

## Effects of Extrusion Processing on Anti-Nutritional Factor Content in Rapeseed Meal and of Extruded Rapeseed Meal on Growth Performance of Growing-Finishing Pigs (Postprint)

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### Abstract

This study aimed to investigate the effects of extrusion processing on anti-nutritional factors and nutrient contents in rapeseed meal (RM), as well as the effects of extruded rapeseed meal (ERM) on growth performance and nutrient apparent digestibility in growing-finishing pigs. Experiment 1: Feed-grade RM was processed using our laboratory's TSE65 twin-screw dry extruder with optimized processing parameter combinations, and the anti-nutritional factors and nutrient contents in RM and ERM were determined. Experiment 2: Using RM and ERM as main test materials, 72 Duroc × Landrace × Yorkshire crossbred pigs with body weight of (33.82±\$3.72) kg were selected and randomly divided into 6 groups, with 3 replicates per group and 4 pigs per replicate. During weeks 1-6, groups 1, 3, and 5 were fed diets supplemented with 6%, 10%, and 14% RM, respectively, while groups 2, 4, and 6 were fed diets supplemented with 6%, 10%, and 14% ERM, respectively; during weeks 7-12, groups 1, 3, and 5 were fed diets supplemented with 10%, 14%, and 18% RM, respectively, while groups 2, 4, and 6 were fed diets supplemented with 10%, 14%, and 18% ERM, respectively. The experimental period was 12 weeks. The results showed that: 1) Compared with RM, the contents of dry matter, crude protein, crude fat, crude ash, calcium, and total phosphorus in ERM all increased; the contents of crude fat and dry matter in ERM were significantly higher ( $P<0.05$ ), while cysteine, lysine, and arginine contents were significantly lower ( $P<0.05$ ), total amino acid content decreased by 1.75% ( $P>0.05$ ), glucosinolate and phytic acid contents were significantly reduced ( $P<0.05$ ), isothiocyanate and oxazolidinethione contents were below the detection limit of 0.15 mg/g, and tannin content showed no significant change ( $P>0.05$ ). 2) During weeks 1-6, at the same supplementation level, the final body weight (FBW) of groups 2 and 4 was significantly higher than that

of groups 1 and 3 ( $P < 0.05$ ); the average daily feed intake (ADFI) of group 4 was significantly higher than that of all other groups ( $P < 0.05$ ); there were no significant differences in average daily gain (ADG) and feed-to-gain ratio (F/G) among all groups ( $P > 0.05$ ); the apparent digestibility of crude protein, crude fat, and dry matter in group 6 was significantly higher than that in group 5 ( $P < 0.05$ ); except for methionine, serine, and glutamic acid, whose apparent digestibility showed no significant difference from group 5 ( $P > 0.05$ ), the apparent digestibility of all other amino acids in group 6 was significantly higher than that in group 5 ( $P < 0.05$ ). During weeks 7-12, at the same supplementation level, the FBW of groups 2 and 4 was higher than that of groups 1 and 3, and the FBW of group 6 was lower than that of group 5, but the differences were not significant ( $P > 0.05$ ); the apparent digestibility of crude protein, crude fat, and dry matter in group 2 was significantly higher than that in group 1 ( $P < 0.05$ ); the apparent digestibility of valine, isoleucine, lysine, histidine, threonine, aspartic acid, tyrosine, glutamic acid, glycine, cysteine, proline, and total amino acids in group 2 was significantly higher than that in group 1 ( $P < 0.05$ ). It can be concluded that extrusion processing can improve the nutritional value of RM and reduce the content of various anti-nutritional factors, and adding ERM to finishing pig diets can improve the growth performance and nutrient apparent digestibility of finishing pigs. The appropriate supplementation level of ERM in diets for 30-60 kg finishing pigs is 10%, and for 61-120 kg finishing pigs is 14%.

