Effects of Extruded Alfalfa Meal-Flaxseed on Sow Reproductive Performance and Colostrum Fatty Acid Composition (Postprint)

Authors: Pan Peiying, Guo Xiaojie, Wang Bo, Wang Tengfei, Wang Chengzhang, Shi Yinghua, Qi Shengli, Li Zhentian

Date: 2018-12-25T00:00:00+00:00

Abstract

This experiment aimed to investigate the effects of adding different amounts of expanded alfalfa meal-flaxseed to sow diets during late gestation and lactation on their reproductive performance and colostrum fatty acid composition. Eighty late-gestating (day 83 of gestation) Landrace × Large White primiparous sows were selected and randomly divided into 4 groups, with 4 replicates per group and 5 sows per replicate. The control group was fed a basal diet, while the experimental groups were fed the basal diet supplemented with 5%, 10%, and 15% expanded alfalfa meal-flaxseed, respectively. The experiment consisted of a 7-day pre-trial period and a 55-day formal trial period. The results showed: 1) Compared with the control group, dietary supplementation with expanded alfalfa meal-flaxseed significantly increased the average daily feed intake of sows ($P<0.05$), and the 15% expanded alfalfa meal-flaxseed supplementation group had the highest average daily feed intake; 2) As the supplementation level of expanded alfalfa meal-flaxseed increased, backfat loss during lactation gradually decreased, while litter weight at day 21, litter average daily gain, individual weight at day 21, and the content of monounsaturated fatty acids (MUFA) and the unsaturated fatty acid/saturated fatty acid (UFA/SFA) ratio in sow colostrum gradually increased, but the differences were not significant ($P>0.05$); 3) At weaning (21 days of age), the 15% expanded alfalfa meal-flaxseed supplementation group exhibited the best uniformity. In conclusion, expanded alfalfa meal-flaxseed can improve sow reproductive performance and increase MUFA content and UFA/SFA ratio in colostrum.

Full Text

Effects of Extruded Alfalfa Meal-Linseed on Reproductive Performance and Fatty Acid Composition in Colostrum of Sows

PAN Peiying, GUO Xiaojie, WANG Bo, WANG Tengfei, WANG Chengzhang, SHI Yinghua, QI Shengli, LI Zhentian*

The Key Laboratory of Innovation and Utilization of Grassland Resources in Henan Province, College of Animal Science and Veterinary Medicine, Henan Agricultural University, Zhengzhou 450002, China

Abstract

This experiment was conducted to investigate the effects of different supplemental levels of extruded alfalfa meal-linseed during late gestation and lactation on reproductive performance and colostrum fatty acid composition in sows. Eighty Landrace×Large White primiparous sows in late gestation (83 days of gestation) were randomly allocated to 4 groups with 4 replicates per group and 5 sows per replicate. The control group was fed a basal diet, while experimental groups were fed the basal diet supplemented with 5%, 10%, and 15% extruded alfalfa meal-linseed, respectively. The trial consisted of a 7-day adaptation period followed by a 55-day formal experimental period. The results showed: 1) Compared with the control group, dietary extruded alfalfa meal-linseed significantly increased the average daily feed intake of sows ($P<0.05$), with the highest intake observed in the 15% supplementation group; 2) With increasing supplementation levels, backfat loss during lactation decreased, while litter weight at day 21, average daily litter weight gain, individual piglet weight at day 21, as well as monounsaturated fatty acid (MUFA) content and the unsaturated fatty acid to saturated fatty acid ratio (UFA/SFA) in sow colostrum increased, though these differences were not significant ($P>0.05$); 3) At weaning (21 days of age), piglets in the 15% supplementation group showed the best weight uniformity. These findings indicate that extruded alfalfa meal-linseed can improve sow reproductive performance and increase MUFA content and UFA/SFA ratio in colostrum.

