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Effects of Dietary Lupin (*Lupinus angustifolius*) Inclusion on the Growth Performance of Growing–Finishing Pigs

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Abstract

This study investigated the potential of replacing soybean meal with lupin (*Lupinus angustifolius*) at varying inclusion levels in the diets of growing–finishing pigs from 12 to 22 weeks of age. A total of 120 crossbred pigs (Duroc × [Yorkshire × Landrace]) were randomly assigned to one of four dietary treatments: a control diet without lupin (LP0), and diets containing 5% (LP5), 9% (LP9), or 12% (LP12) lupin. Growth performance parameters were recorded over a 70-day feeding period. Pigs fed the LP12 diet exhibited a significantly lower body weight and average daily gain (P <0.05) than those fed the LP0, LP5, and LP9 diets. Feed intake did not differ significantly among the treatments (P >0.05), whereas the feed conversion ratio was significantly higher in the LP9 and LP12 groups than in LP0 and LP5 (P <0.05). Economic analysis indicated that the LP5 diet provided the greatest economic benefit, reducing feed cost per kilogram of gain without impairing performance. These findings suggest that the dietary inclusion of lupin up to 9% does not compromise growth performance, with 5% being the most economically advantageous level for fattening pigs.

Keywords

Nutritional value, supplement, feed efficiency, economic efficiency

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Introduction

Livestock make a significant contribution to the overall agricultural output of Vietnam, with swine being the most important in terms of both economic value and nutritional supply (Sharifuzzaman *et al.*, 2024). According to a report by the Department of Livestock Production – MARD (2025), the number of pig herds has continued to expand, reaching approximately 26.59 million heads at the end of 2024, an increase of 4.1% compared to the previous year. Despite its significant potential, the pig production industry in Vietnam faces several challenges, notably the high cost of feed, which accounts for 65-70% of total production expenses. Soybean meal, a primary protein source in pig diets, has experienced substantial price volatility in recent years due to global supply chain instability and climate-related impacts on crop yields (FAO, 2023; USDA, 2024), which have negatively impacted production efficiency and farmer profitability. Furthermore, the increasing competition between human food demand and livestock feed use for soybean products raises concerns about long-term sustainability. Against this backdrop, identifying cost-effective and nutritionally sound alternative protein sources is an urgent concern.

Lupin (*Lupinus angustifolius*), a legume known for its high protein content (30-40%) and nitrogen-fixing capabilities, is extensively cultivated and utilized in animal feed systems globally, particularly in Australia and Europe (Abraham *et al.*, 2019). Previous studies in pigs have shown that replacing soybean meal with sweet lupin at moderate inclusion levels (up to 20–30% of the diet) can maintain growth performance and carcass quality, provided that the diets are balanced for energy and amino acid requirements (Gdala *et al.*, 1997; van Barneveld, 1999; Ciurescu *et al*., 2025). However, higher inclusion rates may reduce feed intake and feed conversion efficiency due to increased dietary fiber and residual alkaloids (van Barneveld, 1999). Currently, research evaluating the nutritional value, optimal inclusion levels, and processing methods of lupin in Vietnam is limited. Its adoption and investigations about its use as a feed ingredient are further hindered by the lack of processing infrastructure, the presence of anti-nutritional factors, and the reliance on established protein sources such as soybean meal. Historically, the low price of soybean meal has restricted lupin use, however, recent increases in soybean prices, coupled with a decline in lupin prices, have stimulated renewed interest in its utilization. Therefore, evaluations are required to accurately determine lupin's potential as an alternative protein source in pig diets. This research aimed to evaluate the impact of including varying levels of lupin in the diets of fattening pigs on their growth performance and economic efficiency.

Materials and Methods

Animals and experimental design

The experiment was conducted over 70 days using 120 healthy crossbred pigs (Duroc × [Yorkshire × Landrace]). Pigs were randomly divided into four dietary treatments, with 30 individuals per treatment. Each treatment group comprised five replicated pens, with six pigs per pen. The dietary treatments were as follows: LP0 (Control): Basal diet with no lupin supplementation; LP5: Basal diet supplemented with 5% lupin; LP9: Basal diet supplemented with 9% lupin; and LP12: Basal diet supplemented with 12% lupin (**Table 1**).

All pigs were housed in environmentally controlled pens with concrete floors, maintained at a temperature of 20-24°C using temperature sensors, and exposed to natural lighting. The animals were provided *ad libitum* access to feed and water throughout the experimental period.