## Full Text

### Effects of Extrusion on Antinutritional Factor Content in Rapeseed Meal and Expanded Rapeseed Meal on Growth Performance of Growing-Finishing Pigs

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## Abstract

This study investigated the effects of extrusion processing on antinutritional factors and nutrient composition in rapeseed meal (RM), as well as the impact of expanded rapeseed meal (ERM) on growth performance and nutrient apparent digestibility in growing-finishing pigs. Experiment 1 utilized a TSE65 twin-screw dry extruder with optimized parameters to process feed-grade RM,

with subsequent analysis of antinutritional factors and nutrient contents in both RM and ERM. Experiment 2 employed 72 healthy Duroc  $\times$  Landrace  $\times$  Large White crossbred pigs (initial body weight  $33.82 \pm 3.72$  kg) randomly allocated into six groups with three replicates per group and four pigs per replicate. During weeks 1–6, groups 1, 3, and 5 received diets containing 6%, 10%, and 14% RM, respectively, while groups 2, 4, and 6 received diets containing 6%, 10%, and 14% ERM, respectively. During weeks 7–12, groups 1, 3, and 5 received diets containing 10%, 14%, and 18% RM, respectively, while groups 2, 4, and 6 received diets containing 10%, 14%, and 18% ERM, respectively. The 12-week feeding trial yielded the following results: (1) Compared with RM, ERM exhibited increased contents of dry matter, crude protein, ether extract, crude ash, calcium, and total phosphorus, with ether extract and dry matter being significantly elevated ( $P < 0.05$ ). The contents of cystine, lysine, and arginine were significantly reduced ( $P < 0.05$ ), while total amino acid content decreased by 1.75% ( $P > 0.05$ ). Glucosinolate and phytic acid contents were significantly reduced ( $P < 0.05$ ), isothiocyanates and oxazolidinethione fell below the detection limit of 0.15 mg/g, and tannin content remained unchanged ( $P > 0.05$ ). (2) During weeks 1–6, at equivalent inclusion levels, final body weight (FBW) in groups 2 and 4 was significantly higher than in groups 1 and 3 ( $P < 0.05$ ), while average daily feed intake (ADFI) in group 4 significantly exceeded all other groups ( $P < 0.05$ ). No significant differences were observed in average daily gain (ADG) or feed-to-gain ratio (F/G) among groups ( $P > 0.05$ ). Apparent digestibility of crude protein, ether extract, and dry matter in group 6 was significantly higher than in group 5 ( $P < 0.05$ ), and group 6 also showed significantly higher apparent digestibility of most amino acids compared with group 5 ( $P < 0.05$ ), except for methionine, serine, and glutamic acid. During weeks 7–12, at equivalent inclusion levels, FBW in groups 2 and 4 was higher than in groups 1 and 3, while FBW in group 6 was lower than in group 5, though these differences were not significant ( $P > 0.05$ ). Apparent digestibility of crude protein, ether extract, and dry matter in group 2 was significantly higher than in group 1 ( $P < 0.05$ ), and group 2 also exhibited significantly higher apparent digestibility of valine, isoleucine, lysine, histidine, threonine, aspartic acid, tyrosine, glutamic acid, glycine, cysteine, proline, and total amino acids compared with group 1 ( $P < 0.05$ ). These findings demonstrate that extrusion processing enhances the nutritional value of RM while reducing multiple antinutritional factors, and that dietary ERM supplementation improves growth performance and nutrient apparent digestibility in finishing pigs. The optimal ERM inclusion level was 10% for 30–60 kg pigs and 14% for 61–120 kg pigs.

**Keywords:** expanded rapeseed meal; growing-finishing pigs; antinutritional factors; growth performance; apparent digestibility

## Introduction

Rapeseed meal (RM) represents a valuable protein feed ingredient for swine and poultry diets; however, its high content of crude fiber and various antinutritional factors—including glucosinolates and tannins—severely compromises feed safety, palatability, and nutrient utilization, thereby limiting its application in livestock diets. While the cultivation of double-low rapeseed varieties in recent years has substantially reduced glucosinolate and erucic acid contents, levels of antinutritional factors such as tannins and phytic acid remain comparable to conventional rapeseed and cannot currently be resolved through breeding approaches alone. Consequently, developing processing methods to reduce antinutritional factor content and improve protein utilization efficiency in RM holds significant practical importance.