Keywords: extrusion; alfalfa meal; linseed; reproductive performance; fatty acid

Alfalfa (*Medicago sativa*) is a perennial leguminous forage with characteristics of rich nutrition, good palatability, and easy digestibility for livestock. Research has shown that alfalfa meal has beneficial effects on weaned piglet litter weight [1]. Linseed is rich in oil and crude protein, with oil content as high as 34%~37% and high unsaturated fatty acid (UFA) content. The crude protein is primarily composed of albumin and globulin, making it a high-quality plant protein. Additionally, linseed has an ideal essential amino acid composition and is rich in minerals, B vitamins, and vitamin E, which exists as tocopherols and acts as a

natural antioxidant. In recent years, many researchers have applied linseed in animal feed, significantly improving feed nutritional value [2]. Farmer et al. [3-4] found that adding 10% linseed and 3.5% linseed oil could reduce saturated fatty acid (SFA) content and increase polyunsaturated fatty acid (PUFA) content in sow serum. Supplementing linseed during late gestation and lactation could enhance piglet immune function and promote post-weaning growth. Extruded feed is a special product manufactured by specific equipment under particular conditions (high temperature, high pressure, etc.). It can gelatinize starch granules, improve palatability, and facilitate nutrient absorption in livestock. The high temperature can also kill many pathogens and parasites and inactivate numerous anti-nutritional factors [5]. Since linseed and its oil-extracted meal contain cyanogenic glycosides, which can be hydrolyzed by coexisting enzymes to produce toxic hydrocyanic acid [6], special treatment is generally required when adding linseed to diets. This experiment eliminated harmful substances through extrusion processing. Moreover, extruded pig feed technology has only emerged in China in recent years, primarily for piglet feed, with limited research on sows. Studies on the effects of linseed on sow reproductive performance are also scarce. Therefore, this experiment aimed to investigate the effects of extruded alfalfa meal-linseed on sow reproductive performance and colostrum fatty acid composition, providing a scientific basis for developing new feed products.

1. Materials and Methods

1.1 Experimental Materials

The extruded ingredient was processed using a 1:1 ratio of alfalfa meal to linseed. Eighty healthy primiparous Landrace×Large White crossbred sows from the same batch, at approximately 83 days of gestation, were selected for the experiment.

1.2 Experimental Design and Diets

A single-factor completely randomized design was employed with 4 groups, each containing 4 replicates of 5 sows. Replicates were balanced for body weight and health status. The basal diet was formulated according to NRC (2012) nutrient standards for sows. The control group (Group 1) received the basal diet without extruded alfalfa meal-linseed, while experimental groups (Groups 2-4) received the basal diet supplemented with 5%, 10%, and 15% extruded alfalfa meal-linseed, respectively. Diet composition and nutrient levels for all groups are presented in Table 1 .

Table 1 Composition and nutrient levels of diets for all groups (air-dry basis)

Items	Groups
Ingredients	

Items	Groups
Corn	
Soybean meal	
Wheat bran	
Extruded alfalfa meal-linseed	
Wheat middling	
Fish meal	
Limestone	
CaHPO	
NaCl	
Soybean oil	
Lys	
Thr	
Choline chloride	
Premix[1]	
Total	
Nutrient levels[2]	
CP	
EE	
CF	
Ash	
TP	
AP	
Lys	
Linoleic acid	
DE/(MJ/kg)	

[1]Premix provided the following per kg of diets: VA 5,500 IU, VD 500 IU, VE 66.1 IU, VB 28.2 µg, VB 5.1 mg, VB 12.6 mg, VB 29.8 mg, VK 540 mg, Mn 40 mg, Zn 120 mg, Fe 150 mg, Cu 10 mg, Co 1 mg, Se 0.25 mg, I 0.5 mg.

[2]Nutrient levels were all calculated values.

1.3 Feeding Management

The trial included a 7-day adaptation period and a 55-day formal experimental period. During late gestation, sows were limit-fed twice daily at 1.25 kg per feeding at 09:00 and 16:00. During lactation, sows were fed ad libitum at 06:00, 10:00, 14:00, and 20:00. Pens were cleaned once daily, and routine immunization and disinfection protocols were followed according to standard farm procedures.

