Research Article

The Effect of High-Protein Supplement Pellet Supplementation on the Growth of Post-Weaning Ettawa Crossbred Kids in Majene Regency, Indonesia

Besse Mahbuba We Tenri Gading[1]*, Andi Sukma Indah[1], Setiawan Putra Syah[1], Aan Andri Yano[2]

[1]Faculty of Animal Husbandry and Fishery, Sulawesi Barat University, Majene 91412, Indonesia; [2]Vocational School, Universitas Sebelas Maret, Surakarta 57126, Indonesia.

Abstract | This study aimed to evaluate the impact of high-protein supplement pellets (HPSP), formulated from a combination of fish waste and moringa leaf (*Moringa oleifera*) meal, on the growth performance and nutritional status of Ettawa crossbred kids in Majene Regency. The research was conducted in two phases. Phase I established a baseline by observing 24 post-weaning kids (12 males, 12 females) under traditional management fed only *Leucaena leucocephala*. Phase II employed a 2 x 2 factorial arrangement (diet × sex) where 24 kids were assigned to a control (20% forage + 80% commercial concentrate) and a treatment diet, where 16% of the commercial concentrate was substituted with HPSP (20% forage + 64% commercial concentrate + 16% HPSP). Results from Phase I indicated suboptimal growth with no sexual dimorphism, likely due to protein-energy imbalance and anti-nutritional factors in *Leucaena*. In Phase II, HPSP supplementation significantly improved average daily gain (ADG) (162.21 vs 142.56 g/d; $P < 0.01$) and feed conversion ratio (FCR) (4.53 vs 5.14; $P < 0.05$). A significant diet × sex interaction was observed for ADG ($P < 0.01$), with males showing a more pronounced response to high-quality nutrition. Furthermore, HPSP significantly enhanced hip height gain ($P < 0.05$), indicating superior skeletal development. In conclusion, the synergistic use of fish waste and moringa leaves in HPSP effectively optimizes the early-stage growth of Ettawa crossbred kids, providing a sustainable, locally sourced solution for livestock development in coastal regions.

Keywords | Ettawa crossbred, Fish waste, Growth performance, *Moringa oleifera*, post-weaning kids, Supplement

Received | May 15, 2026; **Accepted** | September 22, 2026; **Published** | November 14, 2026

***Correspondence** | Besse Mahbuba We Tenri Gading, Faculty of Animal Husbandry and Fishery, Sulawesi Barat University, Majene 91412, Indonesia; **Email:** bessemahbuba@unsulbar.ac.id

Citation | Gading BMWT, Indah AS, Syah SP, Yano AA (2027). The effect of high-protein supplement pellet supplementation on the growth of post-weaning Ettawa crossbred kids in Majene regency, Indonesia. J. Anim. Health Prod. 15(1): 76-84.
DOI | https://dx.doi.org/10.17582/journal.jahp/2027/15.1.76.84
ISSN (Online) | 2308-2801

Copyright: 2027 by the authors. Licensee ResearchersLinks Ltd, England, UK.
This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

INTRODUCTION

In Indonesia, Majene Regency serves as a strategic hub for such livestock development, ranking as the second-largest goat producer in West Sulawesi with 77,194 heads as of 2023 (Rivai *et al*., 2025). This region contributes 29.17% of the provincial goat population (Indonesia Central Bureau of Statistics, 2022), highlighting its significant potential for optimizing goat-derived products, particularly milk. Ettawa crossbreed is a high-milk producing goat that is commonly raised in this region. Arief and Pazla (2023) reported Ettawa crossbreed can produce milk up to 1.16 kg/day, while Arief *et al*. (2018) reported higher amount reaching 1.83 kg/day. No single study reported milk production of Ettawa crossbreed in Majene Regency, however, Ibrahim (2023) reported that average daily gain (ADG) of Ettawa crossbreed in the region only reaches 105.75 g/day, indicating suboptimal nutritional

management. In other regions, however, Hasanah *et al.* (2025) reported higher ADG up to 130 g/day.

This low growth rate highlights a critical gap in the early development phase, as the long-term productivity of adult goats is fundamentally determined by their performance as kids. Supporting this, Wolber *et al.* (2021) revealed that breed had no significant effect on milk yield; instead, production is predominantly determined by physiological milestones such as age at first kidding, lifetime prolificacy (average number of kids born), and the duration of lactation. These findings underscore the importance of the pre-weaning phase, as rapid growth in kids ensures they reach the required body conditions for earlier reproductive maturity. Consequently, optimizing the performance of kids through superior nutrition is essential, as the timing of their first kidding, a key driver of lifetime milk output, is a direct result of their developmental success during early life.

Data from past four years confirms that Majene Regency possesses significant marine potential, with capture fisheries production reaching 8,920.6 ton in 2022 and 9,435.9 tons in 2023, before climbing further to 9,715.1 tons by 2024 (Majene Regency Central Bureau of Statistics, 2025). This high level of productivity, however, generates a substantial volume of byproducts, as fish processing typically yields approximately 25-70% waste, primarily comprising heads, bones, fins, and scales (FAO, 2018). Nutritionally, fish waste is a dense protein source; for instance, protein content can reach 22.1-23.9% in scales, 17.4-19.00% in fins, and 25.9-27.3% in bones (Maktoof *et al.*, 2020). Fish waste provides crucial enzymes including proteases, lipases, and carbohydrase, and essential amino acids specifically lysine (6-8 g/100 g), methionine (2.5-3.5 g/100 g), and threonine (4-5 g/100 g) that improve poultry diet efficiency (Chen *et al.*, 2024). Consistently, Caruso *et al.* (2020) reported that protein levels can reach up to 57.92% of total fish waste. Given its abundance and nutrient profile, this fish waste is believed to be highly beneficial for optimizing the performance of Ettawa crossbred kids, offering a sustainable and locally-sourced solution for livestock feed in the region (Sutisna, 2024).

