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Original Research Article

Effects of raw material extrusion and steam conditioning on feed pellet quality and nutrient digestibility of growing meat rabbits

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A B S T R A C T

This study was conducted to investigate the effects of raw material extrusion and steam conditioning on feed pellet quality and nutrient digestibility of growing meat rabbits, in order to determine appropriate rabbit feed processing methods and processing parameters. In Exp. 1, an orthogonal design was adopted. Barrel temperature, material moisture content and feed rate were selected as test factors, and acid detergent fiber (ADF) content was selected as an evaluation index to research the optimum extrusion parameters. In Exp. 2, a two-factor design was adopted. Four kinds of rabbit feeds were processed and raw material extrusion adopted optimum extrusion parameters of Exp. 1. A total of 40 healthy and 42-day-old rabbits with similar weight were used in a randomized design, which consisted of 4 groups and 10 replicates in each group (1 rabbits in each replicate). The adaptation period lasted for 7 d, and the digestion trial lasted for 4 d. The results showed as follows: 1) ADF was significantly affected by barrel temperature ($P < 0.05$); the optimum extrusion parameters were barrel temperature 125 °C, moisture content 16% and feed rate 9 Hz. 2) Raw material extrusion and steam conditioning both significantly decreased powder percentage, pulverization ratio and protein solubility ($P < 0.05$), significantly improved hardness and starch gelatinization degree of rabbit feed ($P < 0.05$). They both had significant interaction effects on the processing quality of rabbit feed ($P < 0.05$). 3) Extrusion significantly improved the apparent digestibility of dry matter and total energy ($P < 0.05$). Extrusion and steam conditioning both significantly improved the apparent digestibility of crude fiber (CF), ADF and NDF ($P < 0.05$), but they had no interaction effects on the apparent digestibility of rabbit feed. Thus, using extrusion and steam conditioning technology at the same time in the weaning rabbits feed processing can improve the pellet quality and nutrient apparent digestibility of rabbit feed.

1. Introduction

Extrusion, as a high temperature and short time processing technology, is widely used in food and feed processing field. Extrusion can change the nutrient content in feed, reduce the number of anti-nutritional factors, improve the hygiene condition of feed, and improve the nutrients utilization efficiency (Alonso et al., 2000; Dust et al., 2004; Decker et al., 2014). Rabbits are herbivores and monogastric animals, whose diet ingredients consist mainly of fiber feed. Gastrointestinal development of rabbits is not perfect after weaning, thus nutrient digestibility is lower, which easily causes digestion diseases. Fiber quality of dietary is very important to rabbits. The extrusion processing can effectively improve the fiber quality and increase digestibility. Therefore, the research on the application of extrusion processing technology in rabbit diet processing seems to be very important. Researches on extrusion are mainly about piglet diets and single raw material processing. These researchers found that when the material moisture content, extrusion temperature and screw speed are suitable, the starch gelatinization degree of maize can be maximized (Wang et al., 2012), and significantly improve the content of soluble fiber in soybean dregs (Jing and Chi, 2013). Sun et al. (2015) showed that low temperature pelleting after expansion improved the processing quality of weaned piglets pellet diets, and could improve the nutrient digestibility. Rojas et al. (2016) reported that

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diets of growing pigs after pelleting and extrusion can significantly improve the apparent ileal digestibility of starch and most indispensable amino acid. So far, the research and application of extrusion technology on rabbits feed processing has been rarely reported. Therefore, this study was conducted to investigate the effect of raw material extrusion and steam conditioning process on feed pellet quality and nutrient digestibility of growing meat rabbits, and to provide a reference for the rational selection of rabbit feed processing methods and parameters.

2. Materials and methods

This study was approved by the Institutional Animal Care and Use Committee of Sichuan Agricultural University.

2.1. Trial design

2.1.1. Extrusion trial design

The orthogonal table $L_9(3^4)$ was used to design an orthogonal trial with 3 factors and 3 levels. Barrel temperature (A), material moisture content (B), feed rate (C) were selected as test factors. Crude fiber (CF), neutral detergent fiber (NDF), acid detergent fiber (ADF) were selected as evaluation indexes to research the optimum extrusion parameters. The plant raw materials (maize, soybean meal, rapeseed meal, wheat bran, alfalfa meal, and peanut shells) in based diets were crushed and mixed as extrusion experimental materials according to the formula. Trial factors and levels are presented in Table 1.

