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Effect of flaxseed supplementation on metabolic profile and reproductive performance of prepubertal gilts

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ABSTRACT

This study was conducted on Large White Yorkshire prepubertal gilts (n=36) to evaluate the effect of flaxseed supplementation on feed intake, bodyweight, metabolic profile and reproductive parameters. The gilts were randomly allocated to three treatments, viz. group 1 (n=12; control), group 2 (n=12) and group 3 (n=12). All gilts received grower-finisher rations, twice daily from 120 days of age until 240 days of age. Additionally, in group 2 and group 3, flaxseed was mixed at a rate of 0.5% and 1.0% of dry matter, respectively. Average daily feed intake did not differ between three groups. Bodyweight and daily bodyweight gain were more in gilts of group 3 than in group 2 and group 1 toward the end of feeding period. The gilts of group 3 had an improved feed conversion ratio compared to their contemporary mates throughout the study period. Over the period of time, a significant reduction in cholesterol levels and linear increase in IGF-1 levels was noticed in gilts of group 3 as compared to their counterparts. Gilts of group 3 reached puberty and expressed estrus at breeding significantly earlier than in their contemporary mates. The number of total piglets born and born alive was maximum in group 3 followed by group 2 and group 1. Piglet birth weight and still birth percentage were similar in all groups. In conclusion, supplementing flaxseed (1.0%) in diet improved body composition variables, age at onset of puberty and reproductive performance of prepubertal gilts.

Keywords: Age at puberty, Bodyweight, Cholesterol, Flaxseed, Prepubertal gilts

Nutrition of prepubertal gilt is a key factor to maximize its reproductive performance and longevity. Various nutritional strategies have been recommended to improve the reproductive performance of gilts (Foxcroft *et al.* 2010). Some of these strategies include feeding of polyunsaturated fatty acids (PUFA; Tanghe and De Smet 2013). These PUFA are essential components of lipids, involved in metabolism of steroid hormones required for development and growth of fetus and increased number of offspring (Brazle *et al.* 2009). Diets with inclusion of PUFA in gilt feeding programs may be an effective nutritional strategy associated with increased fat reserves and bodyweight and help trigger puberty (Amaral *et al.* 2010, Smits *et al.* 2011). In the current pork production systems, pigs are fed a mixture of maize, soybean meal, de-oiled rice bran, wheat bran and barley, all of which are high in linoleic acid (n-6 PUFA) and low in á-linolenic acid (n-3 PUFA). To increase the n-3 PUFA uptake in pigs, diets can be supplemented with flaxseed or fish (meal/oil). Flaxseed is one of the highest sources of á-linolenic acid (58% of the total fatty acids) and offers about 23% protein and 28% dietary fibre, thus making it an energy dense replacement (Rosero *et al.* 2015). Although, much evidence exists that supplemental flaxseed in dairy cattle has positive effects on reproduction (Gonthier *et al*. 2005), data on flaxseed requirements of prepubertal gilts are scarce and limited. Therefore, the present study was undertaken to determine the effects of supplemental flaxseed on metabolic profile and reproductive performance of prepubertal gilts.

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MATERIALS AND METHODS

Care and use of animals: The study was conducted at an organized commercial swine farm located in peri-urban areas of Ludhiana. Large White Yorkshire prepubertal terminal line gilts (n=36) were selected during the months of April through August. During the study, average daily temperature and relative humidity inside the shed were 27.3±0.7°C and 55.4±1.9%, respectively. The gilts were randomly allocated to three treatments, viz. group 1 (n=12; control), group 2 (n=12) and group 3 (n=12). All the gilts were housed in groups (4 gilts/pen/group) in the finishing pens. Grower-finisher rations were prepared using maize, soyabean meal, rice bran, wheat bran, salt and mineral mixture. Additionally, in group 2 and group 3, flaxseed was mixed at a rate of 0.5% and 1.0% of dry matter (Tanghe *et* *al.* 2015), respectively, as n-3 PUFA source from 120 days until 240 days of age. All diets were isonitrogenous and isocaloric based on calculated values (Table 1). The gilts were fed grower-finisher ration from 120 days until 240 days of age, twice daily at the rate of 2.5%/kg bodyweight/day/animal during the study period (Table 1, NRC 2012) and had free access to drinking water throughout the day. The amount of feed was rescheduled fortnightly according to the weight of animals. Representative feed samples within each group were taken for compositional analyses (Table 1) from a Bureau of Indian Standards approved government laboratory (Punjab Biotechnology Incubator, Mohali, Punjab).

