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Effects of Different Dietary Linseed Supplementation Forms on Growth Performance, Carcass Characteristics, Meat Quality, and Nutritional Composition of Qinchuan Beef Cattle

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Research Article

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Abstract

This study aimed to evaluate the effects of dietary cold-pressed linseed cake supplementation on growth performance, carcass traits, meat quality, and nutritional composition in Qinchuan beef cattle. Eighteen healthy 18-month-old cattle (282 ± 10 kg) were randomly assigned to three dietary treatments (n = 6): a control diet (CON), a diet supplemented with 12% cold-pressed linseed cake (CLC), and a diet supplemented with 12% crushed linseed (CLS). The trial consisted of a 15-day adaptation period and a 100-day feeding period.Compared with the CON group, dietary linseed supplementation increased dry matter intake and average daily gain ($P < 0.05$), whereas no significant differences were detected between the CLC and CLS groups ($P > 0.05$). The CLC group had a lower feed-to-gain ratio and lower feed cost per unit of gain. Carcass weight, net meat yield, and meat-to-bone ratio were improved in the linseed-supplemented groups ($P < 0.05$). Shear force decreased during postmortem ageing, indicating improved tenderness. In addition, dietary linseed supplementation increased the contents of α-linolenic acid (C18:3 n-3) and total amino acids in beef ($P < 0.05$).The results indicate that cold-pressed linseed cake can improve growth performance, feed efficiency, carcass characteristics, and beef nutritional quality in Qinchuan beef cattle, and may be used as a cost-effective feed ingredient in beef cattle production.

1. Introduction

Qinchuan cattle are an important indigenous beef breed in China, characterized by relatively rapid growth, desirable meat quality, and strong environmental adaptability, and they represent a valuable genetic resource for the development of the beef industry in northwestern China and nationwide (Qin et al. 2021; Cao et al. 2024). With the advancement of intensive and standardized beef production systems, increasing attention has been directed toward optimizing dietary formulations to enhance growth performance and meat quality, while also exploring alternative feed resources and reducing feeding costs (Zhang 2021; Zeng et al. 2023).

Cold-pressed linseed cake, a by-product of linseed oil extraction, has attracted increasing interest as a potential feed ingredient for ruminants because it is rich in crude protein, dietary fibre, unsaturated fatty acids, especially α-linolenic acid, and mineral elements (Tao et al. 2022; Zhang et al. 2024; Nie et al. 2025). Previous studies have shown that linseed and its processing by-products can improve growth performance, feed utilization, carcass traits, beef quality, and nutrient composition in ruminants (Hou et al. 2021; Wu et al. 2017; Wei 2025; Mi et al. 2018; Zhang 2025). In beef cattle, dietary inclusion of linseed or related by-products has also been reported to modify intramuscular fatty acid profiles by increasing the proportion of unsaturated fatty acids and regulating the expression of genes involved in lipid metabolism. These findings indicate that linseed-based feed resources may be useful in the production of high-quality beef with improved nutritional value.

linseed may not only improve the nutritional value of beef, but also exert a gradual influence on rumen fermentation and nutrient utilization in ruminants. Previous studies have reported that dietary

supplementation with linseed can improve rumen fermentation characteristics, enhance nutrient digestibility, and increase the content of n-3 polyunsaturated fatty acids (Soder et al. 2012; Silva et al. 2016; Schroeder et al. 2014; Cortes et al. 2011; Hawkins et al. 2013a; Gandra et al. 2016). Similar positive regulatory effects have also been observed when unsaturated fatty acids were supplied to beef cattle in different forms and under different physiological conditions (Spitalniak-Bajerska et al. 2020; Kim et al. 2024). Moreover, the association between rumen microbial composition and carcass merit or meat quality further suggests that dietary strategies capable of modulating ruminal metabolism may contribute to improvements in beef production and quality (Holman et al. 2024; Li et al. 2025).

However, despite these promising findings, evidence regarding the application of cold-pressed linseed cake in Qinchuan cattle remains limited. Therefore, the present study was conducted to evaluate the effects of dietary supplementation with cold-pressed linseed cake on growth performance, carcass traits, meat quality, and nutritional composition in Qinchuan cattle, with crushed linseed included as a comparative treatment.

2. Materials and Methods

2.1 Animals and experimental design

Eighteen clinically healthy Qinchuan cattle aged 18 months, with an average initial body weight of 282 ± 10 kg, were used in this study. The animals were randomly assigned to one of three dietary treatments, with six cattle per treatment: a control diet (CON), a diet supplemented with 12% cold-pressed linseed cake (CLC), and a diet supplemented with 12% crushed linseed (CLS). The experiment consisted of a 15-day adaptation period followed by a 100-day feeding trial.

2.2 Diets and feeding management

The experimental diets were formulated according to NY/T 815–2004 to meet the nutrient requirements of beef cattle. The ingredients and nutrient composition of the experimental diets are presented in Table 1. Cattle were fed twice daily at 08:00 and 16:00 h and had free access to drinking water throughout the experimental period. Feed intake was recorded daily.