The utilization of fish waste as a functional feed ingredient has demonstrated significant benefits across various livestock and aquatic species. In poultry production, the inclusion of 20% fish waste meal enhances DM intake and weight gain in broiler chickens (Asrat *et al.*, 2023), while lower inclusion level of 5% to 15% have been shown to increase hen-day egg production and mass in White Leghorn layers (Alemayehu *et al.*, 2015). Furthermore, adding 5% waste sardine fish oil significantly improves chemical quality and nutritional profile of eggs (Fadlilah *et al.*, 2023). Beyond poultry, formulated diets containing up to 50% protein from fish waste achieve growth and survival rates in Nile tilapia fry (*Oreochromis niloticus*) comparable to commercial pellets (Anizah *et al.*, 2021). Similarly, in ruminants, sheep diet supplemented with 25% to 50% of fermented fish silage significantly outperform conventional feed, resulting in superior weight gain and enhanced carcass characteristics (Rahmi *et al.*, 2012).

Complementing marine by-products, *Moringa oleifera* offers a potent botanical alternative. Widely cultivated in Sulawesi as a signature medicinal crop (Sifatu *et al.*, 2022; Syamsiah, 2014), its prevalence suggests substantial biomass availability despite a lack of formal production data. González-Burgos *et al.* (2021) reported that *M. oleifera* exhibits a rich nutritional composition, featuring 28.50% carbohydrates, 25.02% proteins, 10.42% fat, 11.83% dietary fiber, and 1.108 mg/100 g β-caroten. In poultry, its inclusion improves growth performance via enhanced gut health (Gul *et al.*, 2024) and boosts immune response (Khan *et al.*, 2021), with 5-10% levels maintaining stable egg production (Olugbemi *et al.*, 2010). Swine studies show that inclusion levels from 5% to 40% do not adversely affect feed conversion or growth (Mukumbo *et al.*, 2014). In ruminants, *M. oleifera* enhances digestibility and nutrient retention without compromising weight gain (Aye and Adegun, 2013). Furthermore, its application in lactating cows improves milk fat and alters methanogen composition (Dong *et al.*, 2019), with in vitro results suggesting a 50% reduction in methane emissions when replacing soybean meal (Elghandour *et al.*, 2017).

Combining fish waste and *M. oleifera* into high-protein supplement pellets (HPSP) presents a strategic synergistic approach to pre-weaning ruminant nutrition. Formulating marine-derived animal protein, which is rich in essential amino acids like lysine and methionine, with *M. oleifera*'s dense plant protein, rich bioactive compounds, and natural antioxidants creates a highly complementary nutrient matrix. Biologically, the phytochemicals in *M. oleifera* are hypothesized to optimize gut health and systemic antioxidant status, thereby enhancing the digestion and metabolic efficiency of the dense protein supplied by fish waste. In Majene, the reported suboptimal ADG underscores an urgent need for targeted nutritional interventions. This study addresses this gap by evaluating the combined supplementation of these locally abundant resources within the HPSP framework optimizes early-stage development, a critical determinant of lifetime productivity.

MATERIALS AND METHODS

This research was conducted in two distinct phases.

Phase 1: Identification of Production Performance and Nutritional Status of Ettawa Crossbred Kids in Traditional Farming System

Study site and period

The first phase was conducted from July to October 2025 in Pamboang subdistrict, Majene Regency (3°27′59″S 118°54′37″E). The area is situated at an altitude of approximately 100-500 meters above sea level (MASL), with an ambient temperature range of 26°C-30°C and relative humidity (RH) of 70%-85%.

Animals and management

Twenty-four post-weaning Ettawa crossbred kids (12 males, 12 females, aged 3±0.52 months) were observed under a traditional intensive management system. Animals were housed in individual pens measuring 1.5 m in length, 1.0 m in width, and 1.7 m in height. The kids were fed 2 kg/head/day of fresh *Leucaena leucocephala* as the sole forage. This species was selected because it represents the most abundant and widely distributed local forage naturally grown and utilized by traditional farmers in Pamboang sub-district. The nutrient composition of *L. leucocephala* is shown in Table 1. No experimental treatments were applied for 8 weeks to establish baseline performance data under existing conditions.

Table 1: Chemical composition of fresh *L. leucocephala.*

Feed	DM	Ash	Crude protein	Crude fat	Crude fiber	NFE
	(%)	(%)	(%)	(%)	(%)	(%)
L. leucocephala	25.85	8.1	20.81	5.42	17.31	50.71

NFE= Nitrogen-Free Extract. Based on the analyses of animal feed laboratory, Hasanuddin University.

Data collection and analysis

Body weight (BW) was recorded at the start and end of period using a 150 kg capacity digital scale (Omron Digital Weight Scale HN289, Krell Precision (YANGZHOU Co., Ltd., China) to calculate average daily gain (ADG). Feed intake (FI) was monitored daily by weighing offered feed and refusals using a 30 kg capacity scale (BENZ WERKZ Digital Scale BZ-6040, Benz Werkz, China). Feed conversion ratio (FCR) was calculated as the ratio of DM intake to weight gain. Morphometric measurements included body length and chest girth. Nutrient profiles were analysed descriptively. Performance differences between sexes were analyzed using an independent sample t-Test via SPSS software.

Phase 2: Production Performance with High-Protein Supplement Pellets

Study site and period

The second phase was carried out from August to October 2025 in Leppe, Majene Regency (-3.5525°N, 118.9818°E). This site is located at an altitude approximately 20 MASL, with recorded temperatures of 25°C-31°C and RH of 75%-88%.