1.4 Measurements

1.4.1 Reproductive Performance Feed intake during lactation was recorded for each sow. Backfat thickness at the P2 position was measured

individually using ultrasound at 90 days of gestation, before parturition, and at weaning to calculate backfat increase from day 90 to parturition and backfat loss during lactation. Total number of piglets born, number born alive, individual piglet weight at birth, and litter weight at days 7, 14, and 21 (weaning) were recorded.

1.4.2 Sow Colostrum Sampling Within 12 hours of parturition, 30 mL of mixed colostrum samples were collected by hand-milking from anterior, middle, and posterior teats. Samples were stored at -20 °C for subsequent composition analysis. One sow was randomly selected from each replicate, with 4 sows sampled per group.

1.5 Data Processing

Experimental data were analyzed using SPSS 22.0 statistical software with T-tests. Differences were considered significant at $P<0.05$. Results are expressed as "mean ± standard deviation."

2. Results

2.1 Effects of Extruded Alfalfa Meal-Linseed on Piglet Survival Rate

As shown in Table 2 , Groups 2 and 3 had relatively higher total number of piglets born and number born alive, while Group 3 showed relatively higher piglet survival rate. However, no significant differences were observed among groups ($P>0.05$).

Table 2 Effects of extruded alfalfa meal-linseed on the fetal survival rate of piglets

Items	Groups
Total number born (head)	11.33±2.27
Number born alive (head)	11.17±2.18
Survival rate (%)	98.81±5.05
Adjusting litter size (head)	

In the same row, values with no letter or the same letter superscripts mean no significant difference ($P>0.05$), while with different letter superscripts mean significant difference ($P<0.05$). The same as below.

2.2 Effects of Extruded Alfalfa Meal-Linseed on Sow Feed Intake and Backfat Thickness

Table 3 shows that average daily feed intake during lactation increased with extruded alfalfa meal-linseed supplementation, with all experimental groups being significantly higher than the control group ($P<0.05$). Backfat increase during

late gestation and backfat loss during lactation decreased with increasing supplementation, though differences among groups were not significant (P>0.05).

Table 3 Effects of extruded alfalfa meal-linseed on ADFI in lactation and backfat thickness of sows

Items	Groups
ADFI (kg)	5.38±0.03c
Backfat thickness (mm)	
Day 90 of gestation	18.57±1.74
Before parturition	19.57±2.06ab
Weaning	16.70±2.15
Backfat increase during late gestation (90 d)	1.00±1.24
Backfat loss during lactation	2.93±1.90

2.3 Effects of Extruded Alfalfa Meal-Linseed on Litter Weight and Individual Piglet Weight

As shown in Table 4 , litter weight and individual weight at birth increased gradually from Groups 2 to 4, but differences compared with the control group were not significant (P>0.05). Litter weight at day 21, average daily litter weight gain, and individual weight at day 21 showed an increasing trend with supplementation, though no significant differences were observed among groups (P>0.05).

Table 4 Effects of extruded alfalfa meal-linseed on litter weight and individual weight of piglets

Items	Groups
Litter weight of piglets (kg)	
Litter weight at birth	15.23±2.08
Litter weight of day 7	27.64±3.13
Litter weight of day 14	43.83±4.13
Litter weight of day 21	60.72±6.93
Average litter daily weight gain (kg)	2.18±0.41
Individual weight of piglets (kg)	
Individual weight at birth	1.35±0.18ab
Individual weight of day 7	2.55±0.28b
Individual weight of day 14	3.96±0.33
Individual weight of day 21	5.69±0.61
Average individual daily weight gain (kg)	0.21±0.03

2.4 Effects of Extruded Alfalfa Meal-Linseed on Piglet Uniformity

Table 5 shows that at birth, Group 2 had the most piglets weighing less than 0.8 kg, while the number of piglets weighing 1.3-1.8 kg increased gradually from

Groups 2 to 4. The control group and Group 3 showed similar uniformity. At weaning, Group 2 had the most piglets in the 3.5-5.0 kg range, while the number of piglets weighing 6.5-8.0 kg increased progressively from the control group to Group 4. Group 4 showed the smallest difference in proportion between 5.0-6.5 kg and 6.5-8.0 kg piglets and had no unqualified piglets weighing less than 3.5 kg, indicating the best uniformity.