Table 1
Composition and nutrient levels of the experimental diets

Item	CON(%)	CLC(%)	CLS(%)
Ingredients			
Corn	55	55	55
Wheat bran	12	4	6
Soybean meal	25	21	19
Linseed	0	0	12
Cold-pressed linseed	0	12	0
Salt	1	1	1
Sodium bicarbonate	2	2	2
Premix	5	5	5
Total	100	100	100
Nutritional level			
DM	90.21	91.34	91.22
CP	15.98	15.55	15.09
EE	4.11	4.65	4.98
CF	45.22	46.78	46.99
Ca	0.28	0.25	0.21
P	0.40	0.55	0.50
GE (MJ/kg)	16.08	17.37	17.96
Notes: Premix provided the following per kilogram of diet: vitamin A, 2640 IU; vitamin D, 340 IU; vitamin E, 26 mg; Fe, 60 mg; Cu, 12 mg; Zn, 48 mg; Mn, 48 mg; Co, 0.12 mg; I, 0.3 mg; and Se, 0.36 mg.			

Nutrient levels shown in the table are analyzed values.

2.3 Feed intake measurement

Feed intake was recorded using a precision-controlled feeding system, which automatically measured the daily amount of feed offered and refusals. Based on these records, average daily feed intake was calculated for each pen and for each animal. Dry matter intake (DMI) was then determined, and the variation in average daily DMI among treatments over the experimental period was analyzed.

2.4 Body weight measurement

Body weight was measured at predetermined intervals throughout the experimental period. Animals were weighed in the morning before feeding, and three consecutive measurements were taken for each animal to obtain an average value. These data were used to determine initial and final body weight at each stage of the experiment. Average daily gain (ADG) and total weight gain were subsequently calculated.

2.5 Feed efficiency

Feed efficiency was evaluated based on feed intake, body weight gain, and feed cost. The calculated variables included daily feeding cost per animal, feed cost per kilogram of body weight gain, and the feed-to-gain ratio (F:G).

2.6 Slaughter procedures and performance measurements

At the end of the feeding trial, animals were slaughtered according to standard commercial procedures. Carcass weight was defined as the weight after exsanguination and removal of the hair, skin, head, viscera, and the distal portions below the carpal and tarsal joints, followed by a 30-min postmortem resting period. Net meat weight was defined as the total weight of all deboned meat cuts.

The following indices were calculated:

Dressing percentage (%) = (carcass weight / pre-slaughter live weight) × 100%

Net meat yield (%) = (net meat weight / carcass weight) × 100%

Net meat percentage (%) = (net meat weight / pre-slaughter live weight) × 100%

Meat-to-bone ratio = net meat weight / bone weight

2.7 Meat quality analysis

Samples collected from different carcass parts were used for meat quality evaluation. Shear force (SF) was determined using a TA.XTC-18 texture analyzer. Cooking loss (CL) was determined gravimetrically based on the difference in sample weight before and after cooking, according to the following equation:

Cooking loss (%) = [(weight before cooking − weight after cooking) / weight before cooking] × 100

Meat colour parameters, including L*, a*, and b*, were measured using an NS808 spectrophotometer. Multiple measurements were taken for each sample, and the mean value was used for statistical analysis.

2.8 Nutritional composition analysis

Amino acid composition was determined according to GB 5009.124–2016 (National Food Safety Standard for the Determination of Amino Acids in Foods). A total of 17 amino acids were quantified using an amino acid analyzer.

Fatty acid composition was determined according to the corresponding national standard method for fatty acid analysis. A total of 37 fatty acids were quantified using a fatty acid analyzer.

2.9 Statistical analysis

All data were analyzed using SPSS Statistics (SPSS Inc., Chicago, IL, USA). Data are presented as means ± SD. Differences among treatments were evaluated by one-way ANOVA, and Duncan's multiple range test was used for post hoc comparisons when treatment effects were significant. Statistical significance was declared at $P < 0.05$, and $0.05 \leq P < 0.10$ was considered a tendency.

3. Results

3.1 Growth Performance and Feed Efficiency

As shown in Fig. 1, daily dry matter intake increased gradually in all groups during the experimental period. Dry matter intake was higher in the CLC and CLS groups than in the CON group. However, from days 61 to 100, the increasing trend became less marked, and the differences among groups gradually decreased. As shown in Fig. 2, body weight increased over time in all experimental groups throughout the trial. Among the three treatments, the increase was most pronounced in the CLC group.

Note

Different lowercase superscripts in the same line indicate significant differences ($P < 0.05$);The same or no letter superscripts indicate insignificant difference ($P > 0.05$). The same below.

3.2 Feed Efficiency

As shown in Table 2, feed-to-gain ratio and feed cost per kilogram of weight gain did not differ significantly among the three groups ($P > 0.05$), although the CON group tended to have a higher feed-to-gain ratio than the CLC and CLS groups. Average daily feed cost per animal differed significantly among treatments over the entire experimental period ($P < 0.05$), with the highest value observed in the CLS group, followed by the CLC group and the CON group.