Experimental design

The study employed a 2x2 factorial arrangement based on a completely randomized design (CRD). Twenty-four post-weaning Ettawa crossbred kids (average weight 11±0.5 kg) were assigned equally to four groups (n = 6 per group). The experimental factors included sex (male vs. female) and dietary treatments consisting of control (T0: forage + commercial concentrate) and treatment (T1: forage + commercial concentrate + high-protein supplement pellet, HPSP). Fresh *Sesbania grandiflora* was utilized as the sole forage for all diets both control and treatment due to its local abundance in Leppe, Majene. The formulation for each diet is detailed in Table 2.

Table 2: The feed ingredients and chemical composition of dietary treatments.

Ingredients (% DM)	Control (T0)	Treatment (T1)
Sesbania grandiflora	20.00	20.00
Commercial concentrate pellet	80.00	64.00
HPSP	0.00	16.00
Total	100	100
Chemical composition		
Dry matter	89.91	90.60
Ash	8.94	10.42
Crude protein	14.59	18.38
Crude fat	7.00	7.54
Crude fiber	5.79	5.34
NFE	63.67	58.31

Note: Based on the analyses of animal feed laboratory, Hasanuddin University. HPSP= High-Protein Supplement Pellet.

Management and procedures

Animals were housed in individual pens measuring 1.25 m in length, 0.8 m in width, and 1.7 m in height and fed twice daily (09.30 and 14.30) at a level of 5% BW on a DM basis. The forage-to-concentrate ratio was maintained at 20:80. The high protein supplement which constituted 16% of the total diet, was composed of a mixture of fish waste meal and *M. oleifera* leaf meal. A 50:50 ratio for this mixture was utilized in accordance with the findings of Gading and Agustina (2025) (Table 3), who identified this proportion as the optimal formulation for performance. Water was provided *ad libitum* throughout the 8-week trial.

Data collection and analysis

Feed samples (forage, concentrate, and pellets) were analyzed according to AOAC (2005) standards. The

performance metrics were similar to Phase I, data included ADG, FI, FCR, morphometric measurements, and feed cost per gain (FCG). Dry matter digestibility (DMD) and organic matter digestibility (OMD) were determined using the two-stage in vitro technique described by Tilley and Terry (1963). Ruminal fermentability parameters were evaluated from rumen fluid samples: pH was measured immediately using a digital pH meter, ammonia-nitrogen concentration was analyzed via the Conway micro-diffusion modified method (Lin and Randolph, 1978), and total volatile fatty acid (VFA) concentration was quantified using modified steam distillation (Packett and McCune, 1965).

Table 3: Feed formulation and nutrient composition of high-protein supplement pellet (HPSP).

Ingredient (% DM)	Level (%)
40	
Moringa leaf meal	40
Mineral mixture	10
Molasses	2
Tapioca starch	3
Rice bran	10
Total	100
Chemical composition	
Dry matter	93.68
Ash	18.64
Crude protein	33.69
Crude fat	8.26
Crude fiber	3.07
NFE	36.34

Note: Based on the analyses of animal feed laboratory, Hasanuddin University.

Table 4: Growth performance and linear body measurement of kids in traditional farming system.

Parameter	Sex		P value
	Male	Female	
Feed intake (g/d)	461.280±1.07	451.980±1.01	ns
FCR	12.070±7.57	9.580±5.46	ns
ADG (g/d)	59.280±46.69	59.520±26.71	ns
Body length gain (mm/d)	0.068±0.02	0.066±0.04	ns
Heart girth gain (mm/d)	0.100±0.04	0.100±0.05	ns
Hip height gain (mm/d)	0.080±0.20	0.070±0.02	ns

ns: non-significant; values are presented as mean ± standard deviation (SD).

Data were analyzed using Analysis of Variance (ANOVA) for the factorial pattern. To account for potential initial variation among individual kids, Analysis of Covariance (ANCOVA) was applied for ADG and body measurements, using initial weight and initial measurements as covariates, respectively. Prior to ANCOVA, key statistical assumptions were verified. Normal distribution and homogeneity of variances were confirmed using Shapiro-Wilk and Levene's tests, respectively. The assumption of homogeneity of regression slopes was evaluated by testing the interaction between covariates and fixed factors (diest and sex); no significant interactions were detected (P>0.05), confirming that regression slopes were homogenous across treatment groups. All analysis were performed using SPSS.

RESULTS AND DISCUSSION

Phase I: Identification of production performance and nutritional status of Ettawa crossbred kids in traditional farming system

The first phase of this study aimed to establish a baseline for the production performance and nutritional status of Ettawa crossbred kids managed under traditional farming systems. This initial identification is crucial, as traditional management involves high variability in feed quality and rearing practices, which directly influences the early growth phase of the kids. The results of the production performance, categorized by sex, are presented in Table 4.

The identification of production performance (Table 4) revealed that sex did not exert a significant effect (P>0.05) on any of the measured growth parameters. Both male and female kids exhibited comparable performance, with an ADG of approximately 59 g/d. This value is lower than that reported by Dzarnisa *et al.* (2018), who observed significantly higher ADG (97.5 g/d) in kids fed a complete feed. This lack of sexual dimorphism is typical in the pre-pubertal stage, as the hormonal differences that drive distinct growth patterns between sexes have not yet fully manifested at this stage (Zhu *et al.*, 2023). Furthermore, the linear body measurements, including body length, heart girth, hip height, were also consistent across groups. To our knowledge, unfortunately, no previous studies have reported similar findings in the pre-weaning kids within this specific context. It is likely that the nutritional regime in the traditional farming system, played a more dominant role in limiting growth development, rather than the inherent growth potential of the kids.

