

## Effects of Extruded Corn Inclusion Level on Pellet Feed Processing Quality and Growth Performance of Weaned Piglets under Double Pelleting: Postprint

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### Abstract

This experiment aimed to investigate the effects of extruded corn inclusion ratio on pellet feed processing quality, growth performance, nutrient apparent digestibility, and serum biochemical indices of weaned piglets under a secondary pelleting process. The diets were formulated with five extruded corn inclusion ratios (percentage of extruded corn in total corn addition) of 0, 25%, 50%, 75%, and 100%, and pellet feed was processed using a secondary pelleting process. A total of 80 weaned piglets at 28 days of age with an initial body weight of  $(8.57 \pm 0.87)$  kg were selected and randomly allocated into 5 groups with 4 replicates per group and 4 piglets per replicate for a 50-day feeding trial, which was divided into two phases: phase 1 (days 1-28) and phase 2 (days 29-50). The results showed that: 1) In terms of pellet feed processing quality, pellet hardness, Pellet Durability Index (PDI), and starch gelatinization degree increased with increasing extruded corn inclusion ratio. 2) Regarding growth performance of weaned piglets, there were no significant differences among groups in final weight, average daily gain (ADG), or average daily feed intake (ADFI) during phase 1 ( $P > 0.05$ ), while feed conversion ratio (FCR) was significantly higher in the 0% group than in other groups ( $P < 0.05$ ); during phase 2, no significant differences were observed among groups in final weight, ADG, ADFI, or FCR ( $P > 0.05$ ); over the entire experimental period, no significant differences were found among groups in final weight, ADG, ADFI, or FCR ( $P > 0.05$ ). 3) For nutrient apparent digestibility in weaned piglets, both dry matter and crude protein apparent digestibility were highest in the 100% group and lowest in the 0% group, with the 0% group being significantly lower than all extruded corn inclusion groups ( $P < 0.05$ ). 4) In serum biochemical indices of weaned piglets, serum total protein content in the 75% group was significantly higher than that

in the 0%, 50%, and 100% groups ( $P < 0.05$ ); serum triglyceride content in the 0% group was significantly higher than that in the 50%, 75%, and 100% groups ( $P < 0.05$ ); serum alkaline phosphatase activity in the 100% group was significantly higher than that in the 0% group ( $P < 0.05$ ); serum calcium content in the 50% group was significantly lower than that in all other groups ( $P < 0.05$ ). Considering the comprehensive effects of extruded corn inclusion ratio on pellet hardness, growth performance of weaned piglets, and processing costs, it is recommended that the extruded corn inclusion rate in weaned piglet diets be 25% of total corn addition under secondary pelleting process conditions.

## Full Text

### Effects of Expanded Corn Additive Proportion under Secondary Pelleting Process on Processing Quality of Pellet Feed and Growth Performance of Weaned Piglets

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## Abstract

This experiment was conducted to investigate the effects of expanded corn additive proportion under secondary pelleting process on pellet feed processing quality, growth performance, nutrient apparent digestibility, and serum biochemical indices of weaned piglets. Five dietary treatments were formulated with varying proportions of expanded corn (0%, 25%, 50%, 75%, and 100% of total corn content) and processed into pellet feed using secondary pelleting. Eighty 28-day-old weaned piglets with initial body weight of  $(8.57 \pm 0.87)$  kg were randomly allocated to 5 groups with 4 replicates per group and 4 piglets per replicate. The 50-day feeding trial consisted of two phases: early phase (days 1-28) and late phase (days 29-50). The results showed that: (1) pellet hardness, pellet durability index (PDI), and starch gelatinization degree increased with higher expanded corn proportions; (2) during the early phase, feed conversion ratio (FCR) in the 0% group was significantly higher than other groups ( $P < 0.05$ ), though final body weight, average daily gain (ADG), and average daily feed intake (ADFI) showed no significant differences; (3) during the late and overall

phases, no significant differences were observed in growth performance parameters among groups; (4) apparent digestibility of dry matter and crude protein was highest in the 100% group and lowest in the 0% group, with the 0% group being significantly lower than all expanded corn groups ( $P < 0.05$ ); (5) serum total protein in the 75% group was significantly higher than in the 0%, 50%, and 100% groups ( $P < 0.05$ ), while serum triglycerides in the 0% group were significantly higher than in the 50%, 75%, and 100% groups ( $P < 0.05$ ). Considering the effects on pellet hardness, piglet growth performance, and processing costs, the optimal proportion of expanded corn in weaned piglet diets under secondary pelleting process is recommended to be 25% of total corn content.