Table 5 Effects of extruded alfalfa meal-linseed on weight distribution of piglets

Items	Groups
Birth weight distribution	
<0.8 kg	
0.8-1.3 kg	
1.3-1.8 kg	
>1.8 kg	
Total	
Weaning weight distribution	
<3.5 kg	
3.5-5.0 kg	
5.0-6.5 kg	
6.5-8.0 kg	
>8.0 kg	
Total	

Weak piglets were those that body weigh less than 0.8 kg at birth, and weaned piglets weighing less than 3.5 kg were disqualified.

2.5 Effects of Extruded Alfalfa Meal-Linseed on Colostrum Fatty Acid Composition

Table 6 demonstrates that with increasing extruded alfalfa meal-linseed supplementation, elaidic acid, eicosenoic acid, and erucic acid content in sow colostrum increased gradually, with Group 4 being significantly higher than the control group ($P<0.05$). The UFA/SFA ratio and MUFA content in colostrum also increased with supplementation. Although UFA content in experimental groups was generally higher than in the control group, with Group 4 showing the highest values, these differences were not significant ($P<0.05$).

Table 6 Effects of extruded alfalfa meal-linseed on fatty acid composition of sow colostrum (mg/kg)

Items	Groups
SFA	
Lauric acid (C12:0)	0.177±0.092

Items	Groups
Myristic acid (C14:0)	5.757±1.295
Pentadecanoic acid (C15:0)	0.629±0.192
Palmitic acid (C16:0)	70.333±12.795
Heptadecanoic acid (C17:0)	1.062±0.453
Stearic acid (C18:0)	14.200±2.706
Arachidic acid (C20:0)	0.288±0.051
Behenic acid (C22:0)	0.114±0.028
MUFA	
Elaidic acid (C18:1 n-9t)	0.542±0.093b
Oleic acid (C18:1)	79.833±7.814
Palmitoleic Acid (C16:1)	6.667±2.275
Eicosenoic acid (C20:1)	14.000±1.400c
Erucic acid (C22:1)	0.597±0.136b
n-3 PUFA	
ALA (C18:3n-3)	0.584±0.078
Cis-11,14,17-eicosatrienoic acid (C20:3 n-3)	3.043±0.323
DHA (C22:6 n-3)	1.036±0.233
n-6 PUFA	
Linoleic acid (C18:2 n-6)	122.000±3.606
-Linolenic acid (C18:3 n-6)	0.796±0.135
Cis-8,11,14-eicosatrienoic acid (C20:3 n-6)	0.945±0.946
Arachidonic acid (C20:4 n-6)	0.167±0.036
Other PUFA	
Eicosadienoic acid (C20:2)	1.713±0.254
SFA	92.560±17.30
UFA	231.924±13.569
UFA/SFA	2.55±0.25
MUFA	101.639±9.709
PUFA	130.285±4.639
n-3 PUFA	4.663±0.634
n-6 PUFA	123.908±3.779
n-6 PUFA/n-3 PUFA	26.86±3.13
EFA	122.584±3.683

3. Discussion

3.1 Effects on Sow Feed Intake and Backfat Thickness

Excessive feed intake during gestation can lead to increased backfat thickness, which impairs feed intake and lactation capacity during the subsequent lactation period [7]; therefore, sows are typically limit-fed during late gestation. The nutritional and feeding goal for lactating sows is to maximize feed intake and nutrient consumption, which benefits milk production, maintains good body condition, shortens the weaning-to-estrus interval, and improves reproductive

performance [8]. Extrusion processing enhances feed aroma and palatability, stimulating animal appetite and increasing voluntary feed intake of lactating sows [9]. Lenehan et al. [10] found that increasing extruded soy protein concentrate in diets improved average daily feed intake in finishing pigs. Backfat loss during lactation affects the weaning-to-estrus interval; excessive loss prolongs this interval [11] and leads to increased atretic follicles, reducing the number of viable embryos in the subsequent parity [12]. Thus, appropriate control of body condition changes in gestating sows is necessary.