The nutritional status of the kids in this study was primarily dictated by the use of *L. leucocephala* as a sole forage source. Based on the chemical composition analysis (Table 1), *L. leucocephala* possesses a high CP content of 20.81%. However, this high protein availability was not reflected in optimal growth efficiency, as evidenced by high FCR of 9.58 to 12.07. This inefficiency in feed utilization is likely due to a protein-energy imbalance within the rumen. Nugroho *et al.* (2023) emphasized that

a balanced supply of protein and energy is a fundamental requirement for optimizing the performance of growing ruminants. Efficient microbial protein synthesis requires a synchronized supply of nitrogen and readily available energy (fermentable carbohydrates) (Pazla *et al*., 2024). In the absence of energy-dense concentrates, the high protein intake from *L. leucocephala* could not be fully captured by rumen microorganisms due to insufficient fermentable energy. Consequently, a significant portion of the ingested protein was likely deaminated and lost as urea or diverted for maintenance energy needs rather than supporting tissue and skeletal deposition.

In addition, both male and female kids exhibited similar FCR ($P > 0.05$). This suggests that feed efficiency was comparable between sexes under a sole *L. leucocephala* diet. The absence of a significant sex effect on FCR may be attributed to the age stage of the kids. During the early post-weaning phase, animals are pre-pubertal, meaning that sex-specific hormonal influences such as testosterone-driven muscle accretion in males have not yet fully manifested (Elhammali *et al*., 2013). Additionally, the digestive tract and rumen microbiome of post-weaning kids are still adapting to a solid forage diet (Khan *et al*., 2016), which can lead to high individual variability and mask potential sex differences in feed efficiency.

The reliance on *L. leucocephala* as a single feed ingredient in traditional systems poses additional challenges for young kids. Beyond the nutrient imbalance, the presence of mimosine, an anti-nutritional factor (ANF) inherent in *L. leucocephala* (Ilham *et al*., 2015), may further restrict growth. In young ruminants where the rumen microbial population is still developing (Abdelsattar *et al*., 2023), the ability to detoxify mimosine and its derivatives is limited. This is because mimosine detoxification is a complex, synergistic process requiring a diverse range of specialized bacteria such as *Streptococcus lutetiensis, Clostridium butyricum, Lactobacillus vitulinus,* and *Butyrivibrio fibrisolvens* (Derakhshani *et al*., 2016), which may not yet be established in the immature rumen. Consequently, this condition can lead to subclinical metabolic stress, which suppresses appetite and contributes to the low ADG and slow linear growth observed in this phase (Loh *et al*., 2020).

Phase II: Identification of nutrient status and production performance with the addition of high-protein feed supplement pellets (HPSP)

Ruminal fermentation characteristics and nutrient digestibility

Following the initial evaluation of Phase 1, which focused on Leucaena plants as a sole fresh feed source, Phase II utilized a separate group of livestock to evaluate the physiological response to the formulated HPSP. The ruminal fermentation profile and nutrient digestibility parameters are presented as descriptive observations in Table 5. Ammonia (NH_3) concentrations were 4.42 mM in the treatment group (HPSP) compared to 3.84 mM in the control group. Although both values remained below the optimal range of 8-11 mM required to support microbial protein synthesis in ruminants (Adamu *et al*., 2024), the numerically higher level observed in the treatment group indicates a potential trend toward nitrogen availability for ruminal microbes. Consistent with this, total VFA levels were also below the standard physiological range of 70-150 mM (Gumilar *et al*., 2018), with values recorded at 23.16 mM in the treatment group with HPSP and 19.12 mM for the control group. These lower concentrations are likely attributable to the immature state of the rumen in young kids, resulting in suboptimal fermentation of carbohydrates and insufficient energy production to meet the animal's metabolic demands.

Table 5: Effects of high-protein supplement pellet (HPSP) on ruminal fermentation characteristics and nutrient digestibility.

Feed	Ammonia (mM)	Total VFA (mM)	pH	DMD (%)	OMD (%)
Treatment	4.42	23.16	6.30	73.01	75.69
Control	3.84	19.12	6.23	72.95	74.31

VFA = volatile fatty acid; DMD = dry matter digestibility; OMD = organic matter digestibility.

Despite the apparent increase in fermentation activity, the ruminal pH remained stable at 6.30, which is within the typical physiological range (6.2-6.8) for maintaining cellulolytic bacteria (Mao and Wang, 2025). This stable pH environment likely facilitated the degradation rates, with DMD and OMD reaching 73.01% and 75.69%, respectively, in the treatment group. These values exceed those reported by Umar *et al*. (2025) and Dwatmadji *et al*. (2025) for local goats fed different complete feed ingredients, suggesting that the synergy between fish waste and Moringa leaves provides accessible nutrients for ruminal enzymes. Consequently, these ruminal parameters may serve as favourable precursors for the feed efficiency and growth performance observed in the subsequent results.

Animal performance

The evaluation of growth performance in post-weaning Ettawa crossbred goats involves a complex integration of FI, nutrient utilization efficiency (FCR), and body weight gain (Table 6). In this study, FI in the treatment group did not differ significantly from the control group ($P > 0.05$), likely because both diets contained nearly identical dry matter content. In addition, the similar FI observed across all groups indicates comparable feed palatability between

Table 6: Effects of high-protein supplement pellet (HPSP) on kids' performance.

Variable	Feed		Sex		P-value		
	Treatment	Control	Male	Female	F	S	FxS
FI (g/d)	460.61±85.10	512.88±79.75	510.81±77.40	462.69±88.54	ns	ns	*
FCR	4.53±1.93	5.14±2.12	4.19±2.07	5.47±1.81	*	ns	*
ADG (g/d)	162.21±71.62	142.56±66.62	178.21±80.94	126.55±42.08	*	ns	**

Note: values are presented as mean ± standard deviation (SD); FI= Feed Intake; FCR= Feed Conversion Ratio; ADG= Average Daily Gain; F= Feed; S= Sex; FxS= interaction between feed and sex; * significant at P < 0.05; ** significant at P < 0.01; ns= non-significant.

Table 7: Effects of high-protein supplement pellet (HPSP) on kids' linear body measurement (mm/day).