2.1.2. Digestion trial design

The two-factor trial design was adopted, and the experiment included 4 groups: control group, in which neither extrusion nor steam conditioning were used; treatment 1, which did not use extrusion but used steam conditioning; treatment 2, which did not use steam conditioning but used extrusion; treatment 3, in which both of extrusion and steam conditioning were used. The plant raw materials were extruded in based diets by using the extrusion process parameters which got from the extrusion experiment. The steam was added before feed pelleting was processed. Conditioning temperature was 65 °C. Four group diets were processed to be 2.5 mm diameter pellet diets. The adaptation period lasted for 7 days, and formal experiment lasted for 4 days.

2.2. Basal diet

According to the Nutrition of the Rabbit (2010) and the actual situation in China, the basal diets were formulated. The composition and nutrient levels of the basal diets are shown in Table 2.

2.3. Animals and feeding management

This experiment was started in animal nutrition institute of Sichuan Agricultural University. Rabbit cages were thoroughly cleaned and disinfected before the experiment. A total of 40 healthy and 42-day-old rabbits (20 females and 20 males) with similar weight (1,066 ± 78 g) were used in a randomized design, which consisted of 4 groups and 10 replicates in each group, 1 rabbit in each replicate. The rabbits in 4 groups were fed control group, treatments 1, 2, and 3 diets, respectively, 3 times a day (08:00, 12:00 and 18:00) during the trial period. All rabbits had free access to feed and water. Natural ventilation and lighting were used. After a 7 days adaptation period, the feces samples were collected 4 days by using total collect method.

Table 1
Factors and levels.

Levels	Factors		
	Barrel temperature, °C	Material moisture content, %	Feeding rate, Hz
1	105	12	7
2	125	14	8
3	145	16	9

Table 2
Composition and nutrient levels of the basal diet (air-dry basis).

Item	Content
Ingredients, %	
Corn	30.17
Soybean meal	7.20
Rapeseed meal	5.39
Wheat bran	20.00
Alfalfa meal	27.45
Peanut shell powder	7.10
Limestone	0.33
$CaHPO_4$	0.60
NaCl	0.50
L-Lysine-HCl	0.26
Premix[1]	1.00
Total	100.00
Nutrient levels,[2] %	
DE, MJ/kg	10.15
CP	16.12
CF	14.53
NDF	29.38
ADF	18.66
Ca	0.80
TP	0.54
Lys	0.80
Met + Cys	0.53

CP = crude protein; CF = crude fiber; NDF = neutral detergent fiber; ADF = acid detergent fiber; TP = total protein.

[1] Premix provided per kg of the diet: vitamin A, 12,000 IU; vitamin D_3, 2,250 IU; vitamin E, 24 mg; vitamin K_3, 2.25 mg; vitamin B_{12}, 0.03 mg; nicotinic acid, 45 mg; *D*-pantothenic acid, 15 mg; folic acid, 1.2 mg; Cu, 15 mg; Fe, 70 mg; Zn, 50 mg; Mn, 15 mg; I, 0.5 mg; Se, 0.15 mg; Co, 0.2 mg; choline chloride, 250 mg; diclazuril, 1 mg.

[2] The CP, CF, ADF, and NDF contents were measured values, and other nutrient levels were calculated values.

2.4. Sample collection

Extrusion materials and 4 kinds of pellet feed samples were collected by using geometric method. The digestive trial feces samples were collected 4 days. All fresh feces were collected at 07:00 every morning, and weighed after removing the rabbit hairs on the dung ball. At the end of the experiment, feces samples were collected, mixed and added with 10% HCl for chemical analyses.

2.5. Determination index and methods

2.5.1. Feed pellet quality index

The method of AOAC (2005) was used to determine the powder percentage, pulverization ratio, bulk density, hardness, and protein solubility. Starch gelatinization was determined by the method of Xiong (2000).

2.5.2. Nutrient apparent digestibility

The GE, DM, CP, ash, CF, ADF, and NDF in the samples of diets and feces were analyzed according to AOAC (2005) procedures.