Table 1. Nutritional composition of various diets fed to gilts

Item	Control diet (Group 1)	FS, 0.5% (Group 2)	FS, 1.0% (Group 3)
Ingredient (kg/100 kg)			
Maize	47.50	47.50	47.00
Soybean meal	11.60	11.60	11.60
Groundnut extraction	19.00	19.00	19.00
De-oiled rice bran	10.00	10.00	10.00
Rice polish	10.60	10.10	10.10
Common salt	0.30	0.30	0.30
Crushed flaxseed	0	0.50	1.00
Specific mineral mixture	1.00	1.00	1.00
Chemical composition (analyzed)			
Moisture (%)	9.25	9.43	9.03
Crude protein (%)	20.73	20.77	20.81
Crude fibre (%)	5.07	5.05	5.02
Ether extract (%)	5.05	5.15	5.25
Total ash (%)	6.14	6.09	6.02
ME (Kcal/kg)	3265.00	3270.00	3274.00
Calcium (Ca, %)	1.15	1.35	1.38
Phosphorus (P, %)	0.67	0.72	0.70
Salt (NaCl, %)	0.59	0.59	0.59
Vitamin A (IU/kg)	2382.00	2764.00	2737.00
Vitamin E (IU/kg)	36.64	37.60	37.60
Lysine (mg/100 g)	0.76	0.81	0.79
Methionine (mg/100 g)	0.54	0.62	0.66
Potassium (K, %)	0.31	0.33	0.29
Aflatoxin B1 (µg/kg)	BDL	BDL	BDL
Aflatoxin B2 (µg/kg)	BDL	BDL	BDL
Aflatoxin G1 (µg/kg)	BDL	BDL	BDL
Aflatoxin G2 (µg/kg)	BDL	BDL	BDL
C18:1 Oleic acid (per 100 g fat)	1.05	1.12	1.17
C18:2 Linoleic acid (per 100 g fat)	0.14	0.36	0.39
C18:3 Linolenic acid (per 100 g fat)	0.09	0.34	0.42
C20:4 Arachidonic acid (per 100 g fat)	0.95	1.03	0.98
C20:5 Cis-5,8,11,14,17-Eicosapentanoic acid (per 100 g fat)	0.02	0.06	0.06
C22:6 Cis-4,7,10,13,16,19-Dicosahexanoic acid (per 100 g fat)	0.03	0.04	0.04

BDL, Below detection limit; FS, Flaxseed supplementation.

Blood sampling: To assess metabolic and endocrine status of animals, blood samples were collected from peripheral ear vein at the initiation of diets at 120 days until 240 days of age at 30 day intervals. Additional blood samples for progesterone analysis were collected from all the gilts that had not been observed in standing estrus at days 240 of age and again at 10 days apart to evaluate whether the gilts that failed to reach puberty were either prepubertal or behaviorally anestrus. Blood samples were centrifuged for 15 min at 3,000 rpm to harvest plasma. The plasma samples were stored at –20°C in duplicate vials until assayed.

Biochemical profile: Plasma glucose, total protein, calcium, cholesterol, triglycerides, aspartate transaminase (AST), alanine transaminase (ALT), gamma glutamyl transpeptidase (GGT), blood urea nitrogen (BUN) and creatinine were assayed in duplicate by Vitros 350 Chemistry System (Ortho Clinical Diagnostics, Buckinghamshire, England) using kits (Ortho Clinical Diagnostics, NY, USA) validated for multi-species use.

Endocrine milieu: Plasma insulin like growth factor-1 (IGF-1) and progesterone concentrations were quantified in duplicate using commercial Porcine specific ELISA kits (Bioassay Technology Laboratory, Shanghai, China) following the manufacturer's protocol (sensitivity 0.63 ng/ml and 0.24 ng/ml for IGF-1 and progesterone, respectively). The intra- and inter-assay coefficient of variations were <8% and <10%. Progesterone concentration of ≥1.0 ng/ml was used to distinguish between prepubertal gilts and behaviorally anestrus gilts.