Measurement (mm/day)	Sex	Treatment	Control	Sex mean	P-value		
					F	S	FxS
Body length	Male	0.22±0.07	0.17±0.02	0.19±0.06	ns	*	**
	Female	0.25±0.14	0.20±0.09	0.22±0.11			
	Feed mean	0.23±0.11	0.18±0.06				
Heart girth	Male	0.20±0.05	0.18±0.04	0.18±0.04	ns	**	*
	Female	0.22±0.15	0.16±0.05	0.18±0.11			
	Feed mean	0.20±0.10	0.16±0.04				
Hip height	Male	0.16±0.02	0.14±0.05	0.14±0.04	*	**	**
	Female	0.16±0.12	0.13±0.08	0.14±0.10			
	Feed mean	0.16±0.08	0.13±0.07				

Note: values are raw (unadjusted) means ± SD. P-values are from two-way ANCOVA with initial measurement as covariate. F= feed; S= sex; F×S = feed × sex interaction; *P < 0.05; **P < 0.01; ns= non-significant.

the treatment group with HPSP relative to the commercial concentrate. This is consistent with the findings of Christi *et al.* (2018), who stated that feed consumption is heavily influenced by palatability, driven by visual, olfactory, and gustatory stimuli. No significant differences were observed between sexes, however a significant interaction between feed and sex (P<0.05) was detected. This suggests that nutrient-dense diets can stimulate a higher appetite in males compared to females, supported by the presence of androgenic hormones that drive higher voluntary intake and superior productivity (Purbowati *et al.*, 2015).

In contrast to intake, the ADG was significantly higher in the treatment group with HPSP compared to the control group (P<0.01). This improvement likely stems from the superior nutrient profile of the HPSP, especially high protein content. Similar trends were reported by Wang *et al.* (2024) and Saro *et al.* (2020), who observed significant ADG improvement in ruminants fed with high-protein diets. Such nutrient surplus is effectively utilized for tissue deposition and growth (Mahgoub *et al.*, 2025). Although sex alone did not significantly affect ADG, a highly significant interaction between feed and sex (P<0.01) was observed. This interaction indicates that when high-quality nutrients are provided, the growth response is more pronounced in males than in females, likely because these young goats are in a peak growth phase where they are highly efficient at converting feed into muscle (Nugraheni *et al.*, 2022). This response is further modulated by the fact that post-weaning goats have not yet reached sexual maturity, the intrinsic growth advantage of males (Ehsaninia and Bagheripour, 2026) may be amplified by improved protein nutrition (Saab *et al.*, 1997), which could explain the significant feed × sex interaction. These improvements in growth were also reflected in FCR where the treatment group showed a significantly lower and more efficient value compared to the control (P<0.05). This indicates that the inclusion of HPSP allowed the animals to achieve higher weight gains with less feed consumption. These values are notably more efficient than those reported by Nuraini *et al.*, (2014), who found FCR values ranging from 9.83-12.50 in local Ettawa crossbred. Furthermore, a significant interaction (P<0.05) between feed and sex for FCR suggests that the efficiency of nutrient utilization is not only a product of diet quality but also the physiological drive of the animal. The synergy between optimized nutrient availability and the metabolic rate of male goats resulted in the most favourable FCR (Sayuti *et al.*, 2024). Ultimately, providing adequate nutrients tailored to the animal's growth phase and sex is essential for maximizing livestock productivity (Mahgoub *et al.*, 2025).

Linear body measurement

The supplementation of HPSP derived from fish waste and moringa leaves resulted in relatively similar body length and heart girth measurements in post-weaning Ettawa crossbred kids (Table 7). This suggests that during this specific growth phase, certain linear dimensions remain

stable despite the high protein density of the supplement. Variations in the animals' ability to deposit muscle and other tissues are likely influenced by management practices, digestive system conditions, and overall health status (Gunawan *et al*., 2016). However, the treatment group achieved a significantly higher hip height than the control ($P<0.05$). This reflects the efficacy of HPSP in supporting primary skeletal expansion, as bones grow continuously at a rapid rate during early development while muscle growth has not yet reached its maximum potential (Lui and Baron, 2011).

While skeletal growth is fundamentally driven by mineralization (Mahgoub *et al*., 2025), this study is limited by the absence of specific analysis regarding Calcium (Ca) and Phosphorus (P) content in the formulated feed. The lack of these data points precludes a definitive mechanical explanation of the bone deposition process within discussion. We hypothesize that the superior hip height gain observed in the HPSP group may be associated with an improved nutrient and mineral availability provided by fish waste and Moringa combination. Furthermore, the significant interaction between feed and sex across all linear body measurements (body length, heart girth, and hip height; $P<0.05$) underscores a sexual dimorphism influenced by the onset of reproductive hormones. The distinct growth response of males and females to HPSP indicate that this nutritional intervention acts specifically on the physiological status of each sex, necessitating specialized feeding management to fully optimize the genetic potential of Ettawa crossbred goats.

CONCLUSION AND RECOMMENDATIONS

The supplementation of high-protein supplement pellets (HPSP) formulated from fish waste and *Moringa oleifera* leaf meal effectively enhances the growth and feed efficiency of post-weaning Ettawa crossbred kids. Compared to traditional feeding systems, HPSP significantly increases average daily gain (ADG) and improves the feed conversion ratio (FCR), while also supporting superior skeletal development through increased hip height gains. Furthermore, a significant interaction between diet and sex indicates that male kids exhibit a more pronounced growth response to this nutrient-dense supplement. These findings suggest that utilizing locally available marine and botanical by-products is a sustainable strategy to overcome nutritional gaps and optimize the early-stage development of livestock in coastal regions like Majene.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the Ministry of Higher Education, Science, and Technology of the Republic of Indonesia for providing the financial support for this research under the Research Grant Number 110/C3/DT.05.00/PL/2025. This support has been instrumental in the completion of this study.

