowest in the R0 treatment 49.31% with a composition of 100% control ration.

The average carcass percentage of male Bali cattle fed complete feed silage with different compositions ranged from 49.31% to 58.46%. The low carcass percentage for R0 is likely due to its composition, which was dominated by sorghum straw without the addition of legumes. Sorghum straw has a relatively high crude fiber content and low protein, resulting in less than optimal nutrient digestibility and nutrient utilization for body tissue formation. This condition results in slower muscle tissue growth and lower carcass weight accumulation.

Carcass percentages in R1 and R2 increased compared to R0, at 54.68% and 55.16%, respectively. This increase indicates that the addition of Indigofera leaves and Moringa leaves to the ration improved feed quality. Both types of forage are known to have high protein content and a better amino acid profile than sorghum straw. Increasing the protein content of the ration plays a crucial role in supporting protein synthesis in the body, particularly muscle tissue formation, resulting in a higher carcass percentage.

Treatment R3 produced the highest carcass percentage, at 58.46%. This indicates that increasing the addition level of Indigofera leaves and Moringa leaves to 7.5% each provides a more optimal positive effect on livestock performance. At this level, the balance between fiber and protein in the ration is thought to be more ideal, resulting in increased nutrient digestibility and more efficient utilization of energy and protein for carcass tissue growth. Therefore, the higher the proportion of legume forage in a sorghum straw-based ration, the greater its contribution to increasing livestock carcass percentage.

The results of this study are higher than the carcass percentage of Kurniawan (2014) research, which is 48.33 ± 1.13. This is due to the slaughter weight of Bali cattle, where there is a relationship between live weight, carcass weight and carcass percentage. The higher the live weight, the higher the carcass weight. According to Wirondas and Ariyani (2022), a higher slaughter weight can affect carcass weight. According to Yosita *et al*. (2012), Bali cattle also have a more compact and dense body confirmation and a lighter digestive weight so that their carcass percentage can be higher than other cattle.

Cholesterol levels in meat

The average meat cholesterol levels of beef cattle based on Table 4 were R0 (23.19) (23.19), R1 (18.11), R2 (14.80) and R3 (10.44), and in the semitendinosus section were R0 (43.20), R1 (39.10), R2 (21.59) and R3 (19.27).

Further tests showed that the cholesterol levels of beef cattle that received the R3 ration were significantly ($P < 0.05$) lower than the R1, R2 and control ration treatments in the infraspinatus section but were not different from the R2 treatment. While the cholesterol levels of beef cattle that received the R3 ration were significantly ($P < 0.05$) lower than the R2, R1 and control ration treatments in the semitendinosus section but were not different from the R2 treatment. In the longisimus dorsi section, the cholesterol levels of beef cattle, although not significantly different, had the same tendency as the cholesterol levels of beef in other muscle parts.

Cholesterol levels in meat in this study decreased as the fortification content in the ration increased. This reduction may be due to the dietary fiber and bioactive compounds (e.g., saponins, flavonoids) in the fortificants, which can interfere with cholesterol absorption and metabolism. Furthermore, it contains antioxidants that can help reduce cholesterol oxidation, thereby reducing the formation of atheroma plaque in blood vessels. It contains flavonoids that can help reduce cholesterol synthesis in the liver. It contains saponins that can help reduce cholesterol absorption in the digestive tract and can help increase bile acid production, which can help reduce blood cholesterol levels. Bioactive compounds such as saponins, tannins, and flavonoids play a role in inhibiting cholesterol absorption and synthesis in the body (Enggarwati and Qomariyah, 2023). Saponins can bind cholesterol and bile acids, thereby increasing cholesterol excretion, while flavonoids play a role in suppressing the activity of the HMG-CoA reductase enzyme involved in endogenous cholesterol formation.

Furthermore, these bioactive compounds can modify rumen fermentation by suppressing protozoan populations, thereby increasing nutrient utilization efficiency and altering volatile fatty acid production patterns, particularly by increasing the proportion of propionate. Increased propionate contributes to suppressing fat and cholesterol synthesis in muscle tissue (Haghikia *et al*., 2022). The high protein content of indigofera and moringa leaves also supports muscle growth without increasing fat deposition, resulting in lower meat cholesterol levels.