2.6. Statistical analysis

The experiment data were pretreatment with Excel 2010. The orthogonal trial data were analyzed by using variance analysis method, other trial data were analyzed by using two-factor variance analysis method of IBM SPSS 20.0 GLM program, and Duncan's test was used to compare data among treatments. Statistical significance between treatments was based on $P < 0.05$. Data were presented as means ± standard deviation.

3. Results

3.1. Effect of extrusion processing on fiber content

The results of orthogonal design were shown in Table 3. As shown in Table 4, ADF was significantly affected by barrel temperature ($P < 0.05$), material moisture content and feed rate did not influence ADF ($P > 0.05$). Barrel temperature, material moisture content and feed rate all did not significantly influence CF and NDF ($P > 0.05$). The order of affect factors about ADF was barrel temperature > moisture content > feed rate. When barrel temperature was 125 °C, moisture content was 16% and feed rate was 9 Hz, ADF content could meet the needs of meat rabbit (Tao, 2004; Yao, 2006).

3.2. Effects of extrusion and steam conditioning on feed pellet quality of meat rabbits

As shown in Table 5, extrusion and steam conditioning both significantly decreased powder percentage, pulverization ratio and protein solubility ($P < 0.05$), significantly improved hardness and starch gelatinization degree of rabbit feed ($P < 0.05$). They both had significant interaction effects on the processing quality of rabbit feed pellet ($P < 0.05$). The starch gelatinization of treatments 3, 2 and 1 improved by 66.43% ($P < 0.05$), 62.92% ($P < 0.05$) and 25.72% ($P < 0.05$), respectively, compared with the control group. Protein solubility reduced by 11.42% ($P < 0.05$), 8.15% ($P < 0.05$) and 4.48% ($P < 0.05$).

3.3. Effects of extrusion and steam conditioning on nutrient digestibility of meat rabbits

As shown in Table 6, raw material extrusion and steam conditioning both significantly improved the apparent digestibility of GE, CF, ADF, and NDF ($P < 0.05$), but the interaction effects were insignificant ($P > 0.05$). Treatments 3 and 2 improved digestibility of GE by 14.42% ($P < 0.05$) and 12.66% ($P < 0.05$), digestibility of CF by 30.44% ($P < 0.05$) and 12.98% ($P < 0.05$), respectively, compared with the control group. Treatment 3 compared with the control group, improved digestibility of ADF and NDF by 32.50% ($P < 0.05$) and 27.36% ($P < 0.05$).

4. Discussion

4.1. Effect of extrusion processing on fiber content

Fiber is an important ingredient in rabbit feed. Its content and type is very important to growth performance and health status of meat rabbits. Extrusion could change content and type of fiber in the diet (Dust et al., 2004). The experiment results showed that extrusion can decrease CF content, significantly affect ADF content. The order of affect factors was barrel temperature > moisture content > feed rate. The CF content of this experiment diet was between 14.18% and 15.65%, which could meet the needs of rabbit nutrition. It means that extrusion improved fiber content and quality. Zhao and Sheng (2010) reported that extrusion decreased the fiber content of maize straw, and the order of affect factors was moisture content > barrel temperature > screw rate. The research result is inconsistent with this experiment result, may be associated with different raw material and extrusion parameters. Extrusion decreased ADF content of diets, which indicates that the lignin and cellulose content decreased and is benefit to the digestion of

Table 3
The results of orthogonal design (DM basis).

Groups	Factors[1] A	B	C	DM, %	CF, %	ADF, %	NDF, %
1	1	1	1	90.82	15.30	19.29	38.03
2	1	2	2	90.29	15.44	19.28	36.72
3	1	3	3	89.43	15.65	19.37	37.38
4	2	1	2	89.66	15.44	18.45	36.34
5	2	2	3	88.58	14.90	18.06	36.98
6	2	3	1	90.30	14.18	18.17	39.16
7	3	1	3	91.16	14.51	19.41	37.41
8	3	2	1	91.01	14.54	19.42	39.07
9	3	3	2	90.30	14.62	19.11	39.95

[1] A = barrel temperature; B = material moisture content; C = feed rate.