Table 1. Experimental design

Items	Experimental diet			
	LP0	LP5	LP9	LP12
Number of experimental pigs (heads)	30	30	30	30
Initial body weight (kg)	37.17 ± 0.26	37.04 ± 0.19	37.05 ± 0.20	37.10 ± 0.24
Gender (%)	50/50	50/50	50/50	50/50
Replicates	5	5	5	5
Number of pigs per pen (heads)	6	6	6	6

The diets were formulated to meet the nutritional requirements for fattening pigs according to established standards.

Experimental diets

The experimental diets had the same net energy, crude protein, crude fat, and crude fiber levels. The nutrient content of the experimental diets (amino acids, minerals, and vitamins, etc.) was formulated according to NRC (2012) recommendations. After mixing, the feeds were analyzed for nutrient composition and evaluated for nutritional value. The diets were divided into two phases based on pig age: from 12 to 17 weeks of age (**Table 2**) and from 18 to 22 weeks of age (**Table 3**).

Nutritional analysis of lupin seeds

The chemical composition of Lupin seeds (*Lupinus angustifolius*) was performed to

Table 2. Ingredient composition and nutritional values of the experimental diets from 12 to 17 weeks of age

Item	Experimental diet			
	LP0	LP5	LP9	LP12
Ingredient composition				
Lupin seeds	0.0	5.0	9.0	12.0
Corn	49.0	46.9	44.8	43.2
Wheat	10.0	10.0	10.0	10.0
Rapeseed meal	3.0	3.0	3.0	3.0
Soybean meal	18.0	15.1	13.2	11.8
Rice bran	16.0	16.0	16.0	16.0
DCP	0.35	0.35	0.35	0.35
Limestone	1.10	1.11	1.12	1.10
Salt	0.40	0.40	0.40	0.40
DL-Methionine 99%	0.22	0.23	0.23	0.23
L-Threonine 99%	0.25	0.26	0.25	0.25
L-Tryptophan 99%	0.08	0.08	0.09	0.09
L-Valine 96.5%	0.05	0.05	0.05	0.05
L-Lysine Sulfate 70%	1.00	1.00	1.00	1.00
Phytase (5000 IU)	0.02	0.02	0.02	0.02
Premix	0.50	0.50	0.50	0.50
Nutritional value				
Metabolizable energy (ME) (Kcal/kg)	3380	3400	3380	3370
Moisture (%)	11.82	11.7	11.6	11.53
Crude protein (%)	15.05	15.13	15.08	15.12
Lipids (%)	4.52	4.61	4.55	4.47
Crude fiber (%)	6.39	6.18	6.56	6.72
Total minerals (%)	6.17	6.11	6.21	6.22
Calcium (%)	0.63	0.64	0.61	0.65
Phosphorus (%)	0.46	0.45	0.47	0.48
Lys (%)	1.23	1.14	0.89	1.19
Met (%)	0.42	0.43	0.42	0.37
Met+Cys (%)	0.69	0.73	0.7	0.66
Thr (%)	0.77	0.79	0.81	0.75

Table 3. Ingredient composition and nutritional values of the experimental diets from 18 to 22 weeks of age

Item	Experimental diet			
	LP0	LP5	LP9	LP12
Ingredient composition				
Lupin seeds	0.0	5.0	9.0	12.0
Corn	46.8	44.8	43.1	42.0
Wheat	10.0	10.0	10.0	10.0
Rapeseed meal	3.0	3.0	3.0	3.0
Soybean meal	11.2	8.2	5.9	4.0
Wheat bran	10.0	10.0	10.0	10.0
Rice bran	16.0	16.0	16.0	16.0
DCP	0.13	0.13	0.13	0.13
Limestone	1.45	1.44	1.46	1.44
Salt	0.30	0.30	0.30	0.30
DL-Methionine 99%	0.05	0.05	0.05	0.05
L-Threonine 99%	0.07	0.07	0.07	0.07
L-Lysine Sulfate 70%	0.46	0.46	0.46	0.46
Phytase (5000 IU)	0.02	0.02	0.02	0.02
Premix	0.50	0.50	0.50	0.50
Nutritional value				
Metabolizable energy (ME) (Kcal kg^{-1})	3350	3330	3320	3320
Crude protein (%)	12.97	13.12	13.07	13.12
Lipids (%)	4.32	4.27	4.37	4.43
Crude fiber (%)	6.39	6.56	6.80	6.94
Total minerals (%)	6.44	6.4	6.23	6.54
Calcium (%)	0.59	0.52	0.58	0.54
Phosphorus (%)	0.46	0.46	0.42	0.44
Lys (%)	0.9	0.87	0.99	0.86
Met (%)	0.25	0.27	0.27	0.23
Met+Cys (%)	0.52	0.54	0.55	0.52
Thr (%)	0.57	0.58	0.64	0.61