Mateo et al. [13] reported that adding non-extruded linseed did not increase sow feed intake during lactation. However, this study found that supplementing the diet with palatable extruded alfalfa meal-linseed improved average daily feed intake, which increased with supplementation level. Additionally, backfat increase during late gestation and backfat loss during lactation decreased with increasing extruded alfalfa meal-linseed supplementation. These results indicate that extruded alfalfa meal-linseed can increase voluntary feed intake in lactating sows while effectively controlling body condition, which is beneficial for milk production, post-weaning estrus, and overall reproductive performance.

3.2 Effects on Piglet Survival, Litter Weight, Individual Weight, and Uniformity

Alfalfa not only has high forage yield but also contains abundant crude protein, vitamins, and inorganic salts, with high levels of essential amino acids [14]. It also contains vitamin E, folic acid, and selenium, which can increase litter size, reduce abortion, decrease embryonic mortality, and enhance sow milk yield and piglet daily weight gain [15]. Many studies have shown that adding fibrous feeds such as forage (meal) to sow diets can improve reproductive performance [16]. Zang et al. [17] reported that alfalfa meal supplementation had highly significant effects on sow feed intake during lactation, piglet survival rate, weaning litter weight, litter weight gain, weaning individual weight, and individual average daily weight gain. Zhang et al. [18] found that alfalfa meal could improve weaned piglet survival rate and weaning litter weight, with 20% alfalfa meal showing the best results.

In addition to rich oil and crude protein, linseed contains high levels of dietary fiber, minerals, vitamin A, B vitamins, vitamin D, vitamin E, and nutrients such as phenolic acids, flavonoids, phytic acid, and lecithin [19]. It is widely used not only in food processing but also in animal feed. However, research on the effects of linseed supplementation in sow diets on piglet performance is relatively limited and inconsistent, requiring further verification. De Quelen et al. [20] found that adding different levels of extruded linseed to sow diets had no significant effects on litter size or average birth weight. Farmer et al. [4] reported that linseed supplementation during late gestation (day 68) and lactation resulted in lower piglet birth weight compared with the control group, but higher individual weight at 21 days of age, though differences were not significant. Quiniou et al. [21] found that extruded linseed could increase piglet birth weight and

average daily litter weight gain, but without significant differences. This study found that extruded alfalfa meal-linseed supplementation during late gestation and lactation had no significant effects on total number of piglets born, number born alive, or piglet survival rate, possibly because supplementation began only in late gestation. However, supplementation improved weaning litter weight, weaning individual weight, and average daily litter weight gain, with these metrics showing an upward trend as supplementation increased. These benefits are likely attributable to both alfalfa meal and linseed, with alfalfa meal potentially having a greater influence.

Many studies have demonstrated that piglet uniformity is an important factor affecting piglet mortality [22]. Birth weight, weaning weight, and fattening performance are closely related; non-uniform birth and weaning litter weights with large individual differences lead to similarly large weight variations during the fattening period [23], which is disadvantageous for management at all production stages. Therefore, improving piglet uniformity is increasingly important in pig production. This study found that extruded alfalfa meal-linseed supplementation during late gestation and lactation had no significant effect on birth uniformity. However, with extended feeding duration, the 15% supplementation group showed the best weaning uniformity, which would facilitate management during nursery and fattening stages and reduce economic losses.

