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Effect of High-Efficiency Conditioning Low-Temperature Pelleting Process on Pellet Feed Processing Quality and Vitamin E Retention Rate (Postprint)

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Abstract

This experiment aimed to investigate the effects of high-efficiency conditioning low-temperature pelleting process on the processing quality of pelleted feed and vitamin E retention rate under the same feed formulation conditions. The control group (Group A) feed adopted conventional livestock and poultry feed processing technology, while the experimental group feeds employed three types of conditioners, namely double-layer conditioner (Group B), conditioning retention vessel (Group C) and expander (Group D), to conduct hydrothermal treatment on the major ingredient mixture in the feed formulation. The hydrothermally treated major ingredient mixture was then mixed with additives and other feed ingredients, conditioned at low temperatures (50, 55, 60 and 65 °C), and pelleted. The results showed that the starch gelatinization degree of the major ingredient mixture after treatment with the double-layer conditioner was significantly lower than that after treatment with the conditioning retention vessel and expander ($P < 0.05$). The starch gelatinization degree of Group D was significantly higher than that of Groups B and C ($P < 0.05$), the pellet hardness of Group C was significantly higher than that of Groups B and D ($P < 0.05$), the pellet durability index of Group C was significantly higher than that of Groups B and D ($P < 0.05$), the pellet formation rate of Group B was significantly lower than the other three groups ($P < 0.05$), and the vitamin E retention rates of Groups B, C and D were significantly higher than that of Group A ($P < 0.05$). The starch gelatinization degree of the 65 °C group was significantly higher than that of the 50, 55 and 60 °C groups ($P < 0.05$), the pellet hardness of the 65 °C group was significantly higher than that of the 50, 55 and 60 °C groups ($P < 0.05$), the pellet durability index of the 65 °C group was significantly higher than that of the 50, 55 and 60 °C groups ($P < 0.05$), the pellet formation rate of the 65 °C group was significantly higher than that of the 50 and 55 °C groups

($P < 0.05$), and the vitamin E retention rate of the 65 °C group was significantly lower than that of the 50, 55 and 60 °C groups ($P < 0.05$). It can be concluded that processing the major ingredient mixture through the conditioning retention vessel for cooking and adopting low-temperature pelleting at 65 °C can effectively protect heat-sensitive components such as vitamin E, and the feed processing quality showed no significant difference compared with conventional livestock and poultry feed processing technology.

Full Text

Effects of High-Efficiency Conditioning and Low-Temperature Pelleting Process on Pellet Feed Processing Quality and Vitamin E Retention Rate

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Abstract: This experiment investigated the effects of high-efficiency conditioning combined with low-temperature pelleting on pellet feed processing quality and vitamin E retention rate under identical feed formulations. The control group (Group A) employed conventional livestock feed processing technology, while experimental groups utilized three different conditioners—double-layer conditioner (Group B), conditioning retainer (Group C), and expander (Group D)—to apply hydrothermal treatment to macro ingredients in the feed formula. The conditioned macro materials were then mixed with additives and other feed ingredients before undergoing low-temperature conditioning (50, 55, 60, and 65 °C) and pelleting.

The results demonstrated that starch gelatinization degree of macro materials after double-layer conditioning was significantly lower than after conditioning retainer or expander treatment ($P < 0.05$). Group D exhibited significantly higher starch gelatinization than Groups B and C ($P < 0.05$). Group C showed significantly greater pellet hardness and pellet durability index compared to Groups B and D ($P < 0.05$). Group B had significantly lower pellet formation rate than the other three groups ($P < 0.05$). Vitamin E retention rates in Groups B, C, and D were all significantly higher than in Group A ($P < 0.05$). The 65 °C treatment group displayed significantly higher starch gelatinization, pellet hardness, and pellet durability index compared to 50, 55, and 60 °C groups (P

< 0.05), with significantly higher pellet formation rate than 50 and 55 °C groups ($P < 0.05$), but significantly lower vitamin E retention than 50, 55, and 60 °C groups ($P < 0.05$). These findings indicate that using a conditioning retainer for macro material processing followed by low-temperature pelleting at 65 °C effectively protects heat-sensitive components like vitamin E while maintaining feed processing quality comparable to conventional livestock feed processing technology.