Table 2
Feed efficiency of Qinchuan beef cattle fed diets supplemented with cold-pressed linseed cake

Item	CON	CLC	CLS	SEM	p-value
Total weight gain/kg	82.5^{b}	98.0^{a}	92.4^{a}	2.39	0.009
Total feed consumption/kg	669.55^{b}	719.33^{a}	713.73^{a}	7.54	0.001
Material to weight ratio	8.14	7.38	7.72	0.15	0.119
Average feed cost per kilogram of feed/RMB	16.42	15.15	16.96	0.34	0.063
Feed cost/RMB	1351.50^{c}	1477.44^{b}	1566.64^{a}	27.55	<0.001
Average feed cost per day/RMB	13.51^{c}	14.77^{b}	15.67^{a}	0.27	<0.001

3.3 Meat Quality

As shown in Table 3, pre-slaughter live weight and dressing percentage were not significantly affected by treatment (P > 0.05). The CLS group showed significantly higher carcass weight and net meat weight than the CON and CLC groups (P < 0.05), whereas no significant difference was observed between the latter two groups (P > 0.05). In addition, both linseed-supplemented groups had significantly higher meat-to-bone ratio and net meat yield than the CON group (P < 0.05), with no significant differences between the CLC and CLS groups (P > 0.05). These findings suggest that dietary linseed supplementation had beneficial effects on slaughter performance.

Table 3
Effects of different forms of dietary flax supplementation on slaughter performance of Qinchuan beef cattle.

Item	CON	CLC	CLS	SEM	p-value
Live weight/kg	391	395	390	1.33	0.185
Carcass weight/kg	238.17^{b}	251.67^{a}	235.67^{b}	2.85	0.015
Net meat weight/kg	116.07^{b}	129.45^{a}	119.19^{b}	2.12	0.001
Meat bone ratio	7.21^{b}	7.60^{a}	7.49^{a}	0.07	0.034
Pure meat percentage/%	48.74^{b}	51.55^{a}	50.29^{a}	0.44	0.002
Dressing percentage/%	60.65	62.91	62.00	0.52	0.223

As shown in Fig. 3, shear force was significantly higher in the CON group than in the CLC and CLS groups during 0–24 h of postmortem ageing (P < 0.05), whereas the CLS group showed the lowest values (P <

0.05). No significant differences were observed among groups at 120 h ($P > 0.05$). However, at 168 h, the differences among groups were similar to those observed at the initial stage of ageing ($P < 0.05$). Overall, shear force decreased progressively in all groups throughout the ageing period.

As shown in Fig. 4, cooking loss at 0 h was significantly higher in the CON group than in the CLS group ($P < 0.05$). At 72 h, significant differences were observed among all groups ($P < 0.05$). In all treatments, cooking loss increased from 0 to 72 h and then decreased from 72 to 168 h, with values at 168 h lower than those recorded at 0 h.

As shown in Fig. 5, L* values in all groups initially increased and then decreased during postmortem ageing, although the turning points differed among groups. In contrast, both a* and b* values generally increased, with a more marked rise observed between 120 and 168 h. The CON group had significantly higher L* values than the CLC and CLS groups ($P < 0.05$). Although a* values were generally comparable among groups, the CON group showed significantly higher values than the CLC and CLS groups at 72 h ($P < 0.05$).

Figure 5. Changes in meat color parameters of beef during postmortem aging. (a) L* value; (b) a* value; (c) b* value.

3.4 Nutritional Composition

As shown in Table 4, no significant differences were observed among the three groups in oleic acid content ($P > 0.05$). However, linoleic acid content was significantly higher in the CLS group than in the CON and CLC groups ($P < 0.05$). In addition, α-linolenic acid was not detected in beef from the CON group, but was detected in both the CLC and CLS groups.

Table 4
Effects of different forms of dietary flax supplementation on the fatty acid composition of beef from Qinchuan beef cattle (%)

Item	CON	CLC	CLS	SEM	p-value
C14:0	2.5^{b}	3.21^{a}	1.83^{c}	0.209	0.001
C14:1	0.69^{c}	0.92^{b}	1.93^{a}	0.114	0.001
C15:0	0.08^{c}	0.32^{a}	0.19^{b}	0.529	0.083
C15:1	0.91^{b}	0.51^{c}	1.36^{a}	0.199	0.240
C16:0	29.99^{a}	26.00^{b}	23.65^{c}	0.901	0.001
C16:1	3.80^{b}	4.24^{a}	2.06^{c}	0.363	0.004
C17:1	0.59	0.61	0.67	0.098	0.062
C18:0	11.54^{c}	12.27^{b}	17.40^{a}	0.960	0.001
C18:1	46.53	46.61	44.11	0.589	0.137
C18:2n6t	0.00	0.27	0.00	0.057	0.052
C18:2n6C	1.96^{c}	3.03^{b}	5.69^{a}	0.66	0.002
C18:3	0.00	0.33^{b}	0.71^{a}	0.105	<0.001
C20:0	0.00	0.16	0.00	0.035	0.079
C20:1	0.00	0.16	0.00	0.034	0.079
C20:4	1.33^{b}	1.39^{b}	2.23^{a}	0.333	0.049

As shown in Table 5, total amino acid content was significantly higher in the CLC and CLS groups than in the CON group ($P < 0.05$). No significant differences were observed in cystine content among the three groups ($P > 0.05$). For the other amino acids, contents did not differ significantly between the CLC and CLS groups ($P > 0.05$), but were significantly higher in both groups than in the CON group ($P < 0.05$). Notably, total amino acid content in the CLC group was 54.27% greater than that in the CON group.

