



Effect of Mash, Pellet and Wafer Feed Prepared from *Indigofera* Legume on Rumen Fermentability, Nutrient Digestibility and Sheep Performance

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ABSTRACT

This study focused on the effects of feeding *Indigofera* legume-based diets in the form of mash, pellets, and wafers on nutritional quality, rumen fermentability, *in vitro* digestibility, performance of local sheep, and *in vivo* nutrient digestibility. The study was conducted experimentally and divided into two phases. Phase I used a completely randomized design with three treatments and six replicates, while Phase II used a randomized block design with three treatments and four blocks. The treatments used were P0 = Mash feed; P1 = Pellet feed; and P2 = Wafer feed, with each treatment consisting of 50% *Indigofera* legume, 50% corn bran, and 5% molasses. The study utilized 12 local sheep aged approximately 5–6 months, weighing around 8 kg. The wafer treatment outperformed the mash and pellet treatments in producing dry matter and crude protein, while the mash treatment yielded the highest values ($P < 0.05$) for total volatile fatty acids, *in vitro* dry matter digestibility, *in vitro* organic matter digestibility, and *in vitro* crude protein digestibility compared to the pellet and wafer treatments. Feeding *Indigofera*-based diets in the form of mash, pellets, and wafers to sheep did not have a significant effect ($P > 0.05$) on the digestibility of dry matter, crude protein, crude fat, crude fiber, nitrogen-free extract, and feed intake. The mash, pellet, and wafer treatments yielded different responses regarding nutritional values and *in vitro* digestibility. Furthermore, the administration of complete rations based on *Indigofera* legumes in these three physical forms resulted in similar nutrient digestibility values but improved the overall production performance of the sheep.

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Authors' Contribution

TA conducted the literature review, experimental investigations, and exploratory examinations and drafted the manuscript. AEH, JJ, AA and SS supervised all experimental procedures and the development of the manuscript. AEH verified the results. All authors reviewed and approved the final version of the manuscript.

Key words

Feed, Pellets, *Indigofera* legumes, Local sheep

INTRODUCTION

Population growth and human development are correlated with the consumption of lamb meat, which is a superior source of protein, contains polyunsaturated fatty acids, and has lower total fat and cholesterol levels compared to goat meat (Chikwanha *et al.*, 2018). Sheep meat production has increased by up to 23%, and consumption continues to rise by 8.1% annually through 2029 (Firtala, 2024). The development of sheep farming in Indonesia exhibits unique dynamics due to the high

demand for sheep meat supply and slaughter, particularly during Muslim religious festivals (Budisatria *et al.*, 2010). Additionally, sheep farming is easier to manage, has a high market demand, and serves as a form of savings when farmers need cash (Devendra, 2002).

However, challenges have emerged in sheep farming development, primarily difficulties in feed supply due to limited land, resulting in a low carrying capacity in forage production areas. Consequently, sheep feed supply is managed through a cut-and-carry method to the pens, leading to poor forage quality and inconsistent forage supply (Udo and Budisatria, 2011), a condition that affects sheep growth and production due to changes in grazing behavior (Sanderson *et al.*, 2007). The provision of forage-based sheep feed requires a shift toward sustainable, high-nutrient feed sources to effectively maintain optimal sheep productivity; one such approach involves the use of the leguminous tree *Indigofera*. *Indigofera* legumes can produce forage year-round and possess high nutritional potential, with crude protein content reaching up to 35%

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(Jayanegara *et al.*, 2019). This allows a portion of the dietary protein to bypass rumen fermentation, leading to more effective protein utilization and enhanced ruminant production (Preston and Leng, 2021).