Keywords: macro materials; conditioner; processing quality; processing technology
Classification Number: S816.34

Introduction

Current livestock feed processing technology in China primarily comprises raw material receiving, cleaning, grinding, proportioning, mixing, conditioning-pelleting, and packaging operations [1]. During feed production, the conditioning process presents a fundamental dilemma: low conditioning temperatures and short durations result in inadequate sterilization and low starch gelatinization, while high temperatures and prolonged times cause severe activity loss in heat-sensitive feed additives, diminishing their efficacy [2]. To compensate, manufacturers often over-supplement feed additives, leading to increased costs and waste. To address these limitations, alternative processes such as high-temperature-high-pressure extrusion (expansion) treatment of raw materials or mixed ingredients followed by low-temperature pelleting, and double-pelleting processes have been adopted in young animal feed production. Although these methods resolve some issues, they require high-power, high-energy equipment such as extruders, expanders, and ring-die pellet mills, resulting in high equipment investment, electricity consumption per ton, and labor costs.

To overcome these deficiencies, the industry has developed a novel high-efficiency conditioning-cooling-low-temperature pelleting process for livestock feed production. This technology first produces matured powdered feed from mixed ingredients (macro materials) without heat-sensitive components and feed additives, then conducts low-temperature pelleting. This approach not only requires relatively lower equipment power but also maximizes retention of heat-sensitive substance activity while producing pelleted feed.

Millet et al. [3] investigated the effects of expander-processed feed on growth performance and gastric mucosa development in pigs throughout the growth cycle, finding that expander processing improved feed efficiency during the growth period but caused some damage to gastric mucosa development over the entire feeding period. Lundblad et al. [4] examined the effects of steam conditioning temperature, expansion, and extrusion processing on ileal digestibility of crude protein, starch, amino acids, dry matter, and phosphorus in pigs. Previous research has primarily focused on the effects of conditioning temperature or equipment on feed processing quality and animal performance, while studies on the impact of high-efficiency conditioning combined with low-temperature pelleting on pellet quality and heat-sensitive components in growing pig feed remain scarce. Therefore, this experiment, using conventional livestock feed processing technology as a control, compared different conditioning methods with low-temperature pelleting to analyze pellet processing quality and heat-sensitive component retention, providing data support for the feasibility and superiority of this novel process.

Materials and Methods

1.1 Experimental Design and Grouping

The control group (Group A) utilized conventional livestock feed processing technology: proportioning, mixing, conditioning, and pelleting. Experimental groups included double-layer conditioner (Group B), conditioning retainer (high-efficiency conditioning group, Group C), and expander (Group D). Corn, soybean meal, and wheat bran were first mixed according to formula ratios, then subjected to high-temperature conditioning using three different conditioners: double-layer conditioner (MUTZ600×2), conditioning retainer (STZW60×40), and expander (PHY260). The processed matured powder was then mixed with premix and other ingredients before low-temperature pelleting at gradually increasing temperatures of 50, 55, 60, and 65 °C, using a die diameter of 3 mm and a length-to-diameter ratio of 8:1. Detailed feed processing parameters and groupings are presented in Table 1 .

Table 1 Feed Processing Parameters and Grouping

Item	Group A	Group B	Group C	Group D
High-efficiency conditioning temperature (°C)	-	85-95	85-95	110-125
Conditioning time (s)	20-30	40-60	120-180	5-10
Macro material conditioning equipment	-	Double-layer conditioner MUTZ600×2	Conditioning retainer STZW60×40	Expander PHY260

Item	Group A	Group B	Group C	Group D
Conditioning temperature before pelleting (°C)	85	50, 55, 60, 65	50, 55, 60, 65	50, 55, 60, 65
Pellet mill	SZLH550×170	SZLH550×170	SZLH550×170	SZLH550×170
Length-to-diameter ratio	8:1	8:1	8:1	8:1
Die diameter (mm)	3	3	3	3

1.2 Experimental Diets

The basal diet composition and nutrient levels for growing pigs (30–60 kg) are shown in Table 2 . Vitamin E (purity 90%) was supplemented at 200 mg/kg to the basal diet for experimental feeds.