**Keywords:** weaned piglets; secondary pelleting; expanded corn; processing quality; growth performance; apparent digestibility; serum biochemical indices

## Introduction

With the continuous development of intensive animal production and animal nutrition research, the nutrition and processing of early-weaning diets for piglets have received widespread attention. Weaning is a critical stage in pig production, as piglets transition from liquid milk rich in lactose to solid diets, which often causes weaning stress leading to intestinal damage and functional disorders. Energy intake from the diet is a key factor in overcoming weaning stress. Corn serves as the primary energy source in animal feeds and is widely used in livestock diets. However, corn starch molecules form compact granular structures with acid- and enzyme-resistant crystalline arrangements that hinder digestion and absorption. Additionally, weaned piglets have immature digestive systems, poor nutrient absorption capacity, and insufficient secretion of digestive enzymes and gastric acid. Therefore, feed manufacturers commonly substitute a portion of corn with expanded corn in piglet diets. Expanded corn undergoes starch granule rupture and high gelatinization, and structural changes in corn provide space for enzymatic action, thereby improving energy utilization efficiency and reducing diarrhea in piglets. Previous studies have demonstrated that expanded corn supplementation significantly increases average daily gain and reduces feed-to-gain ratio in weaned piglets. However, these studies focused on the effects of adding a fixed amount of expanded corn, while research on the optimal proportion of expanded corn for maximal growth performance and its impact on pellet feed processing quality under secondary pelleting conditions remains scarce. This study aimed to determine the optimal proportion of expanded corn as a replacement for regular corn under secondary pelleting conditions and evaluate its effects on pellet processing quality and weaned piglet growth performance.

## Materials and Methods

### 1.1 Basal Diet Composition

The composition and nutrient levels of the basal diet are presented in Table 1. The premix provided the following per kilogram of diet: VA 2,104 IU, VD 300

IU, VE 6.66 IU, VK 0.83 IU, VB 1.53 mg, VB 0.9 mg, VB 6 g, pantothenic acid 5.0 mg, niacin 10.1 mg, biotin 0.02 mg, Cu 33.33 mg, Fe 30 mg, Mn 13.33 mg, Zn 26.67 mg, I 0.28 mg, Se 0.08 mg. Crude protein was measured, while other nutrient levels were calculated values.

## 1.2 Experimental Design

The experiment employed a secondary pelleting process. Corn, expanded soybean meal, and other ingredients requiring grinding were first ground through a 2.0 mm sieve. All powdered macro-ingredients except heat-sensitive materials and premix were blended to create a macro-mixture, which underwent high-temperature pelleting (conditioning temperature 90°C, die diameter 3 mm, length-to-diameter ratio 5:1). The resulting pellets were then ground through a 1.5 mm sieve and mixed with heat-sensitive ingredients, premix, and oil. Finally, low-temperature pelleting was performed (conditioning temperature 60°C, die diameter 3 mm, length-to-diameter ratio 5:1). Five dietary treatments were formulated with expanded corn proportions of 0%, 25%, 50%, 75%, and 100% of total corn content. The feeding trial was conducted at the Nankou Research Base of the Chinese Academy of Agricultural Sciences using a single-factor design. Eighty 28-day-old weaned piglets with initial body weight of  $(8.57 \pm 0.87)$  kg were randomly assigned to 5 groups based on litter, parity, and body weight, with 4 replicates per group and 4 piglets per replicate. The 50-day trial consisted of two phases: early phase (28 days) and late phase (22 days).