NOVELTY STATEMENT

The novelty of our study lies in its strong evidence that the formulation of high-protein supplement pellets (HPSP) combining fish waste and *Moringa oleifera* leaf meal effectively optimizes the growth performance and feed efficiency of post-weaning Ettawa crossbred kids. To the best of our knowledge, this study is among the first to demonstrate that supplementation with a locally sourced HPSP combining fish waste and *Moringa oleifera* leaf meal significantly enhances average daily gain, improves the feed conversion ratio, and supports superior skeletal development through accelerated hip height gains. This study advances sustainable livestock management in coastal regions, particularly in Majene Regency, by providing a practical framework to overcome early-stage nutritional gaps and maximize the lifetime productivity of Ettawa crossbred goats using abundant marine and botanical by-products

AUTHOR'S CONTRIBUTION

BMWTG, ASI, SPS, and AAY contributed to the study conception and design. Material preparation, data collection, and field experimentation were performed by BMWTG, ASI, and SPS. Data analysis, interpretation, and statistical evaluation were conducted by AAY and BMWTG. The first draft of the manuscript was written by BMWTG and AAY. All authors commented on previous versions of the manuscript, read, and approved the final manuscript.

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.

Conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Abdelsattar, Mahmoud M, Zhao W, Saleem AM, Kholif AE, Vargas E, Zhang N (2023). Physical, metabolic, and microbial rumen development in goat kids: A review on the challenges and strategies of early weaning. Animals, 13: 2420. https://doi.org/10.3390/ani13152420

Adamu B, Furo A, Dapellum AU, Surayya A, Muhammed UA (2024). Hematological and biochemical indices, rumen ph,

ammonia concentration in rumen liquor and urine ph of white fulani (Bunaji) bull yearling calves fed graded levels of urea and molasses ensiled rice straw supplemented with maize offal and cowpea husk. Int. J. Sci. Res. Arch., 11(02): 1874–1884. https://doi.org/10.30574/ijsra.2024.11.2.0597

Alemayehu Y, Urge M, Getu A (2015). Effects of levels of inclusion of locally processed fish waste meal in the diets of white leghorn layers on egg production and quality. Iran. J. Appl. Anim. Sci., 5(3): 689–698.

Anizah MR, Manaf SR, Hilaliyah MJN (2021). Utilization of fish waste as fish meal substitute in formulated fish diet on the growth performance of nile tilapia fish fry (*Oreochromis niloticus*). Food Res., 5(Suppl. 4): 21–29. https://doi.org/10.26656/fr.2017.5(S4).001

AOAC. (2005). Official methods of analysis of AOAC international (18th ed.). AOAC International. Gaithersburg, MD, USA.

Arief E, Somen S, Roza E, Pazla R, Rizqan (2018). Production and quality of etawa raw milk using palm oil industry waste and paitan plants as an early feed. Pak. J. Nutr., 17: 399–404. https://doi.org/10.3923/pjn.2018.399.404

Arief, Pazla R (2023). Milk production and quality of etawa crossbred goats with non-conventional forages and palm concentrates. Am. J. Anim. Vet. Sci., 18(1): 9–18. https://doi.org/10.3844/ajavsp.2023.9.18

Asrat M, Anja A, Kassu Y (2023). The effect of inclusion of fish waste meal on the growth performance and carcass characteristics of broiler chicken. J. Sci. Inclusive Dev., 5(2): 25–42.

Aye PA, Adegun MK (2013). Chemical composition and some functional properties of moringa, leucaena and gliricidia leaf meals. Agric. Biol. J. N. Am., 4(1): 71–77. https://doi.org/10.5251/abjna.2013.4.1.71.77

Caruso G, Floris R, Serangeli C, Paola LD (2020). Fishery wastes as a yet undiscovered treasure from the sea: Biomolecules sources, extraction methods and valorization. Mar. Drugs., 18(622): 1–30. https://doi.org/10.3390/md18120622

Chen S, Maulu S, Wang J, Xie X, Liang X, Wang H, Wang J, Xue M (2024). The application of protease in aquaculture : Prospects for enhancing the aquafeed industry. Anim. Nutr., 16: 105–121. https://doi.org/10.1080/10407782.2023.2215958

Christi RF, Rochana A, Hernaman I (2018). Physical quality and palatability of fermented concentrates diets of Ettawa cross goats. J. Ilmu Ternak., 18(2): 121–25.

Derakhshani H, Corley SW, Jassim RA (2016). Isolation and characterization of mimosine, 3, 4 DHP and 2, 3 DHP degrading bacteria from a commercial rumen inoculum. J. Basic Microbiol., 56: 580–585. https://doi.org/10.1002/jobm.201500590

Dong L, Zhang T, Diao Q (2019). Effect of dietary supplementation of *Moringa oleifera* on the production performance and fecal methanogenic community of lactating dairy cows. Animals, 9: 262. https://doi.org/10.3390/ani9050262

Dwatmadji T, Suteky, Soetrisno E, Yanti N, Sitinjak EH (2025). Dry matter, organic matter, crude protein, and crude fibre digestibility of local goats supplemented with herbs and humic acid. BIO Web Conf., 159: 02006. https://doi.org/10.1051/bioconf/202515902006

Dzarnisa, Rachmadi D, Azhar A, Riza RF, Hidayati A (2018). Milk production, physiological condition and performance of Etawa crossbreed goats feed by ration supplemented with mangosteen peel flour. IOP Conf. Ser. Earth Environ. Sci., 119: 012040. https://doi.org/10.1088/1755-1315/119/1/012040

Ehsaninia J, Bagheripour A (2026). Unraveling sexual size dimorphism in growth traits of dairy goats: A genetic evaluation that accounts for dominance effects. Anim. Genet., 57(3): e70125. https://doi.org/10.1002/age.70125

Elghandour MMY, Vallejo LH, Salem AZM, Mellado M, Camacho LM, Cipriano M, Olafadehan OA, Olivares J, Rojas S (2017). *Moringa oleifera* leaf meal as an environmental friendly protein source for ruminants: Biomethane and carbon dioxide production, and fermentation characteristics. J. Clean. Prod., 165: 1229–1238. https://doi.org/10.1016/j.jclepro.2017.07.151

Elhammali NSA, Alqurashi AM, Ibrahim MT, Elsheikh AS (2013). Puberty of crossbred male goat kids. J. Am. Sci., 9(4): 95–99.