determine the proximate composition, namely crude protein, ether extract, crude fiber, calcium, and phosphorus. The energy content was calculated using standard equations. Metabolizable energy (ME) was estimated based on the ME prediction equation of Noblet & Perez (1993):

ME (kcal kg^{-1} DM) = $0.96 \times (4151 + 23X_1 + 38X_2 - 64X_3 - 122X_4)$

where X_1 is the crude protein content (% DM), X_2 is the ether extract content (% DM), X_3 is the crude fiber content (% DM), and X_4 is the total ash content (% DM).

Amino acid profiles were also determined. The nutritional composition and anti-nutritional factors (ANFs), namely tannins, trypsin inhibitors, and non-starch polysaccharides (NSPs), were analyzed. Dry matter was analyzed according to TCVN - 4326 (2001). Crude protein was determined following TCVN - 4328 (2007), and the lipid content was analyzed as per TCVN - 4331 (2001). Crude fiber and total ash were analyzed following TCVN - 4327 (2007). Calcium and phosphorus were quantified using TCVN - 1537 (2007) and TCVN - 1525 (2001), respectively. Amino acid analysis was performed according to TCVN - 8764 (2012). The total tannin content was analyzed using the LFOD-TST-SOP-8262 method, while trypsin inhibitor activity was determined by the AOCS Ba 12a-2020 method. Total NSP was analyzed following the LFOD-TST-SOP-8361 method.

Growth performance parameters

During the duration of the experiment, the individual body weights (BW) of the pigs were recorded at the start of the trial (12 weeks of age), and then weighed at 17 weeks of age and 22 weeks of age to estimate the body weight gain and average daily weight gain (ADG) on a treatment basis. Feed intake was estimated by examining the remaining feed amount in each pen before the morning feeding and determining the average for each pen. The feed conversion ratio (FCR) was then calculated using the values obtained for feed intake and ADG.

Statistical analysis

All data were analyzed using one-way analysis of variance (ANOVA) to determine the effects of dietary lupin supplementation on the growth performance parameters. When significant differences were detected, Tukey's HSD post-hoc test was used to compare means among the treatments. All statistical analyses were performed using IBM SPSS Statistics 28.0.

Results and Discussion

Nutritional composition and anti-nutritional factors of lupin seeds

Chemical analysis of the lupin seeds revealed 28.90% crude protein, 5.15% lipids, and 2,151 kcal/kg net energy (**Table 4**). Crude fiber was 15.77%, due to the seed coats, with low levels of calcium and phosphorus. These values align with previous reports (Petterson *et al.*, 2000; Konizecka *et al.*, 2017). Lupin's crude protein exceeded that of DDGS and palm kernel meal but was lower than soybean meal (NRC,

Table 4. The nutritional components and essential amino acids in lupin seeds

Item	Mean	SD	CV
Nutritional component			
Dry matter (%)	89.89	1.63	1.82
Net energy (Kcal kg^{-1})	2152	36.80	1.71
Crude protein (%)	28.90	0.96	3.33
Lipids (%)	5.15	0.20	3.93
Crude fiber (%)	15.77	0.53	3.33
Total minerals (%)	2.55	0.17	6.54
Calcium (%)	0.29	0.03	11.95
Phosphorus (%)	0.28	0.07	24.87
Essential amino acids			
Lysine	1.19	0.01	0.97
Histidine	0.66	0.02	2.30
Leucine	1.65	0.03	1.60
Isoleucine	1.00	0.02	2.00
Valine	0.98	0.02	2.12
Methionine	0.14	0.01	7.14
Threonine	0.85	0.02	1.79
Tryptophan	0.22	0.01	2.59
Phenylalanine	1.00	0.03	2.53