## 1.3 Feeding Management

All groups were maintained under identical environmental conditions with ad libitum access to feed and water via automatic drinkers. Feed was provided four times daily at 08:00, 12:00, 16:00, and 20:00. Ventilation was provided by exhaust fans, and pig houses were disinfected three times weekly. Ambient temperature was maintained at 26–28°C with relative humidity of 60–70%. Routine immunization procedures for piglets were followed throughout the trial.

## 1.4 Measurement Indicators

**1.4.1 Pellet Hardness** Pellet hardness was determined according to the method described in *Feed Inspection and Testing*.

**1.4.2 Pellet Brittleness** Brittleness, defined as the deformation distance at maximum force, was measured using a TA-XT2i Texture Analyzer (Stable Micro Systems, UK) with the following parameters: pre-test speed 2 mm/s, test speed 0.8 mm/s, post-test speed 2 mm/s, trigger force Auto-5 g, compression distance 60%, and data acquisition rate 500 pps.

**1.4.3 Pellet Durability Index (PDI)** PDI was determined using the American Society of Agricultural Engineers standard method.

**1.4.4 Starch Gelatinization Degree** Starch gelatinization degree was measured using the simplified enzymatic method commonly employed in the American feed industry.

**1.4.5 Growth Performance** Piglets were fasted for 24 hours with free access to water on days 27 and 49, and weighed individually on days 28 and 50. Average body weight was calculated per replicate. Daily feed consumption was recorded accurately to calculate total feed intake per phase.

Average daily feed intake [ADFI, g/(d · pig)] = Total feed intake / (Number of pigs × Days)

Average daily gain [ADG, g/(d · pig)] = Total weight gain / (Number of pigs × Days)

Feed-to-gain ratio (F/G) = Total feed intake / Total weight gain

**1.4.6 Nutrient Apparent Digestibility** Fresh fecal samples were collected during the final 3 days of the trial, mixed thoroughly, treated with 10% hydrochloric acid for nitrogen fixation, 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. Apparent digestibility was determined using the internal indicator method with 4 mol/L HCl-insoluble ash as the indicator. HCl-insoluble ash content was measured by acid digestion, crude protein by Kjeldahl method (GB/T 6432-1994), and dry matter by oven drying (GB/T 6435-2006).

Apparent nutrient utilization (%) = [(a/c - b/d) / (a/c)] × 100

Where: a = nutrient content in diet (%); b = nutrient content in feces (%); c = indicator content in diet (%); d = indicator content in feces (%).

**1.4.7 Serum Biochemical Indices** On day 50, one piglet per replicate was randomly selected for jugular vein blood collection. Serum was obtained by centrifugation and analyzed for urea nitrogen, total protein, albumin, globulin, high-density lipoprotein, calcium, and alkaline phosphatase activity using commercial kits (Nanjing Jiancheng Bioengineering Institute).

## 1.5 Data Processing and Analysis

Data were expressed as mean ± standard deviation. One-way ANOVA was performed using SPSS 18.0 software.

## Results

### 2.1 Effects of Expanded Corn Proportion on Pellet Feed Processing Quality

As shown in Table 2, pellet hardness increased significantly with higher expanded corn proportions ( $P < 0.05$ ), reaching maximum in the 100% group and minimum in the 0% group. Brittleness initially increased then stabilized,

with the 0% and 25% groups showing significantly lower values than other groups ( $P < 0.05$ ). PDI increased with expanded corn proportion, with the 50%, 75%, and 100% groups being significantly higher than the 0% and 25% groups ( $P < 0.05$ ), and the 75% and 100% groups significantly higher than the 50% group ( $P < 0.05$ ). Both first and second granulation starch gelatinization degrees increased with expanded corn proportion. For first granulation, all groups differed significantly ( $P < 0.05$ ), with the 100% group highest and 0% group lowest. For second granulation, the 75% and 100% groups were significantly higher than the 0%, 25%, and 50% groups ( $P < 0.05$ ), which also differed significantly among themselves ( $P < 0.05$ ).