Table 5
Effects of different forms of dietary flax supplementation on the amino acid composition of beef from Qinchuan beef cattle (%)

Item	CON	CLC	CLS	SEM	p-value
Amino acid total	13.21^{b}	20.38^{a}	20.88^{a}	1.384	< 0.001
Asp	1.21^{b}	1.85^{a}	1.93^{a}	0.127	< 0.001
Thr	0.61^{b}	0.93^{a}	0.96^{a}	0.063	< 0.001
Ser	0.51^{b}	0.77^{a}	0.79^{a}	0.050	< 0.001
Glu	2.03^{b}	2.98^{a}	2.98^{a}	0.176	< 0.001
Pro	1.06^{b}	1.73^{a}	1.71^{a}	0.128	0.003
Gly	0.58^{b}	0.99^{a}	0.92^{a}	0.073	0.007
Ala	0.79^{b}	1.23^{a}	1.23^{a}	0.083	< 0.001
Cys	0.11	0.12	0.11	0.003	0.659
Val	0.65^{b}	0.99^{a}	1.02^{a}	0.067	< 0.001
Met	0.28^{c}	0.46^{b}	0.53^{a}	0.043	0.001
LLE	0.62^{b}	0.95^{a}	1.00^{a}	0.067	< 0.001
Leu	1.12^{b}	1.68^{a}	1.76^{a}	0.111	< 0.001
Tyr	0.47^{b}	0.70^{a}	0.74^{a}	0.049	< 0.001
Phe	0.56^{b}	0.90^{a}	0.98^{a}	0.726	< 0.001
Lys	1.25^{b}	1.89^{a}	1.93^{a}	0.122	< 0.001
His	0.50^{b}	0.89^{a}	0.97^{a}	0.084	0.003
Arg	0.83^{b}	1.27^{a}	1.29^{a}	0.919	< 0.001

4. Discussion

4.1 Feed intake and body weight changes

Dietary supplementation with cold-pressed linseed cake or ground linseed improved feed intake and growth performance in Qinchuan beef cattle. Compared with the control diet, flax-supplemented diets increased feed intake and promoted body weight gain, suggesting that flax-derived feed ingredients

exert beneficial effects on animal performance. Similar findings have been reported previously. Hou et al. (2021) showed that dietary supplementation with linseed cake improved growth performance in fattening lambs, while Wu et al. (2017) reported that replacing soybean meal with linseed cake improved production performance in sheep. In addition, Wei (2025) found that replacing soybean meal with linseed meal improved nutrient digestibility and gastrointestinal microbial composition in fattening lambs, thereby contributing to improved growth and feed utilization. Comparable positive responses to flax-derived nutrients or unsaturated fatty acid supplementation have also been observed in other production systems or animal species, including finishing pigs, broilers, and geese (Li et al. 2025; Ni et al. 2026; Chang et al. 2026), suggesting that flax-derived ingredients may exert relatively broad growth-promoting effects when appropriately included in the diet.

These positive effects may be related to the nutritional characteristics of flax-derived feed ingredients. Cold-pressed linseed cake contains considerable amounts of crude protein, unsaturated fatty acids, fibre, and mineral elements (Tao et al. 2022; Zhang et al. 2024; Nie et al. 2025), which may improve diet palatability and nutrient availability, thereby supporting greater feed intake and body weight gain. Moreover, the retention of bioactive compounds during cold processing, together with the relatively high fibre content of linseed products, may contribute to improved digestive utilization and a more stable feeding pattern. Previous studies have also suggested that linseed supplementation can affect ruminal fermentation, nutrient digestibility, and long-chain fatty acid flow in ruminants (Soder et al. 2012; Silva et al. 2016; Schroeder et al. 2014; Cortes et al. 2011; Hawkins et al. 2013a; Gandra et al. 2016). Similar responses to dietary n-3 fatty acid supplementation have also been reported in preweaned dairy calves and lactating cows (Spitalniak-Bajerska et al. 2020; Kim et al. 2024). Therefore, the improved growth performance observed in the present study may be associated with the combined effects of enhanced palatability, improved nutrient supply, better digestive utilization, and favorable modulation of gastrointestinal or ruminal function.

4.2 Feed efficiency

Feed efficiency is an important indicator of nutrient utilization in beef cattle. In the present study, supplementation with cold-pressed linseed cake or ground linseed reduced the feed-to-gain ratio and improved feed efficiency in Qinchuan beef cattle, suggesting enhanced utilization of dietary nutrients. Similar findings have been reported previously. Wei (2025) found that replacing soybean meal with linseed meal improved nutrient digestibility and gastrointestinal microbial composition in fattening lambs, thereby contributing to improved feed utilization efficiency. Likewise, Wu et al. (2017) reported that replacing soybean meal with linseed cake improved feed conversion in sheep. Although direct evidence in beef cattle remains limited, studies in other species also indicate that feed efficiency can be influenced by diet-related microbial and metabolic regulation (Wang et al. 2019; Zhou et al. 2026).