Bodyweight and feed intake variables: Gilts were weighed individually using a digital scale. Bodyweight was recorded at day 120 and then every 30 days until day 240. Daily feed intake per pig was calculated by dividing the total feed intake by the number of pigs per group. Daily feed intake, bodyweight gain and feed conversion ratio were calculated at day 150 and every 30 day interval until day 240.

Age at puberty: At 120 days of age, gilts were exposed daily to a vasectomized boar (>10 months of age) for 10 min each day. Gilts were observed daily for signs of standing estrus until 240 days of age. The first day of exhibition of physical signs of estrus was considered pubertal estrus. The estrus which would typically take place at second or later relative to time of pubertal estrus was considered as breeding estrus. The reproduction and production data, viz. duration of estrus, pregnancy rate, total number of farrowing, total piglets born at birth, piglets born alive, proportion of still births and mummified piglets, piglet mortality (within 24 h of birth) and piglet weight at birth were recorded.

Ultrasound examination: The diagnosis of pregnancy was performed at day 25 post-mating by ultrasound machine (BestScan S6 Ultrasound Diagnostic System, BMV Technology Co., Ltd., Shenzhen, China) using a B-mode linear array abdominal transducer with 5/7.5 MHz interchangeable frequency by positioning the transducer head on skin surface of lower abdomen, just ahead of hind legs (adjacent to second last teat line). A pregnant uterus exhibited visualization of embryonic vesicle (anechoic).

Statistical analysis: Data were analyzed using mixed model equation methods with SAS (statistical analysis system, version 9.3, USA) program. All variables were tested for normality using Sharpiro-Wilk test. The effects of treatments and period of evaluation on bodyweight, feed intake variables, hormone and metabolic levels were tested by repeated measures analysis of variance with the effect of individual gilts kept within the period. Due to lack of normality, the endocrine and metabolic data were transformed to alogarithmic scale. The model included supplemental flaxseed as fixed effect and bodyweight at puberty as linear covariates. Reproduction and production data were analyzed using multivariate GLM analysis according to the data distribution. Tukey-Kramer adjustment was used for multiple comparisons between concentrations. Results for fixed effects have been reported as mean±standard error (SE). The minimum significant interaction was considered at 5% level.

RESULTS AND DISCUSSION

Impact on body composition variables: Various body composition measurements of gilts in three groups have been given in Table 2. Average daily feed intake did not differ between three groups, on the days of evaluation, however, feed intake increased gradually (P<0.05) with increasing overtime. Supplementation of flaxseed to gilts was successful to have an impact on bodyweight (BW) and daily bodyweight gain (BWG) after 180 days of age since the two variables were more (P>0.05) in gilts of group 3 and group 2 than in control group. Towards the end of feeding period (day 240), the effect on BW was significant (P<0.05) in gilts of group 3 as compared to their counterparts. Correspondingly, gilts of group 3 had an improved (P<0.05) feed conversion ratio (FCR) than in their contemporary mates throughout the study period. Likewise, a better (P>0.05) FCR was also observed in gilts of group 2 as compared to those kept on control diet. These findings are in agreement with the observations of Moreira *et al.* (2016) who established positive correlation of dietary flaxseed supplementation with daily bodyweight gain and FCR in pigs. Although, gilts of group 1 and group 2 had a lesser BWG, in the current study all gilts had BWG approximating 0.3 kg/day which has been suggested as minimum daily gain for puberty attainment (Banerjee 2019). Bortolozzo *et al.* 2009 reported that gilts should be bred when they attain a weight of 80–140 kg. They further noticed that weight exceeding upper threshold has been associated with structural problems (lameness) and failure to exhibit estrus. In the present study, gilts of all groups never attained maximum bodyweight threshold.