Feeding a diet primarily composed of *Indigofera* leaves mixed with additives has proven to be economically unfeasible in livestock operations. This is because chopped forage, when consumed by livestock, results in a high feed conversion ratio due to significant feed wastage and suboptimal utilization. Therefore, to maintain the efficiency of livestock operations, feed formulations must be adjusted to alter the physical form of the feed such as mash (flour), wafers, and pellets tailored to the crude protein requirements and TDN (total digestible nutrient) values of the sheep. Paste-form concentrates offer the advantage of being a cost-effective feed, but their loose physical form causes sheep to be more selective in their eating, leading to nutritional imbalances. Feed particles smaller than 1.18 mm that enter the rumen pass through the rumen cavity rapidly, thereby inhibiting the regurgitation and rumination processes (Ferreira *et al.*, 2011). Therefore, innovations in the form of pellet and wafer feeds are needed. Pellets are cylindrical-shaped feed produced by compressing feed raw materials using a die-cutting machine, resulting in shapes with varying diameters, lengths, and hardness levels. Retnani *et al.* (2009) noted that pelleted feed is one of the most reliable forms for storage, ensuring consistent availability and a steady supply to maintain feed quality. Wafers are a modified form of livestock feed in the shape of cubes, consisting of forage, concentrates, and other additional nutrients in desired proportions to meet livestock nutritional needs (Karimizadeh *et al.*, 2017). This study focused on the effects of feeding *Indigofera* legume-based diets in the form of mash, pellets, and wafers on nutritional quality, rumen fermentability, *in vitro* digestibility, performance of local sheep, and *in vivo* nutrient digestibility.

Pellet feeding affects the consumption of animal feed, effectively digesting, absorbing nutrients, rumen fermentation produces total VFA (volatile fatty acids) (Khampa *et al.*, 2018). Pellet feed also affects rumen pH, fermentation end products, rumen microbial populations as well as overall livestock production (Cherdthong *et al.*, 2019). Complete wafer feed made from tapioca flour as a source of carbohydrates can improve the digestibility of organic matter (Istiadi *et al.*, 2020). Complete wafer feed with the addition of prilled fat significantly improves rumen fermentation activity and nutrient digestibility of sheep in *in vitro* conditions (Saputra *et al.*, 2025).

MATERIALS AND METHODS

The research began with the collection and drying

of *Indigofera* legume raw materials until their moisture content reached 10–11% and they were ready for grinding. The subsequent step involved mixing the material with various other ingredients, namely corn bran (as an energy source) and molasses (as a binder), followed by the extrusion process to produce feed in the form of mash, pellets, and wafers. The resulting feed products were then comprehensively analyzed (Table I).

Chemical composition and fiber fraction measurement with NIRS

Near infrared spectroscopy (NIRS) testing utilized a Buchi NIRFlex N500 with dense cells. Spectra collection involved dry samples that had been ground and placed in a petri dish holder. The samples were irradiated with near-infrared light within a 10000–4000 cm^{-1} wavelength range. The radiation was applied three times to produce three spectra for each sample. The spectral data in NIRS consisted of vibrations of C-H, N-H, C-O-H, C-C, and O-H structural bonds in the NIR region. This chemical structure represents quality parameters such as protein, fiber, carbohydrates, fat, water content, acid content, neutral detergent fiber (NDF), acid detergent fiber (ADF), hemicellulose, and lignin (Despal *et al.*, 2020).

Fermentation rumen characteristic

The testing of ammonia production and VFA *in vitro* was conducted according to the method established by Tilley and Terry (1963). Rumen fermentation and digestibility were evaluated using a two-stage *in vitro* technique. Rumen fluid was sourced from fistulated Frisian Holstein bulls maintained at the Dairy Animal Nutrition Laboratory, Institute Pertanian Bogor University. Fermentability tests were carried out in 100 ml fermentation tubes. A 0.5 g sample was combined in each tube with 40 ml of preheated McDougall's buffer and 10 ml of rumen fluid. The contents were aerated with CO_2 gas for 30 sec to establish anaerobic conditions, sealed with a ventilated rubber stopper, and incubated in a shaking water bath at 39°C for 4 h. After fermentation, the tubes were centrifuged at 3500 g for 15 min, and the supernatant was collected to analyze NH_3 and total VFA. NH_3 levels were measured using the Conway method, while total VFA were determined via steam distillation.