Extrusion processing subjects feed materials to high temperature, pressure, and shear forces before extrusion through a die or sudden release from a pressure vessel, causing instantaneous expansion. Under these conditions, RM undergoes cell wall rupture, molecular structure disruption, starch gelatinization, and protein denaturation, forming a porous structure that facilitates digestive enzyme action and enhances nutrient utilization. Simultaneously, extrusion can inactivate antinutritional factors such as phytic acid and tannins, reducing their binding with proteins and thereby improving protein availability. Previous research by Mou Yongyi et al. demonstrated that extrusion significantly reduced tannin content and altered flavor from astringent to sweet. Leming et al. reported that heat treatment effectively reduced glucosinolate content in RM, with wet heat treatment proving more effective than dry heat treatment. Tian Zhenzhen et al. found that extrusion of double-low RM severely degraded isothiocyanates and oxazolidinethione, while tannin content remained largely unchanged. Zhou Lijun et al. achieved detoxification rates of 89.30–93.30% through instantaneous high-temperature and high-pressure treatment, and observed no significant adverse effects on growth performance or hepatic, renal, and thyroid function when using the detoxified RM at inclusion levels up to 23% (complete soybean meal replacement) in chicken diets. However, previous studies have primarily focused on either processing technology for RM detoxification or the effects of detoxified RM on animal performance, with relatively narrow evaluation criteria and lacking comprehensive assessment of how extrusion affects RM nutrient composition, antinutritional factor content, and the subsequent effects of ERM on growth performance and nutrient apparent digestibility in growing pigs. Therefore, this study aimed to investigate the effects of extrusion on RM nutrient composition and antinutritional factor content, while evaluating the feasibility of using ERM as a protein feed ingredient for growing-finishing pigs to enhance RM utilization, increase dietary inclusion levels, and reduce production costs.

## Materials and Methods

**1.1 Extrusion Processing Technology and Parameters** Feed-grade RM was processed using a TSE65 twin-screw dry extruder in our laboratory. Extrusion parameters were as follows: screw speed 30 Hz, die aperture 4 mm (3 holes retained), feed rate 9 Hz, extrusion temperature 120 °C, and moisture addition 10%.

**1.2 Experimental Animals and Grouping** Seventy-two healthy commercial crossbred growing-finishing pigs (Duroc × Landrace × Large White) with an average initial body weight of  $(33.82 \pm 3.72)$  kg were randomly allocated into six groups according to body weight, with three replicates per group and four pigs per replicate. No significant differences in body weight existed among groups or replicates ( $P > 0.05$ ).

**1.3 Experimental Diets and Design** The 12-week feeding trial consisted of two phases (early phase: weeks 1-6; late phase: weeks 7-12). During the early phase, groups 1, 3, and 5 received corn-soybean meal-based diets supplemented with 6%, 10%, and 14% RM, respectively, while groups 2, 4, and 6 received diets supplemented with 6%, 10%, and 14% ERM, respectively. During the late phase, groups 1, 3, and 5 received diets containing 10%, 14%, and 18% RM, respectively, while groups 2, 4, and 6 received diets containing 10%, 14%, and 18% ERM, respectively. Diets were formulated according to NRC (2012) nutrient requirements for 30-120 kg growing pigs and actual production levels. Diet composition and nutrient levels are presented in Table 1 .

**1.4 Husbandry Management** The trial was conducted at the Nankou Pilot Base of the Chinese Academy of Agricultural Sciences. Pig pens were thoroughly cleaned and disinfected one week before the trial. A 3-day adaptation period preceded the 12-week experimental period (divided into two 6-week phases). Pigs were housed in mixed-gender groups with ad libitum access to feed and water. Pens were maintained clean and well-ventilated, with strict temperature control and regular disinfection.

## 1.5 Sample Collection and Analysis

**1.5.1 Nutrient and Antinutritional Factor Analysis** Nutrient composition was determined for crude protein (GB/T 6432-1994, Kjeldahl method), ether extract (M392885 automatic Soxhlet extraction system), amino acids (L-8900 high-speed amino acid analyzer), dry matter (GB/T 10358-1989), crude ash (GB/T 6438-2007), calcium (GB/T 6436-2002, permanganate method), and total phosphorus (GB/T 6437-2002, spectrophotometry). Antinutritional factors were analyzed for glucosinolates (NY/T 1582-2007, HPLC), phytic acid (SN/T 3635-2013, spectrophotometry), tannins (SN/T 0800.9-1999), isothiocyanates (GB 13087-91, gas chromatography), and oxazolidinethione (NY/T

1799-2009, UV spectrophotometry).

**1.5.2 Growth Performance Measurement** Pigs were weighed at 08:00 after overnight fasting at the end of weeks 6 and 12. Final body weight (FBW), average daily feed intake (ADFI), average daily gain (ADG), and feed-to-gain ratio (F/G) were calculated on a replicate basis using the following formulas:  $ADG = (\text{final weight per pig} - \text{initial weight per pig}) / \text{days}$ ;  $ADFI = \text{total feed consumption} / (\text{number of pigs} \times \text{days})$ ;  $F/G = \text{total feed intake} / \text{total weight gain}$ .