## 2.2 Effects of Expanded Corn Proportion on Growth Performance of Weaned Piglets

As presented in Table 3, no significant differences were observed among groups in final body weight, ADG, or ADFI during the early phase ( $P > 0.05$ ). However, FCR in the 0% group was significantly higher than other groups ( $P < 0.05$ ). During the late phase, no significant differences were detected in final body weight, ADG, ADFI, or FCR among groups ( $P > 0.05$ ). Over the entire trial period, no significant differences were found in ADG, ADFI, or FCR ( $P > 0.05$ ), though ADG was highest in the 100% group, followed by the 25% group, and lowest in the 0% group. ADFI was highest in the 25% group, while F/G decreased progressively with increasing expanded corn proportion.

## 2.3 Effects of Expanded Corn Proportion on Nutrient Apparent Digestibility

Table 4 shows that dry matter apparent digestibility was highest in the 100% group, followed by the 25% group, and lowest in the 0% group, with the 100% group being significantly higher than all other groups ( $P < 0.05$ ) and the 0% group significantly lower than others ( $P < 0.05$ ). Crude protein apparent digestibility was highest in the 100% group and lowest in the 0% group, with significant differences among all groups except between the 25% and 75% groups ( $P > 0.05$ ).

## 2.4 Effects of Expanded Corn Proportion on Serum Biochemical Indices

As shown in Table 5, serum total protein in the 75% group was significantly higher than in the 0%, 50%, and 100% groups ( $P < 0.05$ ). No significant differences were observed in albumin or globulin contents among groups ( $P > 0.05$ ), though albumin was highest in the 75% group. Serum alkaline phosphatase activity in the 100% group was significantly higher than in the 0% group ( $P < 0.05$ ). Serum triglyceride content decreased progressively with increasing expanded corn proportion, with the 0% group significantly higher than the 50%, 75%, and 100% groups ( $P < 0.05$ ). Serum high-density lipoprotein content in the 25% and 75% groups was significantly higher than in the 50% group ( $P < 0.05$ ). Serum

calcium content in the 50% group was significantly lower than in other groups ( $P < 0.05$ ).

## Discussion

### 3.1 Effects of Expanded Corn Proportion on Pellet Feed Processing Quality

With rapid development of the feed industry, pellet processing quality requirements have become increasingly stringent alongside nutritional considerations. Due to the physiological characteristics of weaned piglets and the unique nature of their dietary formulations, piglet feeds require high starch gelatinization but low pellet hardness. Appropriate expanded corn supplementation significantly enhances pellet cohesiveness, reduces pelleting difficulty, improves pellet durability, increases starch gelatinization, and facilitates digestion and absorption. The aromatic flavor of expanded corn also improves palatability. Previous research demonstrated that 50% expanded corn with low-temperature pelleting significantly improved pellet hardness, PDI, and starch gelatinization compared to conventional pelleting. Our study similarly found that pellet hardness, PDI, and starch gelatinization increased with expanded corn proportion under secondary pelleting. This occurs because expansion breaks hydrogen bonds between starch chains, altering starch structure and causing gelatinization, which increases dietary gelatinization and provides binding properties that create more compact, stable pellet structures. Brittleness decreased with higher expanded corn proportions, likely due to increased cohesiveness reducing deformation susceptibility. Processing methodology also significantly impacts pellet quality; secondary pelleting produces higher hardness, PDI, and starch gelatinization than conventional pelleting because macro-ingredients undergo high-temperature conditioning for complete gelatinization while heat-sensitive ingredients remain uncharred during low-temperature final pelleting. Our combination of expanded corn and secondary pelleting further improved processing quality. However, excessive expanded corn increases post-conditioning viscosity, causing blockages and excessively hard pellets. Additionally, high expanded corn usage increases energy consumption and costs. Since piglet diets typically require hardness around 20 N, our data suggest that 25% expanded corn under secondary pelleting provides moderate hardness with starch gelatinization exceeding 50%.