The beneficial effect observed in the present study may be related to the nutritional value of flax-derived feed ingredients. Cold-pressed linseed cake contains substantial amounts of crude protein, unsaturated fatty acids, and minerals (Tao et al. 2022; Zhang et al. 2024), which may improve nutrient supply and reduce nutrient loss during growth. In addition, these nutrients may help optimize ruminal fermentation

and promote nutrient digestion and absorption. Previous studies have shown that the physical form of linseed and the supplementation strategy can influence digestibility, fatty acid utilization, and ruminal fermentation characteristics (Soder et al. 2012; Schroeder et al. 2014; Cortes et al. 2011; Hawkins et al. 2013a; Hafla et al. 2014). Furthermore, in vitro evidence suggests that dietary additives may alter fermentation characteristics and bacterial community profiles (Hao et al. 2024), supporting the possibility that flax-derived ingredients may affect feed efficiency partly through microbial regulation. Considering that cold-pressed linseed cake is more economical than linseed, the present results indicate that it may serve as a cost-effective feed ingredient for improving feed efficiency in Qinchuan beef cattle.

4.3 Slaughter performance

Dietary supplementation with cold-pressed linseed cake or ground linseed improved slaughter performance in Qinchuan beef cattle, particularly net meat yield and other carcass-related traits, indicating a positive effect on carcass development. These improvements may be associated with enhanced growth performance and nutrient utilization, which in turn contributed to better carcass characteristics.

Comparable results have been reported in previous studies. Hou et al. (2021) found that dietary supplementation with linseed cake significantly increased dressing percentage, carcass weight, and loin eye area in fattening lambs. Similarly, Wu et al. (2017) reported that replacing soybean meal with linseed cake improved dressing percentage and net meat yield in sheep. Beneficial effects of flax-derived ingredients on slaughter performance and muscle fatty acid traits have also been observed in other species, such as geese (Chang et al. 2026). In addition, the association between rumen microbiota and carcass merit in beef cattle suggests that dietary strategies capable of modulating ruminal metabolism may influence carcass development and carcass quality (Holman et al. 2024). These findings support the positive effects of flax-derived feed ingredients on slaughter performance observed in the present study.

The mechanism underlying these effects may be related to the nutritional characteristics of flax-derived feed ingredients. Cold-pressed linseed cake provides considerable amounts of crude protein and unsaturated fatty acids, which may promote muscle protein deposition and improve carcass composition (Tao et al. 2022; Zhang et al. 2024). In addition, linseed supplementation has been shown to influence lipid metabolism and fatty acid deposition in cattle (Li et al. 2010), which may partly explain the improvement in carcass traits observed in the present study. Therefore, flax-derived feed ingredients may enhance the meat production potential of Qinchuan beef cattle through improved nutrient supply and nutritional modulation.

4.4 Meat quality

Dietary supplementation with cold-pressed linseed cake or ground linseed improved meat quality traits in Qinchuan beef cattle, particularly colour and tenderness, while reducing moisture loss during processing. These findings suggest that flax-derived feed ingredients can enhance both the sensory characteristics and eating quality of beef.

The beneficial effects observed in the present study may be related to the nutritional properties of flax-derived feed ingredients. Previous studies have shown that linseed cake or related flax-derived products can improve meat quality traits in ruminants (Hou et al. 2021; Wu et al. 2017). In addition, linseed supplementation has been reported to modify intramuscular fatty acid composition and lipid metabolism in cattle (Li et al. 2010), which may contribute to improved colour stability, tenderness, and overall nutritional quality of beef. The high level of unsaturated fatty acids in flax-derived feed ingredients may also influence muscle lipid deposition and meat quality characteristics. Furthermore, improved nutrient digestibility and gastrointestinal microbial status associated with flax-derived feed ingredients (Wei 2025) may indirectly contribute to improved meat quality. The observed improvement in meat quality may also be related to broader physiological effects of n-3 fatty acids on growth, antioxidant status, and metabolism reported in young ruminants and dairy cattle (Spitalniak-Bajerska et al. 2020; Kim et al. 2024).

This effect may also be associated with the cold-pressing process, in which incomplete oil extraction results in the retention of substantial nutrients and bioactive compounds in cold-pressed linseed cake, thereby preserving functional components involved in the regulation of meat quality. In addition, ruminants exhibit a strong capacity to utilize oilseed cakes, suggesting considerable potential for their application as feed resources (Tao et al. 2022; Nie et al. 2025). It has been reported that the composition and distribution of the rumen microbial community are closely related to meat quality traits in beef cattle (Holman et al. 2024). Therefore, dietary strategies that modulate the rumen microecological environment may indirectly influence beef quality and its nutritional composition.

4.5 Nutritional composition of beef

Dietary inclusion of different forms of linseed and its by-products increased the deposition of unsaturated fatty acids in Qinchuan beef and improved the amino acid profile, thereby enhancing the nutritional value and flavor-related characteristics of beef.

Zhang (2025) reported that dietary linseed supplementation not only altered the fatty acid composition of beef, but also improved the n-6/n-3 polyunsaturated fatty acid ratio in fattening cattle, thereby contributing to better meat quality and flavor. Similarly, Li et al. (2010) found that linseed supplementation during the late fattening period could regulate the intramuscular fatty acid profile in beef cattle. Comparable findings have also been observed in other ruminants and livestock species. For example, dietary linseed inclusion in sheep improved fatty acid composition and related nutritional indices (Mi et al. 2018; Wu et al. 2017; Chang et al. 2026). These findings are generally consistent with the results of the present study, further supporting the positive role of linseed-based feed ingredients and their by-products in modulating muscle lipid composition.