2012). Essential amino acids were relatively low (methionine 0.14%, lysine 1.19%), which is consistent with the literature (Petterson *et al.*, 2000; Nalle *et al.*, 2011), though the overall profile was comparable to soybean meal. Lupin's essential amino acid SID had a range of 81-93%, similar to soybean meal (Kim *et al.*, 2006; NRC, 2012). Protein digestibility exceeded 90%, but energy digestibility remained below 60% (Bohumila *et al.*, 2009; Márcia *et al.*, 2014). Anti-nutritional factors were low: tannins at 0.33% (Antongiovanni *et al.*, 2016) and trypsin inhibitors at 0.3 mg TID g^{-1}, significantly lower than soybean meal (Nalle *et al.*, 2012). Non-starch polysaccharides (NSP) comprised 51.08%, impacting nutrient and energy utilization (Wilkinson, 2017).

Anti-nutritional factors (ANFs) in lupin, including NSPs, oligosaccharides, trypsin and chymotrypsin inhibitors, tannins, saponins, phytates, and alkaloids, are important to evaluate due to their effects on nutrient digestibility. In modern lupin cultivars, ANF levels are comparable to those in soybean meal and considered low enough for use in pig diets without negative impacts (Kim *et al.*, 2006). Tannins, at 0.33%, were higher than values reported by Petterson *et al.* (2000) (0.01-0.03%) due to the inclusion of both hydrolyzable and condensed forms (**Table 5**). Still, this level is well below the 0.25% threshold shown by Antongiovanni *et al.* (2016) to have no adverse effect on pig growth. The trypsin inhibitor content was 0.3 mg TID g^{-1}, consistent with Nalle *et al.* (2012) (0.23 mg TID g^{-1}) and Petterson *et al.* (1997) (0.12 mg TID g^{-1}), and significantly lower than in most legumes. Total NSP content averaged 51.08%, aligning with Nalle *et al.* (2012) and Abraham *et al.* (2019), who reported 49.6% and 47-51%, respectively. While high NSP levels may reduce nutrient and energy digestibility, they are manageable with appropriate diet formulation.