Cholesterol levels were consistently higher in the Semitendinosus (ST) muscle than in the Infraspinatus (IF) muscle across all treatments, reflecting differences in their physiological function and muscle fiber composition. The ST, a locomotor muscle, typically has more glycolytic fibers and higher intramuscular fat content. The Semitendinosus muscle is a locomotor muscle that actively functions for movement, and is therefore dominated by white muscle fibers (glycolytic type) that tend to store higher levels of intramuscular fat. This intramuscular fat is directly related to cholesterol content, as cholesterol is abundant in adipose tissue and muscle cell membranes. Conversely, the Infraspinatus muscle functions as a postural muscle that works more stably and continuously, and is therefore dominated by red muscle fibers (oxidative type) with higher fat metabolism activity. Oxidative muscle fibers tend to utilize fat as an energy source, resulting in lower accumulation of fat and cholesterol within muscle tissue. Therefore, these differences in muscle fiber composition and physiological function are what caused cholesterol levels in the Semitendinosus muscle to be consistently higher than in the Infraspinatus muscle across all treatments.

Differences in cholesterol levels are likely influenced by differences in fat content. Cholesterol is related to fat fraction, while differences in fat content are influenced by age, feed, consumption, species, and muscle location. According to Rahman *et al.* (2015), protein has an inverse relationship with fat content, where muscles with higher protein content will have lower fat content. Differences in protein content can be influenced by water content, fat content, and activity during life. Furthermore, it is explained that muscles with higher protein content will have lower fat content, so lean meat contains relatively more minerals (Dewi *et al.*, 2016). Therefore, meat protein is the most valuable constituent of meat and greatly determines its economic and nutritional value.

The balance of cholesterol in tissues can increase or decrease. The main pathway for cholesterol excretion in the body is through conversion by the liver into bile acids. Approximately half of the cholesterol is excreted in the feces after being converted to bile acids, and most of the cholesterol excreted in the bile is reabsorbed. Furthermore, Prifianingrum (2021) explains that cholesterol helps transport processed fats from the liver throughout the body via the blood vessels. This process continues and repeats itself.

CONCLUSIONS AND RECOMENDATIONS

The conclusion of this study:

- Feeding complete feed silage based on sorghum straw with fortification of Indigofera leaves and Moringa leaves up to a level of 7.5% each (R3) significantly increased feed intake and average daily gain while improving the feed conversion ratio, resulting in the best growth performance of Bali Cattle.
- Increasing the fortification level by 7.5% each with indigofera leaves and moringa leaves in the ration significantly increased the digestibility of crude protein, crude fiber and crude fat.
- The carcass percentage of Bali cattle fortified with indigofera and moringa leaves tended to increase with increasing fortification levels. The combination of 65% sorghum straw with 7.5% each of indigofera and moringa leaves resulted in a better carcass percentage than the other treatments.
- The addition of Indigofera leaves and Moringa leaves to sorghum straw-based rations can reduce meat cholesterol levels. Adding 7.5% each of indigofera and Moringa leaves yielded the best results, with lower cholesterol levels.

Recomendations from this research:

- The use of Indigofera leaf and Moringa leaf fortification in complete feed silage should use a combination of 7.5% because it has been proven to increase growth, nutrient digestibility and reduce cholesterol levels in Balinese beef.
- Further research is needed to evaluate the impact of fortification on rumen fermentation profiles and reproductive performance to obtain more comprehensive results.
- An economic feasibility analysis is crucial to determine the cost-effectiveness and practical adoption of this fortification strategy for farmers that the use of this fortification material benefits livestock farmers at various business scales.
- The combination of fortification with other local feed ingredients can be further studied to produce a more balanced, efficient, and high-storage complete feed silage.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia for its support of this research through the Fundamental Research Grant (BIMA Scheme) under contract number 082/C3/DT.05.00/PL/2025.

NOVELTY STATEMENT

This research offers a novel approach to addressing the limitations of sorghum straw as a livestock feed ingredient through the use of complete feed silage fortified with a combination of legume leaves (Indigofera and Moringa leaves) for Bali cattle. The research findings indicate that this fortification can improve Bali cattle growth, feed nutrient digestibility, and lower meat cholesterol. These results provide a practical contribution to the development of sustainable tropical ruminant feeding systems.

AUTHOR'S CONTRIBUTION

SB, MM, SSD, and HS: Idea formulation and research design. SB, MM: Sample material collection and laboratory analysis. SSD, HS: Report manuscript compilation and writing.

Generative AI and AI-assisted technology statement

The authors declare that generative AI-assisted tools were used solely for the creation of Figures 1 and 2 for visualization purposes. The scientific content, data analysis, and interpretation were entirely conducted by the authors.

Conflict of interest
The authors have declared no conflict of interest.