The observed results may be partly explained by the high contents of α-linolenic acid and other unsaturated fatty acids in linseed-based ingredients, which may modulate ruminal lipid metabolism and subsequently promote the deposition of unsaturated fatty acids in muscle tissue (Li et al. 2010; Tao et al. 2022). Several studies have shown that linseed supplementation can alter long-chain fatty acid

profiles, improve nutrient digestibility, and modify rumen fermentation parameters in ruminants, thereby influencing the conversion and enrichment of dietary fatty acids in animal-derived products (Silva et al. 2016; Soder et al. 2012; Cortes et al. 2011). Meanwhile, cold-pressed linseed cake contains abundant protein and various nutrients (Zhang et al. 2024; Nie et al. 2025), which may provide substrates for muscle protein deposition and help optimize the muscle amino acid profile. Therefore, the improvements in fatty acid and amino acid quality observed in the present study may be attributed to the combined effects of nutrient supply and lipid metabolic regulation. Overall, these findings indicate that cold-pressed linseed cake may be used as an effective dietary ingredient to improve the nutritional value of beef.

5. Conclusion

In conclusion, under the conditions of the present study, dietary supplementation with linseed or linseed cake improved feed intake, average daily gain, and feed utilization efficiency in Qinchuan beef cattle. The cold-pressed linseed cake treatment showed the best overall feeding efficiency, with an average feed cost of CNY 15.15 per kg weight gain. Moreover, cold-pressed linseed cake improved slaughter-related traits, beef tenderness, and the contents of α-linolenic acid and amino acids in beef, thereby enhancing the nutritional value and eating quality of the meat. Therefore, cold-pressed linseed cake may serve as a promising feed ingredient for the development of high-quality beef products.

Declarations

Ethics statement

The study was approved by the Ethics committee of Aksaray University (2025/1–2). In addition, all procedures have followed the European policy for the safety of animals used for scientific research and other scientific purposes, which conform to the ethical standards set out in the 1964 Declaration of Helsinki and its subsequent amendments.

Ethics approval

All procedures involving animals in this study were performed in accordance with the institutional guidelines for the care and use of animals and were approved by the Animal Ethics Committee of Northwest A&F University.

Consent to participate

Not applicable, as this study did not involve human participants.

Consent for publication

Not applicable, as this study did not involve any individual person's data in any form.

Conflict of interest

All authors declare that there are no actual or po-tential conflicts of interest.

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Author Contributions

All authors contributed to the study conception and design.Material preparation and data collection and were performed by [Mr. Zhulong Gu]. All authors read and approved the final manuscript."

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Figures

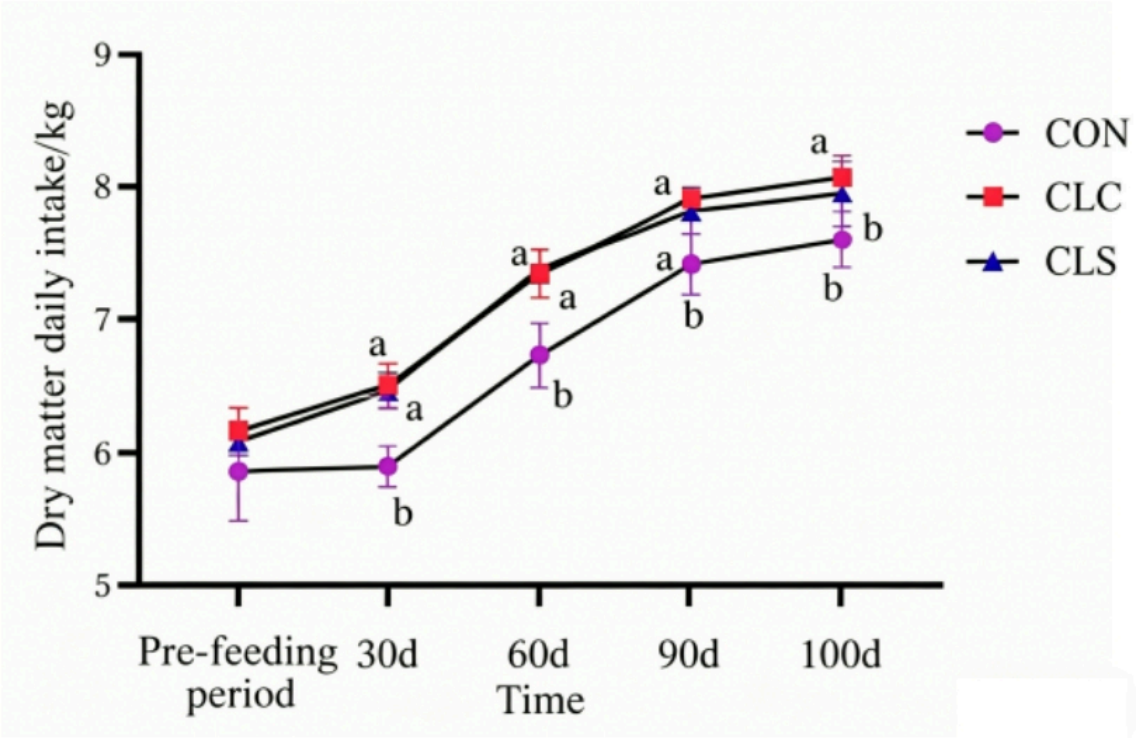


Figure 1

Changes in daily dry matter intake of Qinchuan beef cattle during the experimental period

Note: Different lowercase superscripts in the same line indicate significant differences (P<0.05);The same or no letter superscripts indicate insignificant difference (P>0.05). The same below.