**1.5.3 Nutrient Apparent Digestibility Determination** Fresh feces were collected daily from each group during the final 3 days of weeks 6 and 12, mixed, weighed, and treated with 20 mL of 5% HCl per 100 g of feces. Samples were then dried at 65 °C for 72 hours, equilibrated at room temperature for 24 hours, ground to pass through a 40-mesh sieve, and stored for analysis. Crude protein, ether extract, dry matter, and acid-insoluble ash contents in diets and feces were determined according to national standard methods to calculate apparent digestibility using the formula:  $\text{Apparent digestibility (\%)} = 100 - [(\text{acid-insoluble ash in diet (\%)} \times \text{nutrient in feces (\%)}) / (\text{acid-insoluble ash in feces (\%)} \times \text{nutrient in diet (\%)})] \times 100$ .

**1.6 Statistical Analysis** Data were initially processed using Excel 2007, followed by one-way ANOVA and covariance analysis using the SAS 9.2 statistical software. Duncan's multiple range test was employed for multiple comparisons and significance analysis. Results are expressed as means  $\pm$  standard deviation, with significance declared at  $P < 0.05$ .

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## Results

### 2.1 Effects of Extrusion on Nutrient and Antinutritional Factor Contents in RM

**2.1.1 Effects on Nutrient Composition** As shown in Table 2, compared with RM, ERM exhibited increased contents of dry matter, crude protein, ether extract, crude ash, calcium, and total phosphorus, with ether extract and dry matter being significantly higher ( $P < 0.05$ ). Crude fiber content in ERM was slightly reduced ( $P > 0.05$ ).

Table 3 reveals that ERM had significantly lower contents of cystine, lysine, and arginine compared with RM ( $P < 0.05$ ), while other amino acid contents remained unchanged ( $P > 0.05$ ). Total amino acid content decreased from 36.64% to 36.00% ( $P > 0.05$ ).

**2.1.2 Effects on Antinutritional Factors** Table 4 demonstrates that extrusion significantly reduced glucosinolate and phytic acid contents in ERM ( $P < 0.05$ ), decreasing from 16.49  $\mu\text{mol/g}$  and 52.38  $\text{mg/g}$  to 1.96  $\mu\text{mol/g}$  and 46.14  $\text{mg/g}$ , respectively, representing reduction rates of 88.11% and 11.91%. Isothiocyanates and oxazolidinethione were severely degraded to levels below the detection limit of 0.15  $\text{mg/g}$ , while tannin content showed no significant change ( $P > 0.05$ ).

**2.2 Effects of ERM on Growth Performance of Growing-Finishing Pigs** During weeks 1-6, at equivalent inclusion levels, FBW in groups 2 and 4 was significantly higher than in groups 1 and 3 ( $P < 0.05$ ), while ADFI in group 4 significantly exceeded all other groups ( $P < 0.05$ ). No significant differences were observed in ADG or F/G among groups ( $P > 0.05$ ). ADFI, ADG, FBW, and F/G exhibited a trend of initial increase followed by decrease with increasing ERM inclusion levels. During weeks 7-12, FBW in groups 2 and 4 was higher than in groups 1 and 3, while FBW in group 6 was lower than in group 5, though these differences were not significant ( $P > 0.05$ ). No significant differences in ADFI or F/G were detected among groups ( $P > 0.05$ ). Over the entire 12-week period, FBW, ADFI, and ADG in groups 2 and 4 were higher than in groups 1 and 3 at equivalent inclusion levels, with FBW and ADG in group 4 being significantly higher than in group 3 ( $P < 0.05$ ). No significant differences in ADFI or F/G were observed among groups ( $P > 0.05$ ). These results are summarized in Table 5 .