In vitro nutrient digestibility

The digestibility test involved two stages. The first stage followed the fermentation procedure described above, but the fermentation period was extended to 48 h. Afterward, the tubes were centrifuged at 3500 g for 15 min to obtain the residue. This residue was then mixed with 40 ml of HCl-pepsin solution and incubated aerobically

in a water bath at 39°C for another 48 h. After 48 h of enzymatic processing, the residue was filtered, dried, and weighed to calculate the dry matter (DM) residue. The organic matter (OM) content of the residue was determined by incinerating it in a muffle furnace at 600 °C for 6 h. The *in vitro* dry matter digestibility (IVDMD) and *in vitro* organic matter digestibility (IVOMD) coefficients were calculated using the following formulas:

$$\text{IVDMD} = \frac{(\text{sample weight} \times \text{DM}) - (\text{residue weight} \times \text{DM} - \text{blank weight} \times \text{DM})}{(\text{sample weight} \times \text{DM})} \times 100\%$$

$$\text{IVOMD} = \frac{(\text{sample weight} \times \text{OM}) - (\text{residue weight} \times \text{OM} - \text{blank weight} \times \text{OM})}{(\text{sample weight} \times \text{OM})}$$

Experimental design, treatment and parameter in vivo

Twelve local sheep, approximately 5–6 months old and weighing about 8 kg each, were used without sex separation. The sheep were weighed to determine their initial weight and then placed in pens. The 12 sheep were divided into three treatment groups within four blocks and reweighed after an adaptation period. The rearing period consisted of three phases: A 3-day adaptation phase, a 28-day preliminary phase, and a 5-day collection phase. Weighing was conducted once a week to track daily weight gain. Weight measurements are carried out weekly during the preliminary phase. Feeding was conducted in the morning and evening. Rations were provided based on body weight, and both the amount fed and the leftover feed were weighed to determine feed intake. Forage (corn silage) was provided at 70%, and concentrate at 30%, in accordance with the sheep's nutritional needs and growth

during the study.

This study was conducted experimentally using a randomized block design (RBD) consisting of 3 treatments and 4 blocks: P0 = Mash feed (50% *Indigofera* legume + 50% corn bran + 5% molasses); P1 = Pellet feed (50% *Indigofera* legume + 50% corn bran + 5% molasses); P2 = Wafer feed (50% *Indigofera* legume + 50% corn bran + 5% molasses). This refers to [Rosani et al., \(2025\)](#) on the use of pellets made from *Indigofera* legumes 50% + 50% gamal with the addition of cassava flour.

Fecal collection was performed using the total collection method. Feces excreted over a 24-h period during the final five days of the rearing period were collected and weighed to determine nutrient losses. Daily fecal samples were taken at 10% of the total fresh weight and then dried in the sun. The dried fecal samples were combined over the 5-day collection period, ground, and prepared for nutritional analysis. The feed digestibility rate was calculated using the formula described by [Cheeke \(2005\)](#):

$$\% \text{ Digestibility} = \frac{\text{Rations consumed} - \text{Excreted feces}}{\text{The amount of diet given}} \times 100\%$$

Digestibility and performance in vivo measurements

Production performance was evaluated based on feed intake, body weight gain (BWG), and feed conversion ratio (FCR), as well as the digestibility rates of crude protein (CP), crude fat (CF), crude fiber (CF), ether extract (EE),

Table I. Composition and nutritional content (% DM) of mash, wafer and pallet feed.