Impact on metabolic profile of gilts: Table 3 shows detailed metabolic milieu of gilts in different groups. The cholesterol levels exhibited a non-significant (P>0.05) difference until day 180 of feeding and were significantly lower (P<0.05) in gilts of group 3 as compared to those of group 2 and group 1 by the end of feeding period. Previous studies (Moreira *et al.* 2016) in gilts fed diets rich in omega-3 fatty acids also showed reduction in cholesterol levels owing to down-regulation of fatty acid synthesis gene expression (cholesterol regulatory element binding protein-1c) and established positive relationship with increased antioxidant activity. There was no difference in plasma triglycerides (TG) levels during the period of study in different groups, except at the end of feeding when TG levels in all groups were higher (P>0.05) than at start of the experiment. The significant impact for TG profiles could merely be due to the fact that TG values at the start of

Table 2. Body composition variables (Mean±SE) in prepubertal gilts of group 1 (control, n=12), group 2 (0.5% FS, n=12) and group 3 (1% FS, n=12) in distinct feeding periods

Parameter	Dietary groups	Age at period of feeding (days)					P value		
		120	150	180	210	240	T	P	T×P
Bodyweight (kg)	Group 1	$43.2\pm0.6^{!}$	$53.3\pm0.6^{\#}$	$59.3\pm0.6^{\wedge}$	$70.7\pm0.6^{*}$	$79.2\pm0.5^{+a}$	0.487	0.032	0.536
	Group 2	$41.9\pm0.6^{!}$	$51.9\pm0.6^{\#}$	$61.4\pm0.5^{\wedge}$	$72.6\pm0.5^{*}$	$83.6\pm0.5^{+b}$			
	Group 3	$41.2\pm0.5^{!}$	$51.1\pm0.5^{\#}$	$63.2\pm0.7^{\wedge}$	$76.8\pm0.4^{*}$	$89.9\pm0.5^{+c}$			
Feed intake (kg/day/animal)	Group 1	–	$1.34\pm0.18^{\#}$	$1.48\pm0.17^{\#}$	$1.77\pm0.13^{*}$	$2.03\pm0.16^{*}$	0.627	0.041	0.289
	Group 2	–	$1.30\pm0.08^{\#}$	$1.54\pm0.13^{\#}$	$1.82\pm0.18^{*}$	$2.11\pm0.08^{*}$			
	Group 3	–	$1.28\pm0.10^{\#}$	$1.57\pm0.08^{\wedge}$	$1.95\pm0.10^{*}$	$2.29\pm0.12^{+}$			
Bodyweight gain (kg/day/animal)	Group 1	–	0.33±0.07	0.29±0.05	0.35±0.06	0.28 ± 0.05^{a}	0.826	0.794	0.953
	Group 2	–	0.33±0.07	0.31±0.06	0.37±0.04	0.35 ± 0.06^{ab}			
	Group 3	–	0.33±0.06	0.40±0.08	0.48±0.08	0.40 ± 0.05^{b}			
Feed conversion ratio	Group 1	–	$4.08\pm0.62^{\#}$	$4.95\pm0.46^{\#a}$	$4.76\pm0.52^{\#a}$	$6.82\pm0.30^{+a}$	0.047	0.178	0.634
	Group 2	–	$3.94\pm0.15^{\#}$	$3.97\pm0.41^{\#b}$	$4.93\pm0.44^{*a}$	$6.03\pm0.90^{+ab}$			
	Group 3	–	$3.87\pm0.18^{\#}$	$3.92\pm0.39^{\#b}$	$4.01\pm0.19^{\#b}$	$5.66\pm0.51^{+b}$			

Values with different alphabetic superscripts differ significantly (P<0.05) from corresponding values in a row. Values with different symbolic superscripts differ significantly (P<0.05) from corresponding values in a column. FS, Flaxseed supplementation; T, Treatment; P, Period; T×P, Interaction of T and P.

Table 3. Plasma metabolic and endocrine profile (Mean±SE) in prepubertal gilts of group 1 (control, n=12), group 2 (0.5% FS, n=12) and group 3 (1% FS, n=12) in distinct feeding periods