**2.3.1 Effects on Apparent Digestibility of Crude Protein, Dry Matter, and Ether Extract** During weeks 1-6, at equivalent inclusion levels, groups 1, 3, and 5 showed lower apparent digestibility of crude protein and dry matter compared with groups 2, 4, and 6, with group 6 being significantly higher than group 5 ( $P < 0.05$ ). No significant difference was observed between groups 1 and 2 ( $P > 0.05$ ). Ether extract apparent digestibility in group 6 was significantly higher than in group 5 ( $P < 0.05$ ). Apparent digestibility of ether extract, dry matter, and crude protein increased progressively with increasing ERM inclusion, while RM inclusion resulted in an initial increase followed by a decrease. During weeks 7-12, groups 2, 4, and 6 exhibited higher apparent digestibility of dry matter, ether extract, and crude protein compared with groups 1, 3, and 5 at equivalent inclusion levels. Increasing ERM inclusion led to gradual decreases in crude protein and dry matter digestibility but increases in ether extract digestibility, whereas RM inclusion produced an initial increase followed by a decrease in crude protein and dry matter digestibility and a continuous increase in ether extract digestibility. These findings are presented in Table 6 .

**2.3.2 Effects on Amino Acid Apparent Digestibility** During weeks 1-6, at equivalent inclusion levels, group 6 demonstrated significantly higher apparent digestibility of most amino acids compared with group 5 ( $P < 0.05$ ), except for methionine, serine, and glutamic acid ( $P > 0.05$ ), with no significant

differences among other groups ( $P > 0.05$ ). Most amino acid digestibility values showed an initial decrease followed by an increase with rising ERM inclusion levels, and an initial slight increase followed by a substantial decrease with increasing RM inclusion. During weeks 7–12, group 2 exhibited significantly higher apparent digestibility of valine, isoleucine, lysine, histidine, threonine, aspartic acid, tyrosine, glutamic acid, glycine, cysteine, proline, and total amino acids compared with group 1 ( $P < 0.05$ ), with no significant differences in other amino acids among groups ( $P > 0.05$ ). Most amino acid digestibility values decreased progressively with increasing ERM inclusion, while RM inclusion produced an initial increase followed by a decrease. These results are detailed in Table 7 .

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## Discussion

**3.1.1 Effects of Extrusion on RM Nutrient Composition** Extrusion processing resulted in slight but non-significant increases in dry matter, crude protein, calcium, and total phosphorus contents, indicating minimal impact on these nutrients. This finding contrasts with Guo Jianlin et al., who reported protein degradation from extrusion, likely attributable to different processing conditions. Notably, their study also found no significant difference in protein content. The significant increase in ether extract and dry matter contents may be attributed to cell wall disruption under high temperature, pressure, and shear forces, releasing intracellular oils into the material. The slight reduction in crude fiber content may result from increased Maillard reaction products following protein heat denaturation, leading to elevated neutral detergent fiber content that increases linearly with processing temperature and intensity. Some researchers suggest that high pressure, temperature, and shear forces during extrusion break chemical bonds between fiber molecules, altering molecular polarity and significantly reducing crude fiber content while increasing soluble fiber. Our results align with Zhong Yongxing's findings of reduced crude fiber content in extruded RM.

**3.1.2 Effects of Extrusion on Antinutritional Factors in RM** The 88.11% reduction in glucosinolates observed in this study is consistent with Huang et al.'s findings of extensive glucosinolate destruction during RM extrusion. The 11.91% reduction in phytic acid indicates that while phytic acid is heat-labile, it remains relatively stable under short-term heating below 120 °C, corroborating Xie Tiemin's results. The negligible 1.43% reduction in tannin content differs from Xiao Zhigang et al., who reported up to 50% tannin reduction. This discrepancy may be attributed to low moisture content and high screw speed in our study, as low moisture impedes instantaneous expansion during extrusion and high speed reduces residence time, thereby decreasing tannin inactivation. The extensive degradation of isothiocyanates and oxazolidinethione to below detection limits aligns with Tian Zhenzhen et al.'s findings.

**3.1.3 Effects of Extrusion on Amino Acid Content in RM** RM contains a relatively balanced amino acid profile, with lysine being the primary limiting amino acid despite abundant methionine and cystine contents. RM quality is highly sensitive to overheating due to Maillard reactions that reduce lysine content and impair essential amino acid availability, particularly lysine. Our study found significant reductions in the heat-sensitive amino acids cystine, lysine, and arginine following extrusion, with total amino acid content decreasing from 36.64% to 36.00%. This reduction is attributed to thermal degradation of these three amino acids at high extrusion temperatures and Maillard reactions between lysine and reducing sugars or carbonyl compounds, which reduce lysine availability and protein biological value.