Ingradiant	%	DM	Ash	OM	CP	CFiber	EE	NFE	TDN
Corn waste silage		7.04	9.20	90.80	5.89		1.65	50.51	60.54
Mash		87.26	3.96	96.04	24.01		5.09	58.21	72.70
Pellet		77.36	3.52	96.48	25.01		4.59	59.18	73.78
Wafer		67.67	3.43	96.57	25.04		4.56	58.93	73.77
Mash feed									
Corn waste silage	0.700	4.224	5.520	54.480	3.534	19.650	0.990	30.306	36.324
Mash	0.300	34.904	1.584	38.416	9.604	3.492	2.036	23.284	29.080
Total	1.000	39.13	7.10	92.90	13.14	23.14	3.03	53.590	65.40
Wafer feed									
Corn waste silage	0.700	4.928	6.440	63.50	4.123	22.925	1.155	35.357	42.378
Wafer	0.300	27.068	1.372	38.628	10.016	3.220	1.824	23.572	29.508
Total	1.000	32.00	7.81	102.19	14.14	26.15	2.98	58.929	71.89
Pellet feed									
Corn waste silage	0.700	4.224	5.520	54.480	3.534	19.650	0.990	30.306	36.324
Pellet	0.300	30.944	1.408	38.592	10.004	3.084	1.836	23.672	29.512
Total	1.000	35.17	6.93	93.07	13.54	22.73	2.83	53.978	65.84

DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extract; NFE, nitrogen free extract; TDN, total digestible nutrients.

and nitrogen-free extract (NFE). All measurements were expressed per sheep and averaged per replicate for statistical analysis.

Statistical analysis

Data were analyzed using one-way analysis of variance (ANOVA) in Statistical Package for the Social Sciences (SPSS) version 20.0 (IBM Corp., USA). When significant differences among treatments were detected, Duncan's Multiple Range Test was applied for mean separation. The level of statistical significance was set at $P < 0.05$, and all results were presented as mean $\pm$ standard deviation (SD).

RESULTS AND DISCUSSION

Nutritional content and physical characteristics

The nutritional content and physical characteristics of mash, pellets, and wafers made from *Indigofera* legumes and corn bran are presented in Table II. The nutrient content analysis showed that the lowest dry matter content ($P < 0.05$) was found in the wafer treatment and the highest in the mash treatment, with values of 67.67% and 87.26%, respectively. There was a decrease in dry matter content in the pellet and wafer treatments compared to the mash treatment. This decrease occurred because water is added to bind the ingredients during the compaction and heating processes involved in producing pellet and wafer feeds (Thomas and Van der Poel, 2020). The high content of dry matter in mash feed is due to the manufacturing process being only ground and having a loose structure without the process of adding steam, pressure and printing (Zhang *et al.*, 2019). The normal moisture content of pellet feed ranges from 12–16% (Farhan and Hussein, 2023). Furthermore, based on crude protein assessment, the highest value was found in the wafer treatment and the lowest in the mash treatment (25.03% vs. 23.93%). The wafering process did not negatively affect the crude protein content because protein values are influenced by gelatinization temperature and starch degradation (Yu *et al.*, 2020); this is evident in the higher crude protein content of the wafer compared to the mash and pellet feed forms. The low value of crude protein in mash feed is due to the separation of particles and fine particles are more easily lost during handling resulting in a decrease in crude protein (Abbas *et al.*, 2024). The crude protein content of the wafer in this study was higher than the results reported by Mucra *et al.* (2020) on corn bran wafers with the addition of sago pulp (11.92–13.92%).

Table II. Nutritional content of various physical forms of feed.

Parameters (% DM)	Treatment	Average
Dry matter	Mash	87,26 $\pm$ 0.81 ^a
	Pellet	77,36 $\pm$ 0.53 ^b
	Wafer	67,67 $\pm$ 0.44 ^c
Ash	Mash	3,95 $\pm$ 0.27 ^a
	Pellet	3,42 $\pm$ 0.37 ^b
	Wafer	3,45 $\pm$ 0.27 ^b
Crude protein	Mash	23,93 $\pm$ 0.62 ^b
	Pellet	24,98 $\pm$ 0.28 ^a
	Wafer	25,03 $\pm$ 0.34 ^a
Ether extract	Mash	5,04 $\pm$ 0.16
	Pellet	4,60 $\pm$ 0.13
	Wafer	4,29 $\pm$ 0.84
Crude fiber	Mash	8,78 $\pm$ 0.83 ^a
	Pellet	7,72 $\pm$ 0.37 ^b
	Wafer	8,09 $\pm$ 0.62 ^{ab}
Nitrogen free extract	Mash	58,31 $\pm$ 1.58
	Pellet	59,28 $\pm$ 0.70
	Wafer	59,15 $\pm$ 1.57

The feed composition for each physical form of feed was 50% *Indigofera* legume + 50% corn bran + 5% molasses binder; different Superkrip values in the same column and row indicate a significant difference ($P < 0.05$).