3.3 Effects on Sow Colostrum Fatty Acid Composition

Linseed is rich in crude protein, MUFA, and PUFA [24]. MUFA primarily functions by reducing plasma low-density lipoprotein, total cholesterol, and triglyceride content while increasing or maintaining high-density lipoprotein content, thereby beneficially regulating lipid metabolism [25]. PUFA has multiple functions, including regulating lipid metabolism, treating and preventing cardiovascular diseases, promoting growth and development, and modulating immune function [26]. Studies have shown that linseed helps improve animal health and immunity [27]. Nudda et al. [28] reported that linseed supplementation in dairy ewes during lactation increased the UFA/SFA ratio, MUFA, and n-3 PUFA content in milk at weaning. De Quelen et al. [20] found that different levels of extruded linseed in sow diets did not affect litter size or average piglet birth weight but increased MUFA and n-3 PUFA content in colostrum while decreasing the n-6 PUFA/n-3 PUFA ratio with increasing supplementation. Yu et al. [29] reported that extruded linseed supplementation had no significant effects on milk yield or milk protein, fat, and lactose content but significantly increased MUFA, PUFA, and n-3 PUFA content in milk. This study found that extruded alfalfa meal-linseed supplementation increased the UFA/SFA ratio and MUFA content in sow colostrum but had limited effects on n-3 PUFA content, possibly related to sampling time and the presence of alfalfa meal in the diet. Nevertheless, the relatively high UFA/SFA ratio and MUFA content are beneficial for piglet growth.

Conclusions

1. Dietary supplementation with extruded alfalfa meal-linseed can increase average daily feed intake of sows, reduce backfat loss during lactation, and increase MUFA content and UFA/SFA ratio in colostrum.
2. Dietary supplementation with extruded alfalfa meal-linseed can improve weaning litter weight, weaning individual weight, and average daily litter weight gain, with the 15% supplementation group showing the best piglet uniformity at weaning.
3. In this experiment, 15% extruded alfalfa meal-linseed supplementation resulted in better reproductive performance in sows, though the optimal supplementation level requires further investigation.

References

[1] 廉红霞, 王成章, 杨雨鑫, 等. 不同苜蓿草粉添加水平对妊娠母猪及其仔猪生产性能的影响 [J]. 西北农林科技大学学报（自然科学版）,2004,32(6):35-40.

[2] 张爱武, 董斌, 左璐雅. 亚麻籽的营养及其在禽类饲料中的应用 [J]. 饲料工业,2011,32(5):51-54.

[3] FARMER C, PETIT H V. Effects of dietary supplementation with different forms of flax in late-gestation and lactation on fatty acid profiles in sows and their piglets[J]. Journal of Animal Science, 2009, 87(8): 2600-2613.

[4] FARMER C, GIGUÈRE A, LESSARD M. Dietary supplementation with different forms of flax in late gestation and lactation: effects on sow and litter performances, endocrinology, and immune response[J]. Journal of Animal Science, 2010, 88(1): 225-237.

[5] 王化山, 徐英, 辛立卫. 膨化技术的优缺点及在动物饲料中的应用 [J]. 中国畜牧兽医文摘,2015,31(9):213.

[6] 周小洁, 车向荣, 于霏. 亚麻籽及其饼粕的营养学和毒理学研究进展 [J]. 饲料工业,2005,26(19):46-50.

[7] THODBERG K, SØRENSEN M T. Mammary development and milk production in the sow: effects of udder massage, genotype and feeding in late gestation[J]. Livestock Science, 2006, 101(1/2/3): 116-125.

[8] 成建国, 呼红梅, 张印, 等. 母猪妊娠期采食水平对其哺乳期采食量和繁殖性能的影响 [J]. 养猪,2016(4):20-24.

[9] 曹剑, 黄庆余. 膨化饲料的优点及应用 [J]. 养殖技术顾问,2010(1):50.

[10] LENEHAN N A, GOODBAND R D, TOKACH M D, et al. Effects of increasing extruded soy-protein concentrate on growth performance of nursery pigs[J]. Kansas State University Swine Day Report of Progress, 2004(10): 64-67.