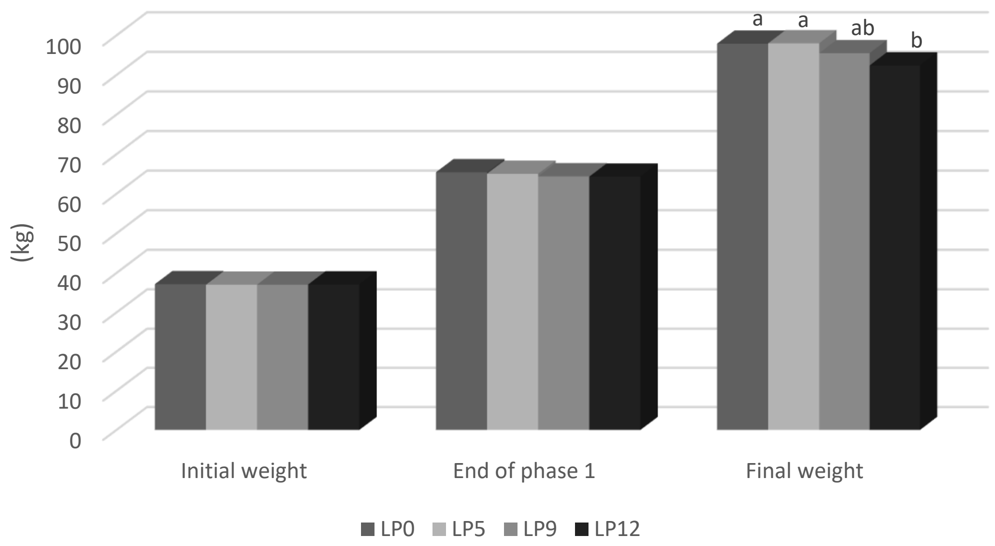
Growth performance

At 17 weeks of age, pigs fed 9% (LP9) and 12% (LP12) lupin showed body weight trends similar to that of the control (LP0) group (no statistically significant differences; P >0.05) (**Figure 1**). This trend intensified and became statistically significant (P <0.05) by the end of the experimental duration. Specifically, LP12 pigs exhibited a significant reduction of 5.4kg in body weight compared to LP0 (P <0.05), while LP5 pigs maintained comparable body weights (P >0.05). This suggests that moderate lupin inclusion is tolerated, but higher levels (12%) negatively impact growth. Donovan *et al.* (1993) reported no adverse effects on growth with lupin supplement up to 9-12%, while Sonta *et al.* (2016) observed a non-significant, consistent trend of lower body weights in pigs fed 15% lupin. The growth reduction observed at higher lupin levels is likely attributable to the relatively high non-starch polysaccharide (NSP) content, which can limit nutrient digestibility and absorption (Lucas *et al.*, 2015). The observed growth reduction at 12% lupin is likely linked to its high NSP content, which can increase digestion viscosity, reduce the digestion passage rate, and physically entrap nutrients, thereby limiting enzymatic access and absorption (Lucas *et al*., 2015; Wilkinson, 2017). These effects are compounded by the increased energy loss associated with microbial fermentation of NSP in the hindgut, which diverts energy away from growth (Choct, 2015). Furthermore, NSP can indirectly alter gut microbiota composition, potentially influencing nutrient utilization efficiency (Gidley & Yakubov, 2019). Interestingly, no effects were detected during the initial phase of the experiment. This could be attributed to the pigs' higher capacity for nutrient utilization and physiological adaptation when their body weights were lower, as well as the relatively short exposure period to high-NSP diets in this phase. In addition, the gastrointestinal microbiota may not have fully adapted to the increased NSP content early in the trial, delaying the onset of measurable negative impacts on growth.

Average daily gain varied by phase (**Figure 2**). From 12-17 weeks, while not statistically significant, the 12% lupin group had the lowest ADG (778 g/day) compared to the control (808 g day^{-1}). From 18-22 weeks, the 12% lupin treatment showed a statistically significant 126 g day^{-1} decrease in ADG (P <0.05), supporting the

Table 5. Anti-nutritional factors in lupin seeds

Item	Mean	SD	CV
Total tannins (%)	0.33	0.03	7.70
Antitrypsin (mgTID g^{-1})	0.30	0.03	10.30
NSP (DP: 3-9) (%)	8.42	0.11	1.26
NSP (DP ≥ 10) (%)	42.66	1.61	3.78
Total NSP (%)	51.08	1.64	3.21



Note: Bars with different superscript letters (a, b) within the same group differ significantly (P <0.05).

Figure 1. Growth performance of the experimental pigs

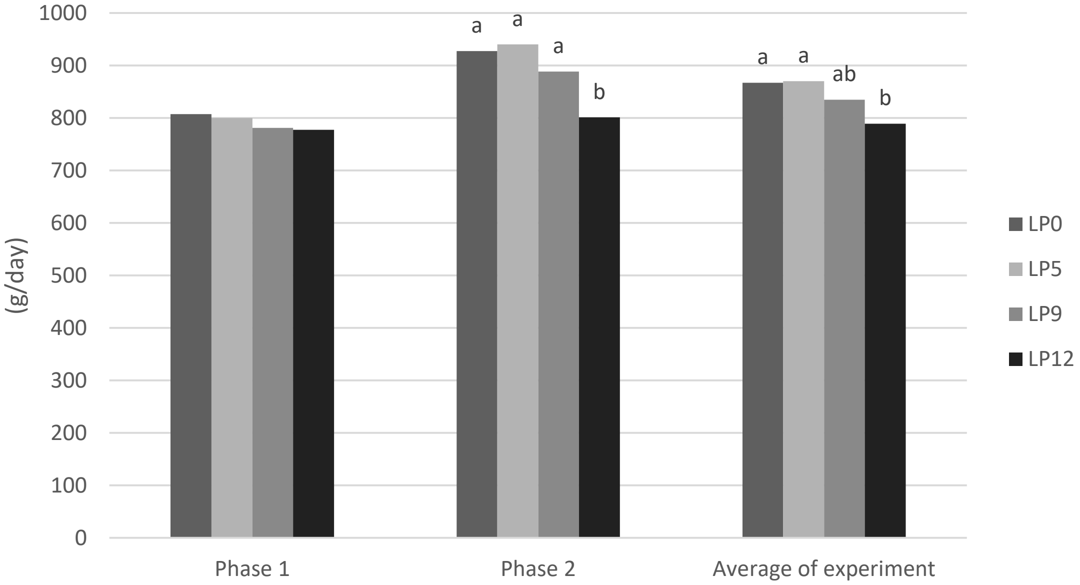
negative impact of higher lupin levels (Jacyno *et al.*, 1992). Overall (12-22 weeks), 12% lupin significantly reduced ADG by 78 g day^{-1} compared to the control (*P* <0.05). This suggests that up to 9% lupin inclusion does not negatively impact ADG, but higher levels (12%) significantly impede the growth rate, consistent with Sonta *et al.* (2016), due to a higher concentration of NSP.