Table 2 Basal Diet Composition and Nutrient Levels (Air-Dry Basis), %

Item	Content
Ingredients	
Corn	65.00
Soybean meal	18.00
Cottonseed meal	3.00
Wheat bran	5.00
Corn germ meal	3.00
Soybean oil	1.00
Premix[1]	4.00
Lys · HCl	0.30
DL-Met	0.10
L-Thr	0.10
Limestone	0.80
NaCl	0.30
Ca(HCO)	0.40
Total	**100.00**
Nutrient levels[2]	
DE (MJ/kg)	13.50
CP	17.50

Item	Content
Ca	0.80
TP	0.60
Lys	1.00
Met+Cys	0.60

[1]Premix provided per kg of diet: VA 6,312 IU, VD 2,600 IU, VE 35 IU, VK 4 mg, VB 2.8 mg, VB 5 mg, VB 4 mg, folic acid 1.1 mg, VB 28.1 µg, pantothenic acid 14 mg, niacin 40 mg, biotin 44 µg, choline chloride 400 mg, Cu 100 mg, Fe 80 mg, Mn 40 mg, Zn 75 mg, L-Lys 3.3 mg, Ca 10 mg, P 2 mg, I 0.3 mg, Se 0.3 mg.
[2]CP was a measured value; others were calculated values.

1.3 Sample Collection

For the control group, three samples were collected before conditioning and at the pellet mill discharge port. For experimental groups, three samples were collected after macro material conditioning, before low-temperature pelleting conditioning, and at the pellet mill discharge port. Collected hot and humid powder and pellet materials were cooled, then reduced to 2 kg using the quartering method, sealed in self-sealing bags, and stored at 4 °C for analysis.

1.4 Analytical Methods

1.4.1 Grinding Particle Size Sample grinding particle size was determined using the national standard GB 6871—1986 fourteen-layer sieve method [5].

1.4.2 Starch Gelatinization Degree Starch gelatinization degree was measured using the simplified enzymatic method developed by Dr. Xiong Yiqiang of the American Soybean Association, which is widely adopted in the U.S. feed industry [6].

1.4.3 Pellet Hardness Pellet hardness was determined according to the method reported by Gu Junhua [7].

1.4.4 Pellet Durability Index (PDI) PDI was measured following Thomas et al. [8]. Five hundred grams of sieved pellet feed was placed in a tumbling box and rotated at 50 r/min for 10 minutes. After rotation, the sample was removed and weighed (m). PDI = (m × 100) / 500.

1.4.5 Vitamin E Content Determination Vitamin E content was determined by high-performance liquid chromatography according to GB/T 17812-2008 [9].

1.5 Data Processing

Experimental data are expressed as mean ± standard deviation. All data were analyzed using SAS 9.2 software for one-way ANOVA and multi-factorial statistical analysis. Duncan' s multiple comparison test was used to examine significant differences, with significance level at $P < 0.05$ and highly significant level at $P < 0.01$.

Results

2.1 Effect of Conditioner Type on Starch Gelatinization Degree of Macro Materials

As shown in Figure 1 [Figure 1: see original paper], starch gelatinization degree of macro materials after double-layer conditioning was significantly lower than after conditioning retainer or expander treatment ($P < 0.05$), while no significant difference was observed between conditioning retainer and expander treatments ($P > 0.05$).

Figure 1 Effects of conditioning type on starch gelatinization degree of macro materials. Value columns with the same small letter superscripts indicate no significant difference ($P > 0.05$), while different small letter superscripts indicate significant difference ($P < 0.05$).