Table 4
The variance analysis of CF, ADF, NDF.

Item	Source of variation[1]	SS	df	MS	F	*P*-value	Significance
CF	A	1.293	2	0.647	3.455	0.224	
	B	0.105	2	0.053	0.281	0.780	
	C	0.391	2	0.195	1.044	0.489	
ADF	A	2.345	2	1.172	23.507	0.041	*
	B	0.047	2	0.023	0.469	0.681	
	C	0.000	2	0.000	0.003	0.997	
NDF	A	3.815	2	1.908	4.420	0.184	
	B	4.133	2	2.067	4.788	0.173	
	C	3.583	2	1.792	4.151	0.194	

CF = crude fiber; ADF = acid detergent fiber; NDF = neutral detergent fiber; SS = sum of squares; df = degree of freedom; MS = mean square.
* Represents significant difference ($P < 0.05$).
[1] A = barrel temperature; B = material moisture content; C = feed rate.

Table 5
Effects of different treatments on processing quality of rabbit pellet diet.

Item	Treatments[1]	Powder percentage, %	Pulverization ratio, %	Bulk density, g/L	Hardness, g	Starch gelatinization, %	Protein solubility, %
Without extrusion	Control	20.54 ± 0.44^a	18.78 ± 0.44^a	0.563 ± 0.002^a	2.94 ± 0.06^d	53.15 ± 0.71^d	52.62 ± 0.26^a
	Treatment 1	6.81 ± 0.04^b	5.66 ± 0.10^b	0.533 ± 0.002^c	6.77 ± 0.35^a	66.82 ± 0.28^c	50.26 ± 0.21^b
Extrusion	Treatment 2	5.43 ± 0.23^c	5.22 ± 0.13^c	0.557 ± 0.002^b	5.81 ± 0.18^b	86.59 ± 0.79^b	48.33 ± 0.11^c
	Treatment 3	4.29 ± 0.12^d	4.74 ± 0.11^d	0.536 ± 0.001^c	4.92 ± 0.18^c	88.46 ± 0.75^a	46.61 ± 0.07^d
P-value	Extrusion	<0.001	<0.001	0.140	0.004	<0.001	<0.001
	Conditioning	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Interaction	<0.001	<0.001	0.004	<0.001	<0.001	0.016

[a,b,c,d] In the same column, values with different small letter superscripts mean significant difference ($P < 0.05$), while with the same or no letter superscripts mean no significant difference ($P > 0.05$).
[1] Control, in which neither extrusion nor steam conditioning was used; treatment 1, which did not use extrusion but use steam conditioning; treatment 2, which did not use steam conditioning but use extrusion; treatment 3, in which extrusion and steam conditioning were both used.

Table 6
Effects of different treatments on nutrient digestibility (%) of rabbit pellet diet.

Item	Treatments[1]	DM	CP	GE	Ash	CF	ADF	NDF
Without extrusion	Control	56.54 ± 3.58	67.29 ± 8.03	51.82 ± 4.50[b]	51.38 ± 2.86	26.97 ± 2.34[c]	20.89 ± 1.54[c]	25.04 ± 2.49[c]
	Treatment 1	57.96 ± 6.83	67.31 ± 6.31	55.69 ± 8.86[ab]	50.53 ± 8.35	29.62 ± 2.88[b]	24.93 ± 1.45[b]	27.04 ± 1.80[bc]
Extrusion	Treatment 2	61.12 ± 2.21	70.57 ± 4.91	58.38 ± 2.77[a]	51.82 ± 3.85	30.47 ± 1.68[b]	22.47 ± 2.24[c]	28.26 ± 1.82[b]
	Treatment 3	61.30 ± 6.89	66.81 ± 10.54	59.29 ± 6.28[a]	47.49 ± 9.03	35.18 ± 2.09[a]	27.68 ± 1.39[a]	31.89 ± 1.35[a]
P-value	Extrusion	0.044	0.614	0.026	0.581	<0.001	<0.001	<0.001
	Conditioning	0.676	0.497	0.280	0.274	<0.001	<0.001	<0.001
	Interaction	0.746	0.495	0.500	0.461	0.217	0.327	0.238

[a,b,c,d] In the same column, values with different small letter superscripts mean significant difference ($P < 0.05$), while with the same or no letter superscripts mean no significant difference ($P > 0.05$).