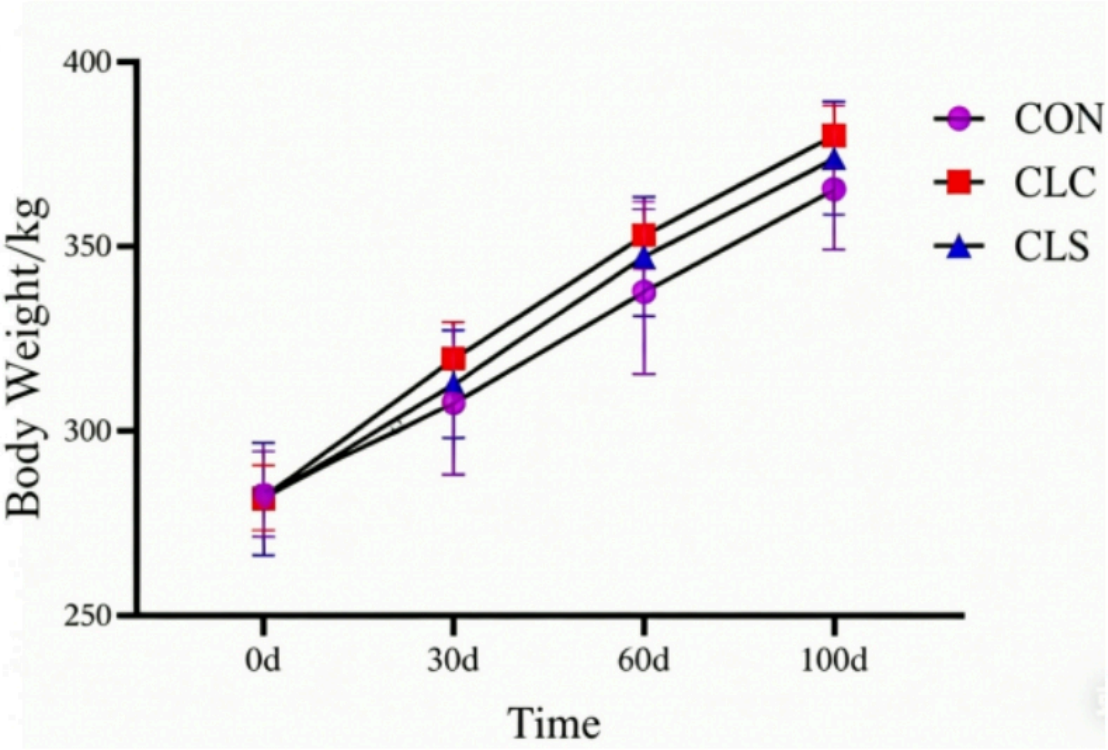


Figure 2

Changes in body weight of Qinchuan beef cattle during the experimental period

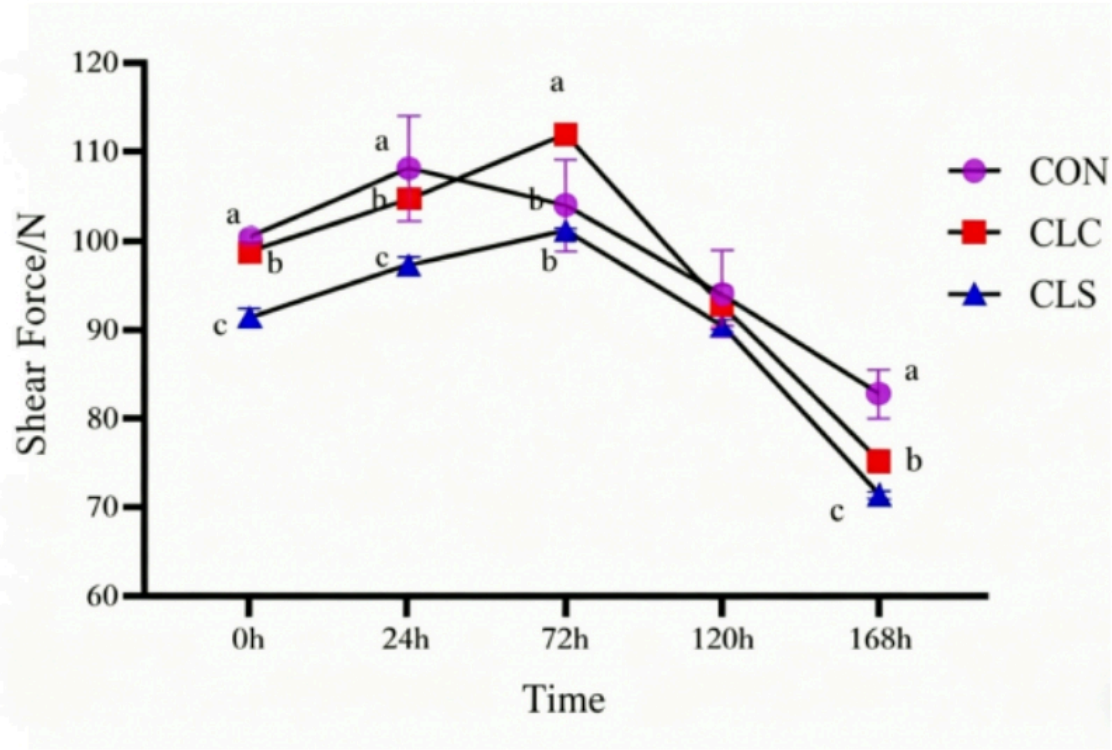


Figure 3

Changes in shear force of beef during postmortem aging