The crude fat values obtained in this study were not significantly different ($P > 0.05$) among the physical treatments, with average values ranging from 4.29% to 5.04%. There is no difference in the value of crude fat in mash, pellet and wafer feed because the difference in feed processing only changes the physical shape but not crude fat supported by the ration formulation used is relatively the same (Rigby *et al.*, 2018). The highest crude fiber content was found in the mash treatment at 8.78%, and the lowest in the pellet treatment at 7.72%. The high crude fiber content in the mash form indicated that the drying, grinding, and crushing processes only affected the fiber structure but did not alter the chemical properties of the fibrous material. The low coarse fibers in pellet feed due to the pelletizing process change the fiber particles to be finer and more homogeneous due to pressure and mold (Čolović *et al.*, 2010). The crude fiber content of the wafer in this study was lower than the results of Sari *et al.* (2015), who reported values of 17.99–21.06% using Kumpai grass with carrageenan as a binder. Furthermore, the nitrogen-free extract (NFE) parameter did not show a significant difference ($P > 0.05$) due to the physical form

of the feed. These physical treatments had no significant effect because the NFE value is generally determined by the overall nutritional composition of the ingredients rather than their physical shape.

Rumen fermentation and in vitro digestibility

The results of the measurements of NH₃ and VFA production, as well as *in vitro* digestibility, for the various physical forms of feed are presented in Table III. The highest rumen pH was observed in the pellet treatment and the lowest in the wafer treatment (6.91 vs. 6.80). Pelleted feed (granules) is a solid feed form that takes a longer time to break down in the rumen, resulting in a lower digestion rate and consequently slowing down the activity of the rumen microflora (Soltani *et al.*, 2020). This contrasts with mash feed, which has finer particle sizes and is therefore more easily and quickly digested by rumen microbes. Likewise, the form of wafers that has the same rumen pH as mash is suspected because wafer feed, although it is dense, has a fine particulate size, so it affects the speed of rumen digestion. The average rumen pH values obtained were consistent with the findings of Definiati *et al.* (2022), who reported rumen pH values of 6.74–6.91 in vegetable waste wafers.

The physical form of the feed had a significant effect ($P < 0.05$) on NH₃ and total VFA production. The highest NH₃ production was observed in the wafer treatment at 12.40 mM, and the lowest in the mash treatment at 7.69 mM. The physical form of wafer feed that undergoes compaction of the physical structure affects the penetration of microorganisms and the speed of rumen fermentation (Kazemi-Bonchenari *et al.*, 2017), this results in an increase in microbial production. Dewhurst and Newbold (2022) conveyed normal NH₃ production for rumen microbial growth ranging from 5–20 mM. NH₃ production represents the nitrogen form resulting from protein decomposition during rumen digestion. The wafer feed form affects microbial penetration and the rumen fermentation rate due to its compacted structure (Kazemi-Bonchenari *et al.*, 2017), resulting in increased microbial production. The highest total VFA value was found in the mash treatment at 135.42 mM, and the lowest in the pellet treatment at 91.56 mM. The high total VFA value in the mash treatment was due to its finer particle size; this condition facilitates the rumen absorption and digestion processes (Storm and Kristensen, 2010). The total VFA content in this study was higher than the 105.62–112.66 mM reported by Sandi *et al.* (2015) but lower compared to the 176.78 mM reported by Paga *et al.* (2021) for legume wafers.

Table III. NH₃ production and total VFA and *in vitro* digestibility of various physical forms of feed.