[11] 胡闪耀, 郑雨剑, 荣雷, 等. 哺乳期经产母猪背膘变化对其繁殖性能的影响 [J]. 猪业科学,2015,32(10):106-108.

[12] PRUNIER A, QUESNEL H. Influence of the nutritional status on ovarian development in female pigs[J]. Animal Reproduction Science, 2000, 60-61: 185-197.

[13] MATEO R D, CARROLL J A, HYUN Y, et al. Effect of dietary supplementation of n-3 fatty acids and elevated concentrations of dietary protein on the performance of sows[J]. Journal of Animal Science, 2009, 87(3): 948-959.

[14] 潘俊良, 李振田, 王成章, 等. 苜蓿草粉在动物饲料中的应用 [J]. 饲料研究,2006(7):63-65.

[15] 苏州, 黎佐绩, 郭礼荣, 等. 饲喂鲜草紫花苜蓿对母猪生产性能的影响 [J]. 江西畜牧兽医杂志,2007(4):24-26.

[16] VESTERGAARD E M, DANIELSEN V. Dietary fibre for sows: effects of large amounts of soluble and insoluble fibres in the pregnancy period on the performance of sows during three reproductive cycles[J]. Animal Science, 2010, 67(2): 355-362.

[17] 臧为民, 廉红霞, 王成章, 等. 不同水平苜蓿草粉对哺乳母猪及其仔猪生产性能及血清指标的影响 [J]. 西北农林科技大学学报（自然科学版）,2005,33(2):54-59.

[18] 张金枝, 任巧玲, 刘建新, 等. 不同苜蓿草粉水平对母猪繁殖性能和血清生化指标的影响 [J]. 中国畜牧杂志,2011,47(3):45-48.

[19] 陈兴发, 韦建福, 徐奇, 等. 亚麻籽和有机铁对仔猪生长性能的影响 [J]. 广东饲料,2017,26(1):22-25.

[20] DE QUELEN F, BOUDRY G, MOUROT J. Effect of different contents of extruded linseed in the sow diet on piglet fatty acid composition and hepatic desaturase expression during the post-natal period[J]. Animal, 2013, 7(10): 1671-1680.

[21] QUINIOU N, GOUES T, VAUTIER A, et al. Consequence of extruded linseed incorporation in sows and/or pigs' diets on performance[C]//61st Annual Meeting of the European Association for Animal Production. Heraklion: European Association for Animal Production, 2010.

[22] LEENHOUWERS J I, DE ALMEIDA JÚNIOR C A, KNOL E F, et al. Progress of farrowing and early postnatal pig behavior in relation to genetic merit for pig survival[J]. Journal of Animal Science, 2001, 79(6): 1416-1422.

[23] 施辉毕, 王立刚, 张跃博, 等. 仔猪均匀度研究进展 [J]. 养猪,2015(1):35-39.

[24] 李高阳, 丁霄霖. 亚麻籽油中脂肪酸成分的 GC-MS 分析 [J]. 食品与机械,2005,21(5):30-32.

[25] 刘跟生, 徐贵发. 单不饱和脂肪酸对心血管的保护作用 [J]. 卫生研究,2006,35(3):357-359.

[26] 王萍, 张银波, 江木兰. 多不饱和脂肪酸的研究进展 [J]. 中国油脂,2008,33(12):42-46.

[27] 孙中义. 亚麻籽饲用研究进展 [J]. 中国麻业科学,2010,32(1):37-41,44.

[28] NUDDA A, BATTACONE G, BEE G, et al. Effect of linseed supplementation of the gestation and lactation diets of dairy ewes on the growth performance and the intramuscular fatty acid composition of their lambs[J]. Animal, 2015, 9(5): 800-809.

[29] 余婕, 周源, 程蕾, 等. 日粮中添加膨化亚麻籽对奶牛乳品质及脂肪酸组成的影响 [J]. 饲料博览,2017(2):5-8.

Note: Figure translations are in progress. See original paper for figures.