Parameter	Dietary groups	Age at period of feeding (days)					P value		
		120	150	180	210	240	T	P	T×P
Glucose (mg/dl)	Group 1	111.9±6.7	116.3±5.7	109.2±4.9	114.6±4.7	119.4±4.1	0.927	0.748	0.935
	Group 2	109.7±8.8	122.2±6.5	113.7±5.2	107.9±7.5	120.6±4.9			
	Group 3	115.8±7.7	108.6±7.6	121.4±4.8	115.5±4.9	117.9±6.2			
Protein (g/dl)	Group 1	9.2±1.7	8.3±1.1	8.5±0.9	7.7±0.8	8.2±1.5	0.961	0.536	0.812
	Group 2	7.6±1.5	8.8±1.3	8.2±1.8	9.3±1.6	8.5±0.9			
	Group 3	7.8±0.8	9.1±0.9	8.1±1.6	7.9±1	8.1±1.3			
Calcium (mg/dl)	Group 1	10.7±0.6	9.6±1.8	11.2±0.7	10.2±1	10.1±1.3	0.982	0.875	0.974
	Group 2	9.9±0.9	10.2±0.7	9.1±1.1	11.3±1.4	10.5±0.7			
	Group 3	10.3±1.5	9.7±1.6	10.6±1.2	9.3±1.7	9.9±1.1			
Cholesterol (mg/dl)	Group 1	116.7±4.6	118.2±5.3	111.1±6.8	113.2±6.5	115.8±4.9^{a}	0.083	0.514	0.485
	Group 2	115.2±5.3	114.9±6.7	112.6±4.9	109.3±7.1	106.9±4.1^{a}			
	Group 3	119.3±7.2$^{!}$	115.1±5.9$^{!}$	111.6±4.4$^{!}$	104.8±6.3$^{!*}$	96.4±5.2^{*b}			
TG (mg/dl)	Group 1	53.7±2.3	51.6±2.6	46.9±3.3	50.5±2.9	48.2±2.7	0.317	0.268	0.295
	Group 2	53.1±2.2	50.9±3	52.1±3.2	49.7±3	47.2±3.1			
	Group 3	51.4±2.8$^{!}$	49.3±3.5$^{!*}$	47.2±3.6$^{!*}$	46.1±2.7$^{!*}$	44.1±3.3*			
AST (U/L)	Group 1	57.6±4	59.3±3.1	61.6±4.3	54.1±3.4	57.9±3.5	0.734	0.922	0.451
	Group 2	59.9±3.6	61.2±3.2	54.9±3.5	58.3±3.8	62.2±3.9			
	Group 3	62.7±4.9	54.5±4.7	60.1±4.9	56.8±3.2	55.4±4.3			
ALT (U/L)	Group 1	46.2±2.6	46.9±2.7	45.7±2.3	48.1±3.2	49.6±3.8	0.886	0.974	0.779
	Group 2	46.4±2.2	48.6±2.8	48.5±3.2	45.9±2.5	47.2±3.9			
	Group 3	45.8±3.3	46.1±2.2	44.2±3.9	46.3±2.4	46.3±2.2			
GGT (U/L)	Group 1	33.1±2.8	31.6±3.3	30.7±2.8	35.9±3.6	34.7±3.1	0.429	0.616	0.537
	Group 2	35.3±3	33.2±3.5	31.8±2.7	34.5±3.8	30.0±3.4			
	Group 3	32.4±2.7	30.9±3.1	34.3±3.2	31.7±3.9	32.4±2.8			
BUN (mg/dl)	Group 1	14.3±2	15.2±2.1	15.6±1.6	13.5±1.1	14.2±1.8	0.563	0.382	0.694
	Group 2	15.9±1.4	13.7±2.2	16.3±2.3	14.3±1.2	14.7±1.1			
	Group 3	13.6±1.7	16.0±1.9	13.8±1.4	15.8±2.2	14.6±2			
Creatinine (mg/dl)	Group 1	1.79±0.38	1.63±0.17	1.48±0.23	1.61±0.35	1.31±0.45	0.936	0.247	0.631
	Group 2	1.46±0.29	1.39±0.41	1.77±0.36	1.25±0.24	1.43±0.27			
	Group 3	1.80±0.45	1.28±0.38	1.26±0.24	1.47±0.16	1.29±0.19			
IGF-1 (ng/ml)	Group 1	209.3±24.2	218.4±18.9	206.3±41.8	221.9±37.9	203.6±27.5	0.192	0.275	0.217
	Group 2	214.6±30.7	223.2±36.2	219.1±49.3	231.8±19.8	235.7±26.4			
	Group 3	201.7±29.4	215.2±31.3	228.5±16.9	236.1±46.2	249.1±32.7			