Feed intake remained unaffected by increased levels of lupin supplementation (*P* >0.05), suggesting that palatability was not compromised even at higher inclusion rates (**Table 6**). This may be attributed to the relatively low levels of anti-nutritional factors (tannins at 0.33% and a minimal alkaloid content) in the diets, which are typically associated with reduced feed acceptability (Kemm *et al.*, 1987; Antongiovanni *et al.*, 2016). In contrast, previous studies have reported a decline in feed intake with high *Lupinus albus* inclusion (Zett *et al.*, 1995), indicating potential differences in the ANF composition among cultivars.

Supplemented with 5% lupin, the FCR did not differ significantly from the control group (*P* >0.05) (**Table 6**). However, a significant increase in FCR was observed at higher inclusion levels, with the 12% lupin group exhibiting the poorest efficiency (3.10), significantly exceeding both the 9% lupin and control groups (*P* <0.05). The reduced feed efficiency at elevated inclusion rates is likely associated with higher dietary fiber and NSP content, which may impair nutrient digestibility and absorption (Wilkinson, 2017).

Economic efficiency

Feed costs represent a substantial portion (65-75%) of the total production expenses in pig production (Department of Livestock Production,



Note: Bars with different superscript letters (a, b) within the same group differ significantly (P <0.05).

Figure 2. Daily weight gain of the experimental pigs

Table 6. Feed intake and feed conversion ratios (FCR) of the experimental diets

Item	Experimental diet				SEM	P
	LP0	LP5	LP9	LP12		
Feed intake (kg/head/day)						
Phase 1	2.14	2.14	2.13	2.13	0.004	0.803
Phase 2	2.77	2.77	2.77	2.77	0.002	0.933
Average	2.46	2.45	2.45	2.45	0.002	0.714
FCR						
Phase 1	2.65^{b}	2.67^{b}	2.73^{a}	2.74^{a}	0.01	0.00
Phase 2	2.99^{c}	2.95^{c}	3.12^{b}	3.46^{a}	0.06	0.00
Average	2.83^{c}	2.82^{c}	2.94^{b}	3.10^{a}	0.03	0.00

Note: Means within the same row with different superscript letters differ significantly (P <0.05).

2019). Therefore, optimizing feed costs while maintaining satisfactory growth performance is crucial for economic viability. The results indicate that the experimental diets significantly influenced the feed cost per kilogram of weight gain in pigs (**Table 7**). Replacing soybean meal with lupin seeds effectively reduced feed formulation costs in both the growing and finishing phases. The LP5 diet (5% lupin) consistently demonstrated superior economic efficiency across both growth phases, resulting in the lowest feed cost per weight gain without negatively impacting pig growth performance. Conversely, the LP12 diet proved to be the least cost-effective, particularly in the later growth phase.

Conclusions

Dietary inclusion of lupin at levels up to 9% had no significant adverse effects on the growth performance of pigs. However, increasing the inclusion rate to 12% resulted in a significant reduction in BW and ADG, likely due to elevated levels of NSP and anti-nutritional factors that may impair nutrient digestibility. From an economic perspective, the 5% inclusion level was the most cost-effective, reducing feed

Table 7. Feed cost per kg weight gain of the experimental pigs (VND kg^{-1})

Item	Experimental diet				SEM	P
	LP0	LP5	LP9	LP12		
Phase 1	21.704^{b}	21.724^{b}	22.090^{a}	22.076^{a}	64	0.007
Phase 2	21.618^{b}	21.018^{c}	22.025^{b}	24.186^{a}	364	0.000
Average	21.657^{c}	21.342^{d}	22.054^{b}	23.147^{a}	207	0.000

Note: Means within the same row with different superscript letters differ significantly (P <0.05).

costs without compromising performance. Future studies are needed to investigate the supplementation of exogenous enzymes targeting NSP degradation as a strategy to improve lupin digestibility, thereby facilitating its inclusion at higher dietary levels. Additionally, such research should assess the feasibility of lupin utilization across various production stages and livestock species.

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