Parameters (% DM)	Treatment	Average
Rumen pH	Mash	6,84 ± 0.02 ^b
	Pellet	6,91 ± 0.05 ^a
	Wafer	6,80 ± 0.04 ^b
NH ₃ production (mM)	Mash	7,69 ± 1.12 ^c
	Pellet	11,13 ± 0.45 ^b
	Wafer	12,40 ± 0.79 ^a
VFA total (mM)	Mash	135,42 ± 18.76 ^a
	Pellet	91,56 ± 9.96 ^c
	Wafer	115,87 ± 16.12 ^b
IVDMD (%)	Mash	78.91 ± 0.99 ^a
	Pellet	72,93 ± 1.28 ^c
	Wafer	76,79 ± 0.68 ^b
IVOMD (%)	Mash	78,09 ± 0.96 ^a
	Pellet	71,51 ± 1.38 ^c
	Wafer	75,61 ± 0.73 ^b
IVCPD (%)	Mash	83,46 ± 9.85
	Pellet	82,39 ± 0.80
	Wafer	84,68 ± 0.65
Moisture content (%)	Mash	9,91 ± 1.21 ^a
	Pellet	9,15 ± 0.69 ^b
	Wafer	8,00 ± 0.19 ^c

VFA, volatile fatty acids; IVDMD: *in vitro* dry matter digestibility; IVOMD: *In vitro* organic matter digestibility; IVCPD: *In vitro* crude protein digestibility. The feed composition for each physical form of feed was 50% Indigofera legume + 50% corn bran + 5% molasses binder; different Superkrip values in the same column and row indicate a significant difference ($P < 0.05$).

Regarding digestibility, the highest IVDMD value was found in the mash treatment and the lowest in the pellet treatment (78.91% vs. 72.93%). Mash feed has a smaller and finer surface area, thereby accelerating digestion and nutrient absorption within the rumen, unlike pellet feed, which requires a longer time for microbial breakdown (Lyu *et al.*, 2022). Similarly, the highest IVOMD value was found in the mash treatment at 78.09%, and the lowest in the pellet treatment at 71.51%. The *in vitro* crude fiber digestibility (IVCFD) values showed no significant difference ($P > 0.05$) due to the physical treatment, with average values of 82.39–84.68%. The relatively similar IVCFD values are likely due to the mechanical processing during chewing, which reduces the pellet feed into a mash-like consistency before it reaches the rumen.

Table IV. *In vivo* nutrient digestibility, feed consumption, weight gain and feed conversion of local sheep.

Parameters	Treatment		
	Mash	Pellets	Wafers
<i>In vivo</i> nutrient digestibility			
Dry matter digestibility (%)	90,09±1,29	90,10±1,27	90,12±1,29
Crude protein digestibility (%)	91,79±2,11	92,85±1,64	92,47±1,82
Crude fat digestibility (%)	89,02±5,80	88,99±5,89	88,94±5,95
Crude fiber digestibility (%)	89,27±2,10	89,31±2,98	89,21±2,61
Digestibility of NFE (%)	91,61±0,63	91,54±0,88	91,68±0,82
Feed intake (g/head/day)	495.65±165.90	487.86±164.43	486.41±160.75
Body weight gain (g/head/day)	71.53±29.87 ^a	101.74±24.57 ^b	69.79±27.58 ^a
Feed conversion	8.18±4.98 ^a	4.73±0.51 ^b	8.64±5.80 ^b

The feed composition for each physical form of feed was 50% *Indigofera* legume + 50% corn bran + 5% molasses binder; Different superscript letters in the same row indicate significant difference ($p < 0.05$)

In vivo nutrient digestibility

The *in vivo* nutrient absorption of local sheep fed *Indigofera* legume-based diets in the form of mash, pellets, and wafers is presented in Table IV. The physical form of the feed had no significant effect on dry matter digestibility ($P > 0.05$), which ranged from 90.09% to 90.12%. This uniformity is presumably because the diets administered across all treatments contained an identical dry matter allocation, set at 3.5% of the sheep's body weight. The comparable dry matter intake levels across treatments indicate that feed palatability was also consistent. As noted by Mackie *et al.* (2002), dry matter digestibility in ruminants reflects a high proportion of nutrients that can be successfully degraded by rumen microbes and digestive enzymes.