**3.2 Effects of ERM on Growth Performance of Growing-Finishing Pigs** Heat treatment through extrusion inactivates myrosinase in RM, thereby inhibiting the enzymatic conversion of glucosinolates to toxic metabolites, partially detoxifying the meal and improving palatability and digestibility. In this study, dietary inclusion of graded ERM levels (6%, 10%, and 14% in early phase; 10%, 14%, and 18% in late phase) increased FBW, ADFI, and ADG while reducing F/G compared with equivalent RM levels, indicating improved palatability of ERM-supplemented diets. Optimal F/G and growth promotion were achieved at 10% ERM inclusion during the early phase and 14% during the late phase, with growth performance showing a quadratic response to increasing ERM levels. This may be explained by: (1) substantial destruction of antinutritional factors and improved digestibility of dry matter and protein, with significant improvements in ether extract and crude fiber digestibility, along with enhanced flavor and palatability that increased feed intake and ADG; and (2) structural disruption of rapeseed proteins, including disulfide bond cleavage and peptide chain unfolding, which facilitates protease hydrolysis and digestion. However, as ERM inclusion increased, the concomitant rise in residual antinutritional factors such as tannins and phytic acid beyond tolerance thresholds may have compromised palatability and protein utilization, thereby reducing growth performance.

**3.3.1 Effects of ERM on Apparent Digestibility of Crude Protein, Dry Matter, and Ether Extract** Apparent digestibility of dietary energy and nutrients in growing-finishing pigs is influenced by dietary chemical composition, processing methods, animal sex and physiological status, analytical methodology, and feeding level. High dietary fiber content typically impairs nutrient digestion and absorption, particularly protein, minerals, and amino acids. Different processing methods can substantially alter protein feed nutritional value and nutrient digestibility, as excessive heating reduces protein digestibility. Our study demonstrated significant increases in apparent digestibility of dry matter, ether extract, and crude protein following RM extrusion, with nutrient digestibility increasing progressively with ERM inclusion but decreasing with RM inclusion. This improvement likely results from disruption of cellular

lignin structures in rapeseed fiber by high temperature, pressure, and expansion, which breaks hydrogen bonds, reduces crystallinity, degrades macromolecules, and transforms the compact structure into a porous matrix that releases digestible components and expands the surface area for digestion. Additionally, protein denaturation and disulfide bond cleavage create a loose structure with expanded surface area that is readily hydrolyzed by proteases. Zhang Qunying et al. reported that nutrient apparent digestibility increases with feed intake, and ERM inactivation of antinutritional factors improved palatability, thereby increasing feed intake and nutrient digestibility. However, excessive heating can reduce lysine availability through Maillard reactions with reducing sugars, diminishing protein biological value.

**3.3.2 Effects of ERM on Amino Acid Apparent Digestibility** Dietary protein nutritional value depends on both total amino acid content and utilization efficiency. Amino acid utilization represents the proportion of digested and absorbed amino acids available for metabolism, with digestibility being the primary influencing factor. Xi Pengbin et al. found that most amino acids in RM (except cystine and methionine) showed positive correlations between apparent digestibility and dietary amino acid levels, consistent with Fan et al. In our study, total amino acid content (17 amino acids) in ERM was slightly lower than in RM, contrasting with Zhong Yongxing's findings, possibly due to differences in extrusion parameters and RM varieties. However, apparent digestibility of all 17 amino acids improved to varying degrees following extrusion, with the 14% ERM group showing significantly higher digestibility than the 14% RM group during the early phase, and the 10% ERM group significantly outperforming the 10% RM group during the late phase for most amino acids. These results align with Zhong Yongxing's findings of significantly improved amino acid digestibility in ERM.

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## Conclusion

Based on the experimental results, the following conclusions can be drawn:

1. Extrusion processing of RM increased contents of crude protein, ether extract, crude ash, calcium, and total phosphorus, as well as apparent digestibility of dry matter, ether extract, crude protein, and amino acids, while reducing crude fiber content and levels of lysine, arginine, and cystine, with no significant effects on other amino acids.
2. Extrusion significantly reduced contents of glucosinolates, phytic acid, isothiocyanates, and oxazolidinethione, but had minimal effect on tannin content.
3. ERM supplementation significantly improved ADG, ADFI, and FBW in growing-finishing pigs, with a trend toward reduced F/G. Growth performance increased initially then decreased with rising ERM inclusion levels.

4. The recommended ERM inclusion level is 10% for 30-60 kg growing-finishing pigs and 14% for 61-120 kg growing-finishing pigs.
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*Note: Figure translations are in progress. See original paper for figures.*

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