2.2 Comparative Analysis of Pellet Feed Processing Quality

As presented in Table 3 , Group D showed significantly higher starch gelatinization than Groups B and C ($P < 0.05$), with no significant difference from Group A ($P > 0.05$). Group C exhibited significantly greater pellet hardness and pellet durability index compared to Groups B and D ($P < 0.05$), without significant differences from Group A ($P > 0.05$). Group B had significantly lower pellet formation rate than the other three groups ($P < 0.05$). Group C demonstrated significantly higher vitamin E retention than Groups A and D ($P < 0.05$), with no significant difference from Group B ($P > 0.05$). Multi-factorial ANOVA revealed that conditioner type had highly significant effects on starch gelatinization degree, pellet hardness, pellet durability index, pellet formation rate, and vitamin E retention ($P < 0.01$).

The 65 °C group displayed significantly higher starch gelatinization, pellet hardness, and pellet durability index compared to 50, 55, and 60 °C groups ($P < 0.05$), with no significant differences from the 85 °C group ($P > 0.05$). The 65 °C group achieved the highest pellet formation rate, significantly greater than 50 and 55 °C groups ($P < 0.05$) but not significantly different from 85 and 60 °C groups ($P > 0.05$). Vitamin E retention in the 65 °C group was significantly lower than in 50, 55, and 60 °C groups ($P < 0.05$) but significantly higher than in the 85 °C group ($P > 0.05$). Multi-factorial ANOVA indicated that conditioning temperature had significant or highly significant effects on all measured parameters ($P < 0.05$ or $P < 0.01$). The interaction between conditioner type and conditioning temperature had highly significant effects on pellet hardness, pellet durability index, pellet formation rate, and vitamin E retention ($P < 0.01$), but no significant effect on starch gelatinization degree ($P > 0.05$).

Table 3 Effects of Conditioning Type and Conditioning Temperature on Processing Quality of Pellet Feed

Item	Group A	Group B	Group C	Group D	P-value
Conditioner Type					
Starch gelatinization degree (%)	25.47±3.35	15.71±1.67	21.82±1.67	26.20±1.67	<0.001
Pellet hardness (N)	41.09±2.10	21.51±1.05	46.03±1.05	36.27±1.05	<0.001
Pellet durability index (%)	96.47±0.57	90.01±0.28	96.78±0.30	95.36±0.30	<0.001
Pellet formation rate (%)	96.09±0.73	93.08±0.37	97.29±0.39	96.25±0.39	<0.001
Vitamin E retention (%)	68.66±1.85	98.33±0.92	96.49±0.92	92.19±1.18	<0.001
Conditioning Temperature					
Starch gelatinization degree (%)	16.76±1.93	19.95±1.93	23.26±1.93	25.00±1.93	<0.001

Item	Group A	Group B	Group C	Group D	P-value
Pellet hardness (N)	35.32±1.21	29.78±1.21	34.61±1.21	38.71±1.21	<0.001
Pellet durability index (%)	92.77±0.35	92.23±0.33	94.43±0.33	96.77±0.35	<0.001
Pellet formation rate (%)	95.10±0.46	94.90±0.42	95.33±0.42	96.84±0.46	<0.001
Vitamin E retention (%)	100.37±1.38	97.68±1.15	97.52±1.07	87.11±1.07	<0.001
Conditioner Type × Temperature					
Interaction effect	-	-	-	-	NS/HS[1]

[1]NS = Not significant for starch gelatinization; HS = Highly significant (P < 0.01) for other parameters.