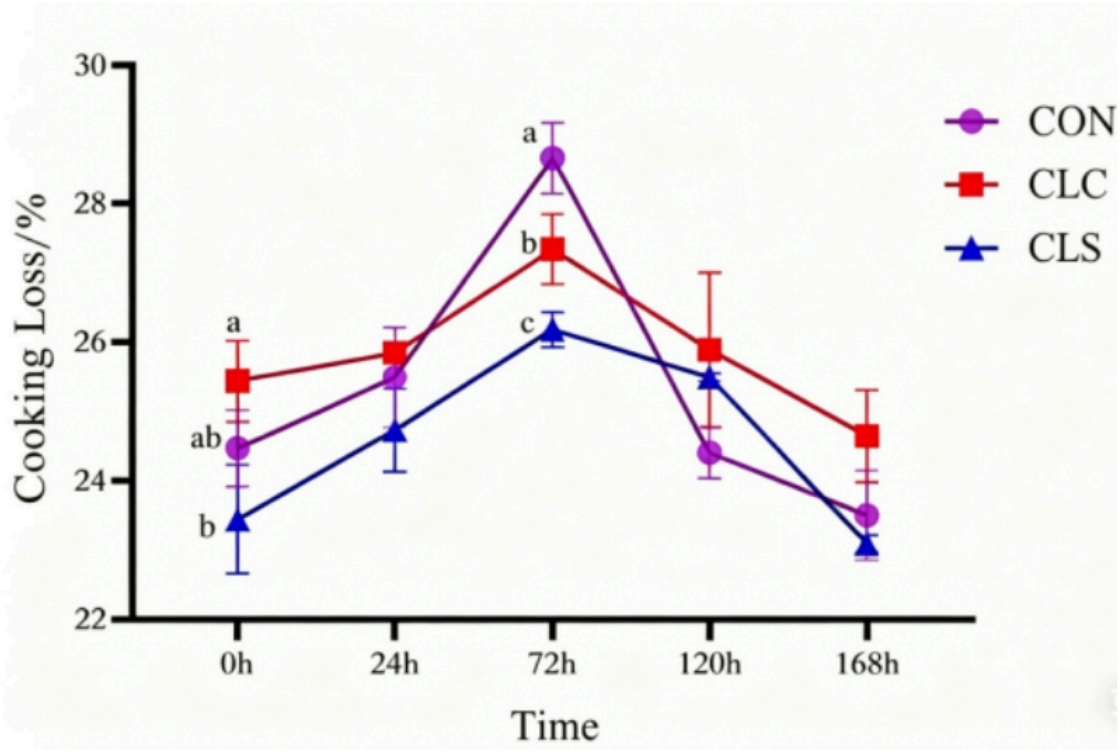


Figure 4

Changes in cooking loss of beef during postmortem aging

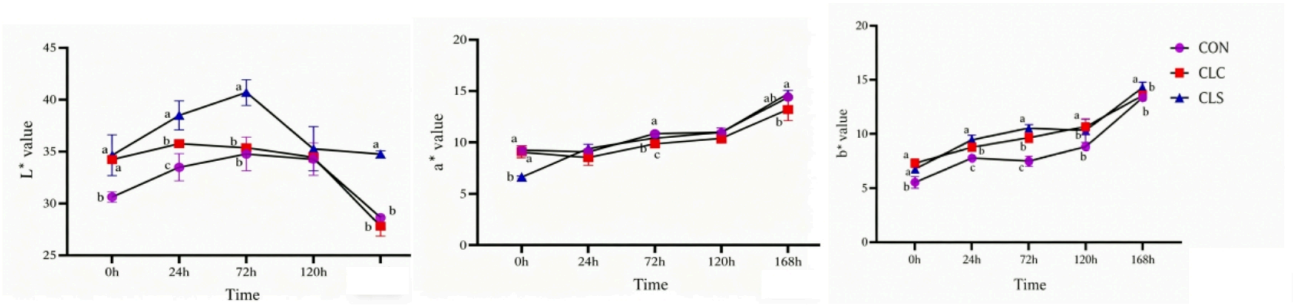


Figure 5

Changes in meat color parameters of beef during postmortem aging. (a) L* value; (b) a* value; (c) b* value.