Values with different alphabetic superscripts differ significantly (P<0.05) from corresponding values in a row. Values with different symbolic superscripts differ significantly (P<0.05) from corresponding values in a column. TG, Triglycerides; AST, Aspartate transaminase; ALT, Alanine transaminase; GGT, Gamma glutamyl transpeptidase; BUN, Blood urea nitrogen; FS, Flaxseed supplementation; T, Treatment; P, Period; T×P, Interaction of T and Ps.

feeding were on the higher side of normal physiological limits whereas at the end of feeding, the values were on lower side. Supplementation of flaxseed failed to have any significant (P>0.05) impact on plasma glucose, total protein, calcium, liver enzymes (ALT, AST, GGT) and kidney function (BUN and creatinine) as revealed by absence of difference in these parameters between the three groups over the 120 day feeding period (Table 3). This suggested that flaxseed supplementation had no adverse effect on energy status, liver enzymes and kidney functions of gilts. Studies showing influence of flaxseed supplementation on complete metabolic profile of gilts are not available. Based on extensive research in dairy cattle, Petit (2003) reported that supplementation of extruded flaxseed for 100 days failed to protect oilseeds against biohydrogenation and exhibited no influence on biochemical milieu.

Impact on IGF-1 secretion: The effects of flaxseed on IGF-1 concentrations were more apparent in supplemented than in control gilts (Table 3). Although non-significant, the IGF-1 levels increased (P>0.05) linearly in group 3 than in their counterparts. Similar observations in gilts fed with feed supplemented with n-3 PUFA than those kept on control diets also resulted in higher plasma IGF-1 (Moreira *et al*. 2016). PUFA stimulates secretion of IGF-1 in reproductive tissues, influencing luteal function and ovulation and hastening age at onset of puberty (Zhuo *et al*. 2014). Moreover, reduced concentrations of IGF-1 observed for control gilts in the current study may result from restricted nutrient in their diet, which may have been compensated by flaxseed supplementation in group 2 and group 3. Further, lower cholesterol levels as observed earlier in group 2 and group 3 might also be related to increased

IGF-1 concentrations. Amdi *et al*. (2014) noticed that reduced cholesterol levels have been positively correlated with higher levels of IGF-1.

Impact on age at onset of puberty: Data indicated that 91.7% (33) gilts apparently displayed physical signs of first estrus at puberty by 240 days of age. Age at puberty was 190.8±0.7 days with a range of 167 to 224 days. The number of gilts that achieved puberty was similar in all groups. Gilts in group 3 reached puberty significantly (P<0.05) earlier than gilts in group 1 and group 2 (Table 4). When gilts that attained puberty before 180 days of age were considered in data analysis, only 36.1% gilts had a first standing estrus at 174.1±0.6 days. No difference (P>0.05) was observed with respect to age at onset of puberty in early pubertal gilts between groups (173.5±0.8 days, 173.3±0.6 days and 174.4±0.6 days in group 1, group 2 and group 3, respectively). However, early onset of puberty was observed in higher proportion of gilts of group 3 (63.6%) followed by group 2 (36.4%) and group 1 (18.2%). Overall, one gilt (8.3%) in each group failed to attain puberty by 240 days of age and were considered to be behaviorally anestrus since they had progesterone concentrations greater than 1.0 ng/ml in samples collected at 240 days and again after 10 days. On the whole, supplementation of 1.0% of flaxseed was the most effective dietary treatment in causing early onset of estrus in gilts. These results are in accordance with those reported earlier by Kummer *et al*. (2009) where gilt diets rich in n-3 PUFA showed early development of ovarian follicles and subsequently expressed puberty at an early age. However, dietary feeding of gilts with no and/or low flaxseed concentrations did not impair puberty attainment.