Fadlilah A, Susanto E, Muthoharoh H, Susila I, Wahyuni, Sutanto E, Handayani IM, Alilmi MD, Afifuddin MMM (2023). The effect of sardines fish oil waste into the diets on the chemical quality of laying hen egg. J. Ilmu Teknol. Hasil Ternak, 18(2): 130–138. https://doi.org/10.21776/ub.jitek.2023.018.02.6

FAO. 2018. The State of Agricultural Commodity Markets 2018. Agricultural trade, climate change and food security. Rome.

Gading BMWT, Agustina (2025). Kualitas nutrien pellet kombinasi limbah ikan dan daun kelor sebagai supplemen pakan protein tinggi. J. Triton, 16(Juni): 95–106. https://doi.org/10.47687/jt.v16i1.1276

González-Burgos E, Ureña-vacas I, Sánchez M, Gómez-Serranillos MP (2021). Nutritional value of *Moringa oleifera* Lam. leaf powder and their neuroprotective effects via antioxidative and mitochondrial regulation. Nutrients, 13: 2203. https://doi.org/10.3390/nu13072203

Gul S, Hussain F, Taj R, Ullah A (2024). Effect of dietary *Moringa oleifera* on production performance and gut health in broilers. J. Adv. Vet. Anim. Res., 11(2): 339–348. https://doi.org/10.5455/javar.2024.k782

Gumilar DAKW, Rianto E, Arifin M (2018). The concentrations of rumen fluid volatile fatty acids and ammonia, and rumen microbial protein production in sheep given feed during the day and night time. IOP Conf. Ser. Earth Environ. Sci., 119: 012045. https://doi.org/10.1088/1755-1315/119/1/012045

Gunawan I, Suwiti NK, Sampurna P (2016). Pengaruh pemberian mineral terhadap lingkar dada, panjang dan tinggi tubuh sapi bali jantan. Bull. Vet. Udayana, 9(2): 128–34.

Hasanah N, Sadia IN, Wandira IA (2025). Changes in the body weight of Peranakan Etawa (pe) goats using different drinking water administration methods at CV. Muda Bakti Barokah Farm. Integr. Sustain. Anim. Prod. Innov., 2(1): 91–98.

Ibrahim S (2023). Pengaruh Pemberian Infusa Daun Kelor (*Moringa oleifera*) terhadap Performance Kambing Peranakan Etawa. Undergraduate Thesis. Sulawesi Barat University. Majene.

Ilham Z, Hamidon H, Rosji NA, Ramli N, Osman N (2015). Extraction and quantification of toxic compound mimosine from *Leucaena leucocephala* leaves. Proc. Chem., 16: 164–170. https://doi.org/10.1016/j.proche.2015.12.029.

Indonesia Central Bureau of Statistics (2022). Goat Population Based on Regency. https://www.bps.go.id/id/statistics-table/2/NDcyIzI=/populasi-kambing-menurut-provinsi.html

Khan MA, Bach A, Weary DM, Keyserlingk MAGV (2016).

Invited review: Transitioning from milk to solid feed in dairy heifers. J. Dairy Sci., 2: 885–902. https://doi.org/10.3168/jds.2015-9975

Khan RU, Khan A, Naz S, Ullah Q, Laudadio V, Tufarelli V, Ragni M (2021). Potential applications of *Moringa oleifera* in poultry health and production as alternative to antibiotics : A review. Antibiotics, 10: 1540. https://doi.org/10.3390/antibiotics10121540

Lin RH, Randolph HE (1978). Determination of nitrogen in milk by microdiffusion of kjeldahl digests. J. Dairy Sci., 61: 870–873. https://doi.org/10.3168/jds.S0022-0302(78)83663-7

Loh ZH, Ouwerkerk D, Klieve AV, Hungerford NL, Fletcher MT (2020). Toxin degradation by rumen microorganisms: A review. Toxins, 12(10): 664. https://doi.org/10.3390/toxins12100664

Lui JC, Baron J (2011). Mechanisms limiting body growth in mammals. Endocr. Rev., 32(3): 422–440. https://doi.org/10.1210/er.2011-0001

Mahgoub O, Osman NEHIE, Lu CD (2025). Nutrient utilization and requirements in sheep and goats raised under different systems and fed low nutritional novel feeds for meat production. Animals, 15: 2658. https://doi.org/10.3390/ani15182658

Majene Regency Central Bureau of Statistics (2025). Volume Produksi Dan Nilai Produksi Perikanan Tangkap Menurut Kabupaten/Kota Dan Jenis Penangkapan Di Provinsi Sulawesi Barat, 2024. https://sulbar.bps.go.id/id/statistics-table/3/

Maktoof AA, Elherarlla RJ, Ethaib S (2020). Identifying the nutritional composition of fish waste, bones, scales, and fins. IOP Conf. Ser. Mater. Sci. Eng., 871: 012013. https://doi.org/10.1088/1757-899X/871/1/012013

Mao J, Wang L (2025). Rumen acidosis in ruminants: A review of the effects of high-concentrate diets and the potential modulatory role of rumen foam. Front. Vet. Sci., 12: 1–7. https://doi.org/10.3389/fvets.2025.1595615

Mukumbo FE, Maphosa V, Hugo A, Nkukwana TT, Mabusela TP, Muchenje V (2014). Effect of *Moringa oleifera* leaf meal on finisher pig growth performance, meat quality, shelf life and fatty acid composition of pork. S. Afr. J. Anim. Sci., 44(4): 388–400. https://doi.org/10.4314/sajas.v44i4.9

Nugraheni AW, Latifah, Nurjanah AS, Kustantinah (2022). Pengamatan konsumsi nutrien kambing Bligon betina lepas sapih pada pemeliharaan kondisi terkontrol dan kondisi lapangan. J. Trop. Anim. Res., 3(1): 21–31.