### 3.2 Effects of Expanded Corn Proportion on Growth Performance of Weaned Piglets

Expanded corn is produced under high temperature and pressure through combined effects of moisture, mechanical shear, friction, and kneading. Extrusion causes corn starch granules to expand, breaks hydrogen bonds, gelatinizes starch, and degrades some starch chains into small oligosaccharides, thereby promoting nutrient digestion and improving piglet performance. The enhanced flavor also increases palatability. Previous studies reported that expanded corn groups

showed significantly higher ADG and lower FCR during the first two weeks post-weaning, with 60% inclusion being most effective. Our results showed that the 0% group had significantly higher FCR during the early phase, while later and overall phases showed no significant differences among groups, though ADG was higher in all expanded corn groups than the 0% group and overall FCR decreased with increasing expanded corn proportion. This may be attributed to insufficient amylase secretion in weaned piglets, as expanded corn groups achieved over 50% starch gelatinization, significantly higher than the 0% group, while expansion also reduced anti-nutritional factors, promoting nutrient utilization. However, increasing expanded corn proportion did not significantly improve overall ADG, suggesting limited benefits of excessive supplementation. ADFI was highest in the 25% group, decreasing with higher proportions, possibly because increased cohesiveness and hardness affected feed intake. Secondary pelleting also improves performance by increasing gelatinization and reducing anti-nutritional factors, as previously demonstrated. Our combination of expanded corn and secondary pelleting further enhanced piglet growth performance.

### **3.3 Effects of Expanded Corn Proportion on Nutrient Apparent Digestibility**

Corn expansion ruptures cell walls, shortens starch chains, increases gelatinization, and reduces anti-nutritional factors, thereby improving nutrient digestibility. Previous research demonstrated that apparent digestibility improved with increasing expanded corn proportions, with enhanced organic matter digestibility in expanded corn groups. Our study similarly found that dry matter and crude protein apparent digestibility were significantly higher in expanded corn groups than the 0% group, increasing with expanded corn proportion. This aligns with previous findings and may be explained by complete starch gelatinization, reduced crude fiber content, cleavage of insoluble to soluble fiber, and protein denaturation facilitating protease access. Additionally, secondary pelleting further increased gelatinization and reduced anti-nutritional factors, enhancing digestibility.

### **3.4 Effects of Expanded Corn Proportion on Serum Biochemical Indices**

Serum biochemical indices are closely associated with animal metabolism and health status, serving as important indicators for evaluating health and disease. Total protein, composed of albumin and globulin, reflects protein metabolism and immune capacity. Albumin, synthesized by the liver, transports nutrients and maintains osmotic pressure, while globulin, synthesized by immune organs, correlates with immunity. Our study showed that serum total protein and albumin in most expanded corn groups were higher than the 0% group, possibly because protein denaturation during expansion increased solubility and absorption. Serum triglycerides decreased with increasing expanded corn proportion, with the 0% group significantly higher than the 50%, 75%, and 100% groups,

likely due to reduced fat content in expanded corn. High-density lipoprotein transports cholesterol from peripheral tissues for excretion. The 25% and 75% groups showed higher high-density lipoprotein levels, indicating that expanded corn reduced stress and improved lipid metabolism. The secondary pelleting process further enhanced these effects by increasing gelatinization and reducing anti-nutritional factors, thereby alleviating weaning stress.

## Conclusion

1. Pellet hardness, PDI, and starch gelatinization increased with expanded corn proportion. Under secondary pelleting, 25% expanded corn provided moderate hardness with starch gelatinization exceeding 50%.
2. Expanded corn supplementation improved growth performance of weaned piglets. Under secondary pelleting, proportions exceeding 25% did not significantly affect performance parameters.
3. Expanded corn supplementation enhanced nutrient apparent digestibility and improved serum biochemical indices.
4. Considering effects on pellet hardness, growth performance, and processing costs, the recommended proportion of expanded corn in weaned piglet diets under secondary pelleting is 25% of total corn content.

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