[1] Control, in which neither extrusion nor steam conditioning was used; treatment 1, which did not use extrusion but use steam conditioning; treatment 2, which did not use steam conditioning but use extrusion; treatment 3, in which extrusion and steam conditioning were both used.

fiber. The digestion experiment result showed that extrusion improved digestibility of CF, NDF. The ADF was selected as the evaluation index and consider all the influence factors. The extrusion parameters were as follows: barrel temperature 125 °C, moisture content 16% and feed rate 9 Hz.

4.2. Effects of extrusion and steam conditioning on feed pellet quality of meat rabbits

High temperature and high humidity are the basis of starch gelatinization. In this research, extrusion and steam conditioning both could significantly improve the degree of starch gelatinization. The improvement from extrusion is much larger than steam conditioning. This is consistent with the research of Alonso et al. (2000a,b). Extrusion can easily create the environment of high temperature, high humidity and high pressure, which is benefit to starch gelatinization. The protein solubility can distinguish different levels of excessive heating, which is an important index to reflect the dietary heat degrees. This research showed that extrusion and steam conditioning both can significantly reduce the protein solubility. This is consistent with the research of Zhu et al. (1996). Powder percentage, pulverization ratio and hardness are the main indexes to evaluate the quality of diet pellets processing. This research found that extrusion and steam conditioning both can significantly reduce the powder percentage and pulverization ratio, improve hardness of rabbit diets. They have significant interaction effects on the processing quality of rabbit feed. The reason for this may be that extrusion and steam conditioning can improve starch gelatinization and adhesive properties of pellet. Sun et al. (2015) and Sørensen et al. (2009) both reported that extrusion significantly improve the hardness and durability index of pellet feed. Therefore, extruding raw materials before steam conditioning can help improve the quality of feed pellet and facilitate the feed intake of meat rabbit.

4.3. Effects of extrusion and steam conditioning on nutrient digestibility of meat rabbits

A large number of researches indicated that extrusion can improve the nutrient availability of diet. Herkelman et al. (1990) and Williams et al. (2010) both reported that extrusion significantly improve the digestibility of dry matter and energy. In this research, extrusion could significantly improve the digestibility of GE, and steam conditioning had no significant effect on the digestibility of GE. The reason may be that extrusion can improve starch gelatinization much more than steam conditioning, which is benefit to the absorption of starch (Murray et al., 2001). Rabbits digest the fiber in the diets mainly by the caecal microbial fermentation, and the degree of fiber digestion is affected by the physical and chemical characteristics of fiber and the residence time in the cecum (Gómez-Conde et al., 2009). The research found that the high pressure, high temperature and high shear forces of extrusion can destroy the fiber ingredient in non-conventional raw material, change the surface structure and make it loose and porous (Dust et al., 2004). It is easy to happen hydrolysis reaction and degrade by the cecum microbial fermentation, which improve the digestibility of fiber. In this work, extrusion and steam conditioning both significantly improved the apparent digestibility of CF, ADF and NDF. But adding extruded corn in diets of meat rabbit, observed no significant increase of fiber and protein digestibility (Gidenne et al., 2005; Cossu et al., 2005). The reason for inconsistent results may be with the extrusion condition, composition of extrusion materials and the meat rabbit breeds. Our work also found that extrusion and steam conditioning have no significant interaction effects on the nutrient digestibility, but have a combination of good effects.

5. Conclusions

In this experimental condition, the extrusion parameters of rabbit diet materials were as follows: barrel temperature 125 °C, moisture content 16% and feed rate 9 Hz. Raw material extrusion and steam conditioning both can significantly reduce the powder percentage, pulverization ratio and protein solubility, significantly improve hardness and starch gelatinization degree of rabbit feed. Extrusion and steam conditioning technology both can improve the pellet processing quality of rabbits feed, and they exists significant interaction effects. Raw material extrusion and steam conditioning both can significantly improve the apparent digestibility of CF, ADF and NDF. Extrusion also can significantly improve the apparent digestibility of DM and GE, but they have no interaction effect.

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