REFERENCES

Ahmadi H, Kurniawati N (2012). Pemberian probiotik dalam pakan terhadap pertumbuhan lele sangkuriang (*Clarias gariepinus*) pada pendederan II. J. Perikan. Kelautan, 3(4).

Akbarillah T, Kaharuddin D (2002). Kajian daun tepung Indigofera sebagai suplemen pakan produksi dan kualitas telur. Lembaga Penelitian Universitas Bengkulu.

Amelia AR, Muhtarudin M, Liman L, Erwanto E (2025). Pengaruh pemberian mineral makro (Ca Dan Mg) terhadap kecernaan serat kasar dan protein kasar ransum pada domba ekor tipis jantan. J. Riset Inovasi Peternakan (J. Res. Innov. Anim.), 9(2): 375-383. https://doi.org/10.23960/jrip.2025.9.2.375-383

Amien I (2013). Pertambahan bobot badan dan konversi pakan sapi Limousin cross dengan pakan tambahan probiotik (Skripsi). Universitas Brawijaya.

Armayanti AK, Lutfhi N, Nuraliah S, Fardila S, Khaeruddin, Prima A, Suryani HF, Wati NE, Ibrahim S, Indah A, Ali N, Susanti I, Utami RN (2024). Nutrisi ternak dasar: Dinamika teori dan perkembangannya. PT Sonpedia Publishing Indonesia.

Bahri S, Amirudin SP (2025). Integrated farming system SIJAKA (Sapi–Jagung–Kacang Tanah). PT Penerbit Qriset Indonesia.

Bahri S (2009). Kajian sistem pertanian terpadu dengan komoditi jagung, kacang tanah dan sapi potong (Tesis). Universitas Hasanuddin.

Bahri S, Purnomo SH (2020). Produksi biji dan biomassa jagung pakan ternak yang diberi pupuk organik dan kepadatan awal tanam berbeda pada lahan kering. J. Tabaro Agric. Sci., 4(2): 496–501. https://doi.org/10.35914/tabaro.v4i2.672

Bahri S, Hasan S, Natsir A, Sirajuddin SN (2023). Integrated farming system: Sistem integrasi Sijagal (Sapi–Jagung–Gamal) (N. Rismawati, Ed.). Edisi pertama.

Dewi AM, Swacita IBN, Suwiti NK (2016). Pengaruh perbedaan jenis otot dan lama penyimpanan terhadap nilai nutrisi daging sapi Bali. Bull. Vet. Udayana, 8(2): 135–144.

Enggarwati ID, Qomariyah N (2023). Aktivitas antihiperkolesterol ekstrak daun ceremai (*Phyllanthus acidus* L.) pada mencit (*Mus musculus*) yang diinduksi high fat diet. LenteraBio: Berkala Ilmiah Biol., 12(3): 439–445. https://doi.org/10.26740/lenterabio.v12n3.p439-445

Haghikia A, Zimmermann F, Schumann P, Jasina A, Roessler J, Schmidt D, Landmesser U (2022). Propionate attenuates atherosclerosis by immune-dependent regulation of intestinal cholesterol metabolism. Eur. Heart J., 43(6): 518–533. https://doi.org/10.1093/eurheartj/ehab644

Hoy CPE, Hartati E, Lestari GAY (2023). Pengaruh silase pakan komplit berbasis sorgum *Clitoria ternatea* dengan penambahan berbagai level konsentrat mengandung $ZnSO_4$ dan ZnCu isoleusinat terhadap fermentasi rumen *in vitro*. Anim. Agric., 1(2): 79–89. https://doi.org/10.59891/animacultura.v1i2.18

Kurniawan W (2014). Potensi sorgum Numbu, CTY-33, dan BMR sebagai pakan pada beberapa level pupuk kandang di tanah sedimentasi Ultisol (Tesis). Institut Pertanian Bogor.

Kurniawan W, Has H, Rahman (2017). Early evaluation of 65th days after sowing BMR sorghum productivity grown on swamp soil applied with different levels of biochar. Proc. Int. Conf. Sustain. Anim. Agric. Dev. Count., pp. 161–164.

Mukhtar M, Bahri S, Syahruddin (2023). Effects of growth characters, biomass production, and nitrogen uptake of elephant grass by different liquid fertilizers as a ruminant feed. Adv. Anim. Vet. Sci., 11(12): 1961–1967. https://doi.org/10.17582/journal.aavs/2023/11.12.1961.1967

Natsir A (2012). Fibre utilization by ruminants. Makassar: Masagena Press.