Impact on reproductive performance: Supplementation of flaxseed during the period of study had different impacts on reproduction (Table 4). Of the 33 gilts that attained puberty, 32 exhibited estrus at breeding. Percentage of gilts which exhibited estrus at breeding was nearly comparable in flaxseed supplemented (100.0%) and control group (90.9%). Age at onset of estrus at breeding was significantly (P<0.05) earlier in gilts of group 3 as compared to those of group 2 and group 1. No difference was observed in duration of estrus at breeding. Proportion of gilts to consider them in pregnancy at day 25 post-breeding was similar (100.0%) in all the groups. All in all, 28 gilts farrowed with 8, 10 and 10 gilts in group 1, group 2 and group 3, respectively. The effects of supplemental flaxseed in group 2 and group 3 positively impacted onset of estrus at breeding and tended to improve maintenance of pregnancy through gestation. The investigation of flaxseed dose-response on reproduction is more straight-forward in monogastrics than in ruminants since pigs have a simple stomach and microbial modification of fatty acids is insignificant. Limited studies in pigs have shown that supplementation of á-linolenic acid in the form of flaxseed is effective in improving their reproductive performance (increased farrowing rate by

Table 4. Reproductive and productive performance (Mean±SE) of prepubertal gilts in different groups

Parameter	Group 1 (control)	Group 2 (0.5% FS)	Group 3 (1.0% FS)
Number of gilts in the study	12	12	12
Number of gilts that attained puberty	11	11	11
Age at onset of puberty (days)	197.5±3.1^{a} (r=169–224)	191.4±2.6^{b} (r=167–224)	183.6±4.2^{c} (r=172–219)
Duration of estrus at puberty (h)	38.4±0.9 (r=24–48)	38.2±1.0 (r=24–48)	37.1±1.0 (r=24–48)
Number of gilts that attained puberty at an early age	Two	Four	Seven
Number of gilts that exhibited estrus at breeding	10	11	11
Age at onset of estrus at breeding (days)	239.4±3.2^{a} (r=214–258)	231.7±3.3^{b} (r=206–264)	224.5±2.7^{c} (r=211–261)
Duration of estrus at breeding (h)	55.2±1.6 (r=24–96)	54.4±1.3 (r=24–72)	56.7±1.5 (r=24–96)
Number of gilts bred	10	11	11
Number of gilts pregnant at day 25 post-breeding	10	11	11
Pregnancy rate relative to gilts bred (%)	100	100	100
Number of farrowing relative to gilts bred	8/10 (80.0%)	10/11 (90.9%)	10/11 (90.9%)
Total piglets born at birth	12.2±0.5 (r=9–16)	12.7±0.4 (r=10–15)	13.4±0.5 (r=9–17)
Piglets born alive	11.1±0.5 (r=7–15)	11.5±0.4 (r=9–14)	12.1±0.5 (r=9–16)
Still births and mummified piglets (%)	9.9±1.0 (r=0–22.2)	9.5±0.9 (r=0–26.7)	9.8±0.9 (r=0–23.1)
Piglet mortality (%)	9.2±0.9 (r=0–23.1)	9.3±0.9 (r=0–21.4)	9.7±1.0 (r=0–22.2)
Piglet weight at birth (g)	973.6±14.9 (r=729.5–1186.4)	984.7±9.7 (r=736.4–1298.2)	977.3±12.1 (r=712.8–1467.6)

Values with different alphabetic superscripts differ significantly (P<0.05) from corresponding values in a column. FS, Flaxseed supplementation.

9.5%, Rosero *et al*. 2016). They further suggested that provision of atleast 37.6% á-linolenic acid is required to improve the reproductive efficiency of sows. As reported earlier, flaxseed offers high (58%) content of á-linolenic acid (Rosero *et al*. 2015). Accordingly, flaxseed seemed to maximize the response of various reproductive criteria in supplemented groups in the present study.

Impact on productive performance: A dose effect on the number of total piglets born and piglets born alive was observed which were maximum in group 3 followed by group 2 and group 1 (Table 4). Piglet weight at birth, percentage of still births and piglet mortality were similar in all groups. The desired outcome of feeding gilts diet supplemented with flaxseed was to increase the concentrations of n-3 PUFA in neonatal piglet tissues. The potential benefits of flaxseed on growing conceptus include enhanced neural development, better immune response and improved near term piglet survival and weight (Farmer *et al*. 2010). Inspite of diverse benefits of feeding flaxseed, data from current study and previous reports (Smits *et al*. 2011) indicated that supplemental flaxseed failed to affect piglet weight and piglet mortality at birth.

It is concluded that dietary supplementation of 1.0% flaxseed was most effective to hasten body composition variables and trigger age at onset of puberty, thus resulting in improved reproduction in prepubertal gilts.

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