Furthermore, all treatment diets contained a comparable crude protein content of approximately 13%, which resulted in equivalent crude protein digestibility values. This consistency is also attributed to the uniform age of the sheep, which standardized both protein intake and digestion (Luo *et al.*, 2022). Numerically, there was a slight increase in crude protein digestibility for the pelleted feed. This observation aligns with Preston and Leng (1987), who reported that the pelleting process reduces feed volume, thereby improving palatability and increasing feed intake.

There were no significant differences in crude fiber digestibility among the treatments, indicating that the physical form of the feed did not affect fiber degradation in the sheep (Sahoo and Karim, 2016). Similarly, crude fat digestibility did not differ significantly; this is likely because the diets contained comparable fat composition (3%–4%), leading to consistent absorption rates. This supports the assertion by Sandri (2009) that feed

digestibility relies primarily on the intrinsic nutritional quality of the diet, which dictates microbial growth, rather than just its physical form (Wardah *et al.*, 2023). Finally, the physical form of the feed had no significant effect on nitrogen-free extract (NFE) digestibility ($P > 0.05$), likely due to the nearly identical NFE content across the experimental diets. According to Budiman *et al.* (2006), an increase in protein content facilitates better nutrient utilization and absorption, which subsequently enhances NFE digestibility.

Production performance

Table IV presents the feed intake, body weight gain, and feed conversion ratio (FCR) of local sheep fed *Indigofera* legume-based diets in various physical forms. Feed intake across all treatments was not significantly different ($P > 0.05$). This uniformity is likely due to the consistent intake of basal forage and concentrate across all groups. As noted by Rahman (2008), feed intake is influenced by animal characteristics, feed palatability, nutritional requirements, and environmental factors. Furthermore, Kronqvist *et al.* (2021) demonstrated that the physical particle size of the feed does not significantly affect total feed intake in ruminants. The total feed intake during the study ranged from 486.41 to 495.89 g/head/day, indicating a consistent capacity of the sheep to consume the provided diets regardless of their physical form.

Although feed intake was comparable, the pellet treatment resulted in superior body weight gain compared to the mash and wafer treatments. This improved growth performance is attributed to the higher feed efficiency and nutrient utilization of the pelleted diet, rather than an increase in dry matter intake. This aligns with the findings of Nguyen *et al.* (2023), who reported that integrating high-

protein forage into the diet of small ruminants enhances overall nutrient utilization and growth.

Consequently, the physical form of the *Indigofera* diets had a significant effect on the feed conversion ratio ($P < 0.05$). The lower FCR observed in the pellet group indicates that less feed was required to produce one kilogram of meat, reflecting a higher efficiency in converting feed into body mass. As Song *et al.* (2021) suggested, pelleted feed is highly effective at improving post-ingestion digestibility and minimizing feed sorting behavior, making it an optimal choice for sheep fattening programs.

CONCLUSION

Feeding a complete diet based on *Indigofera* legumes in the form of mash, pellets, and wafers yielded different responses in terms of *in vitro* digestibility, but resulted in relatively similar *in vivo* nutrient digestibility values. Despite the similar digestibility rates, the physical modification of the feed significantly improved production performance. Specifically, *Indigofera* legume-based pellet feed is considered the best physical form because it produced superior body weight gain and the most efficient feed conversion ratio, making it highly recommended as a feed strategy for small ruminants.

DECLARATIONS

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Ethics approval

The study followed research ethics guidelines pertaining to livestock, in accordance with the Animal Science and Health regulations outlined in Government Law No. 41/2014 issued by Ministry of Agriculture, the Republic of Indonesia.

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Statement of conflict of interest

The authors have declared no conflict of interest.

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