Nisa F, Subrata A, Pangestu E (2018). Kehilangan bahan kering, acid detergent fiber dan N-acid detergent fiber daun *Moringa oleifera* secara *in vitro*. J. Sain Petern. Indones., 13(3): 282–286. https://doi.org/10.31186/jspi.id.13.3.282-286

Nurmi N, Bahri S, Azis MA, Dzakaria S (2023). Infiltrasi peningkatan peresapan air ke dalam tanah melalui aplikasi pupuk organik sekam padi pada pertanaman sorgum (*Sorghum bicolor* L.). J. Penelitian Pertanian Terapan, 23(3): 385–392. https://doi.org/10.25181/jppt.v23i3.2955

Periambawe DKA, Sutrisna R (2016). Status nutrien sapi peranakan ongole di Kecamatan Tanjung Bintang Kabupaten Lampung Selatan. J. Ilmiah Petern. Terpadu, 4(1).

Prifianingrum IS (2021). Pengaruh pembacaan absorbansi dengan variasi waktu terhadap kadar kolesterol total pada sampel hiperkolesterolemia dengan metode chod-pap (Disertasi Doktoral). Poltekkes Kemenkes Yogyakarta.

Purwantari T (2008). Fermentabilitas *in vitro* dan produksi biomassa mikroba ransum komplit yang mengandung jerami sorgum, konsentrat dengan penambahan suplemen pakan (Skripsi). Inst. Pertan. Bogor.

Putri SE, Abdullah FM, Septiyaningsih R, Aulia F, Rahayu TP (2025). Nutrisi seimbang untuk unggas: Memahami pentingnya protein dan serat. J. Ilmiah Ilmu-Ilmu Petern., 28(1): 1–11. https://doi.org/10.22437/jiiip.v28i1.35982

Rahman IG, Sukmiwati M, Dahlia (2015). Pengaruh metoda pemasakan berbeda terhadap karakteristik tepung ikan betok (*Anabas testudineus*) (Skripsi). Universitas Riau.

Rukmana RH (2005). Usaha Tani Jagung. Kanisius.

Rusdy M (2017). Pengawetan hijauan pakan. Politik Sosial Genius.

Saputri KW, Nur'aini SN, Hakim M (2025). Pengaruh penambahan EM4 dalam fermentasi solid kelapa sawit terhadap kualitas nutrisi bahan pakan. Bull. Petern. Trop., 6(2): 160–166. https://doi.org/10.31186/bpt.6.2.160-166

Sayuti M, Sahara L, Rachman AB, Metaragakusuma AP, Febrisiantosa AF (2024). Evaluating complete silage for goat feeding in Gorontalo, Indonesia. Curr. Res. Biosci. Biotechnol., 5(2): 17–21. https://doi.org/10.5614/crbb.2024.5.2/NEHZ10BA

Sitanggang LP (2019). Pengaruh konsentrasi tepung Indigofera dalam pembuatan pelet ikan mas (*Cyprinus carpio*). Tapian Nauli: J. Penelit. Terapan Perikan. Kelautan, 1(2): 53–59.

Sudono A, Rosdiana RF, Setiawan BS (2003). Beternak Sapi Perah Secara Intensif. Jakarta. Agromedia Pustaka.

Suharlina S, Abdullah L, Lubis AD (2019). Kualitas nutrisi hijauan (*Indigofera zollingeriana*) yang diberi pupuk organik cair asal limbah industri penyedap masakan. J. Pertan. Terpadu, 7(1): 28–37. https://doi.org/10.36084/jpt..v7i1.179

Sukarne S, Nursan M (2022). Effectiveness test of duck mie (innovation of noodle-shaped feed) on Peking duck productivity. J. Biol. Trop., 22(2): 398–406. https://doi.org/10.29303/jbt.v22i2.3429

Syamsu JA (2011). Reposisi paradigma pengembangan peternakan (M. Arief, Ed.). Absolute Media.

Wahyuni E, Amin M (2020). Manajemen pemberian pakan sapi Bali. J. Petern. Lokal, 2(1): 1–7. https://doi.org/10.46918/peternakan.v2i1.829

Wirondas WRW, Ariyani F (2022). Produksi karkas dan nonkarkas domba lokal dengan variasi bobot potong di BBPKH Cinagara. J. Pengembangan Penyuluhan Pertanian, 19(36): 158–164. https://doi.org/10.36626/jppp.v22i1.887

Yosita M, Santosa U, Setyowati EY (2012). Persentase karkas, tebal lemak punggung dan indeks perdagingan sapi bali, peranakan ongole dan australian commercial cross. Students E-J., 1(1): 15.