Nugroho IA, Rizqiana S, Syarifuddin NA (2023). Performance of Peranakan Etawah (PE) goats obtaining moringa molasses multinutrient block (UMMMB) urea supplementation in ration. J. Anim. Res. Wetland, 3(1): 20–28. https://doi.org/10.20527/jpplb.v3i1.1729

Nuraini IGS, Budisatria, Agus A (2014). The effect of feed supplement level on the performance of bligon does kept by small farmers. Bull. Petern., 38(1): 34–41. https://doi.org/10.21059/buletinpeternak.v38i1.4614

Olugbemi TS, Mutayoba SK, Lekule FP (2010). Effect of moringa (*Moringa oleifera*) inclusion in cassava based diets fed to broiler chickens. Int. J. Poult. Sci., 9(4): 363–367. https://doi.org/10.3923/ijps.2010.363.367

Packett LV, McCune RW (1965). Determination of steam-volatile organic acids in fermentation media by gas-liquid chromatography. Appl. Microbiol., 13(1): 22–27. https://doi.org/10.1128/am.13.1.22-27.1965

Pazla R, Zain M, Agustin F, Marlida Y, Udin Z, Jaswandi, Masrizal, Hendri, Negara W, Tjiptosumirat T, Putri EM, Muslim M (2024). Influence of protein-energy balance on growth, production, and reproduction in *Pesisir heifers*. Adv. Anim. Vet. Sci., 12(3): 546–58. https://doi.org/10.17582/journal.aavs/2024/12.3.546.558

Purbowati E, Rahmawati I, Rianto E (2015). Jenis hijauan pakan dan kecukupan nutrien kambing jawarandu di kabupaten Brebes Jawa Tengah. Pastura, 5(1): 10–14. https://doi.org/10.24843/Pastura.2015.v05.i01.p02

Rahmi M, Faid M, Elyachioui M, Berny EH (2012). Protein rich ingredients from fish waste for sheep feeding. Adv. J. Microbiol. Res., 2012: 1–5.

Rivai MI, Nurlaelah S, Rasyid T (2025). Small-holder goat farmer profile demographic-based on financial aspect in Majene Regency, West Sulawesi Province. J. Glob. Innov. Agric. Sci., 13(1): 397–404. https://doi.org/10.22194/JGIAS/25.1540

Saab SA, Sleiman FT, Nassar KH, ChemalyI, El-Skaff R (1997). Implications of high and low protein levels on puberty and sexual maturity of growing male goat kids. Small Rumin. Res., 25: 17–22. https://doi.org/10.1016/S0921-4488(96)00972-8

Saro C, Mateo J, Caro I, Carballo DE, Fern M, Vald C, Javier F (2020). Performance, blood biochemistry profile, ruminal fermentation parameters and carcass and meat quality of heavy fattening Assaf lambs. Animals, 10: 2177. https://doi.org/10.3390/ani10112177

Sayuti M, Sahara L, Rachman AB, Metaragakusuma AP, Febrisiantosa A (2024). Current research on biosciences and 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

Sifatu WO, Hasniah, Hartini, Sofyani WOW (2022). Muna people in the peninsula of Sulawesi island and the moringa tree. J. Agrimanex, 2(2): 135–141. https://doi.org/10.35706/agrimanex.v2i2.6616

Sutisna MAR (2024). Peluang pertumbuhan ekonomi di Kabupaten Majene Provinsi Sulawesi Barat. Environ. Soc. Governance Sustain. Bus., 1(2): 122–129. https://doi.org/10.61511/esgsb.v1i2.2024.1180

Syamsiah (2014). Eksplorasi tumbuhan obat tradisional di Kecamatan Pamboang Kabupaten Majene Sulawesi Barat. J. Bionat., 15(2): 127–136.

Tilley JMA, Terry RA (1963). A two-stage technique for the in vitro digestion of forage crops. Grass Forage Sci., 18: 104–111. https://doi.org/10.1111/j.1365-2494.1963.tb00335.x

Umar M, Hidayati N, Purdiyanto J, DK Agustina. 2025. Digestibility of dry matter and organic matter in feed with pollard substitution in male Jawarandu goats. J. Agripet, 25(2): 134–139. https://doi.org/10.17969/agripet.v25i2.42911

Wang H, Fu J, Wu X, Wang Y, Li W, Huang Y, Zhong J, Peng Z (2024). Methionine and lysine on growth performance, rumen fermentation and serum indexes for Yaks. Animals, 14(1751): 1–12. https://doi.org/10.3390/ani14121751

Wolber M, Hamann H, Herold P (2021). Genetic analysis of lifetime productivity traits in goats. Arch. Anim. Breed., 64: 293–304. https://doi.org/10.5194/aab-64-293-2021

Zhu Y, Ye J, Qin P, Yan X, Gong X, Li X, Liu Y, Li Y, Yu T, Zhang Y, Ling Y, Wang J, Cao H, Fang F (2023). Analysis of serum reproductive hormones and ovarian genes in pubertal female goats. J. Ovarian Res., 16(69): 1–12. https://doi.org/10.1186/s13048-023-01150-0