Discussion

3.1 Effect of Conditioner Type on Starch Gelatinization Degree of Macro Materials

The conditioning process is a critical factor affecting feed processing quality, and selecting an appropriate conditioner is essential for final pellet quality and production energy consumption [10]. Common conditioners in livestock feed production include single-layer, double-layer, conditioning retainers, and expanders [11–13]. Feed manufacturers configure different conditioners based on product requirements. This study examined commonly used conditioners in livestock feed processing. Expanders are typically used in weaned piglet feed processing, where conditioning effectiveness positively correlates with expander ring gap opening; however, smaller gaps reduce production capacity and increase energy consumption [14]. Conditioning retainers provide longer retention times (2–10 min), with high-speed mixing in the upper section and low-speed homogenization and heat preservation in the lower section, enabling thorough steam-material mixing for improved maturation and pathogen elimination [15]. In conventional pig feed production, double-layer conditioners are commonly used due to lower energy consumption, though they provide lower feed maturation [16]. Li Qiwu [17] studied the effects of single-layer, double-layer conditioners, and extruders on material starch gelatinization, concluding that single- or double-layer conditioners could increase gelatinization by approximately 20%. Our results showed that macro material processing through an expander achieved starch gelatinization up to 25%, significantly higher than double-layer conditioning but not significantly different from conditioning retainer treatment.

3.2 Effect of Low-Temperature Pelleting Conditioning Temperature on Pellet Feed Processing Quality

After high-temperature conditioning of macro materials, the cooled matured powder was mixed with additives and heat-sensitive ingredients before low-temperature pelleting at 50, 55, 60, and 65 °C. Under hydrothermal treatment, macro materials absorb water and expand, transforming tightly arranged -starch molecules into gelatinized -starch [18], which increases viscosity and improves pellet hardness and durability index [17,19–21]. Pellet processing quality depends not only on equipment performance and raw material characteristics but largely on the conditioning process. As a pre-pelleting step, conditioning hydrothermally treats feed to gelatinize starch, denature protein, and soften materials, thereby improving pellet quality and feed digestibility [2,16]. Zhang Xianling et al. [22] investigated conditioning temperature effects on broiler pellet quality, finding that increasing temperature from 65 °C to 90 °C improved pellet durability index, hardness, and starch gelatinization, enhancing processing quality. Pellet hardness and durability index relate to conditioning temperature, die length-to-diameter ratio, and steam quality during conditioning. Lin Yunjian et al. [23] studied effects of die length-to-diameter ratio and post-conditioning moisture on productivity, power consumption, and pellet quality, recommending a 10:1 ratio for grain-rich compound feeds. In this study, macro materials were first matured then cooled before low-temperature pelleting. At 50 and 55 °C conditioning temperatures, pellet hardness and durability index were lower than at 85 °C because cooled starch undergoes retrogradation, where gelatinized starch reverts to granular form [24–26]. Subsequent low-temperature pelleting failed to disrupt this granular structure, resulting in lower hardness and durability compared to 85 °C [19]. At 65 °C conditioning temperature, retrograded starch branches reopened [27], increasing gelatinization and making durability index and hardness comparable to 85 °C treatment.

3.3 Effect of Low-Temperature Pelleting Conditioning Temperature on Vitamin E Retention

Vitamin E, a fat-soluble vitamin and primary antioxidant [28,29], cannot be synthesized by animals and must be obtained from feed [30]. As a heat-sensitive additive, its retention is directly affected by conditioning temperature. Lewis et al. [31] studied conditioning temperature and duration effects on vitamin retention, finding temperature had weak significant effects, with 88 °C showing weakly significant lower retention than 77 °C. Yan Fangfang [32] investigated effects of wet extrusion and ring-die pelleting on four fat-soluble vitamins, reporting 70.04% vitamin E retention for ring-die pelleting. Our study yielded consistent results: conventional livestock feed processing achieved 68% vitamin E retention, whereas high-efficiency conditioning with low-temperature pelleting achieved approximately 98% retention, representing a 44% improvement. The 65 °C group showed significantly lower vitamin E retention than 50, 55, and 60 °C groups.

The conclusions drawn from this study are: First, high-efficiency conditioning combined with low-temperature pelleting effectively improves retention of heat-sensitive feed ingredients, with vitamin E retention in Groups B, C, and D all significantly higher than in Group A. Second, the conditioning retainer is recommended for macro material maturation in this process, with 65 °C being the optimal low-temperature pelleting conditioning temperature.

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