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ABSTRACT

Extruded linseed (exLIN) is used most often in pigs' diets in order to improve the ratio between ω6 and ω3 PUFA in pork meat. The aim of this trial was to investigate the effect of exLIN incorporation in sows' and/or pigs' diets on both performance of sows and their progeny. At each physiological stage, different diets were formulated on the same net energy bases (gestation: 9.3, lactation: 9.6, growing/ finishing periods: 9.3 MJ/kg) and amino acid bases (5.0, 8.5, 8.3 and 7.4 g digestible lysine, respectively). During gestation and lactation, diets with 3.5% exLIN (L group, n=29) were compared to diets enriched with an equivalent amount of lipids through 1.4% palm oil (P group, n=29) or without addition of lipid (C group, n=29). Pigs from L and C sows were studied during the fattening period in order to investigate the effect of the duration of exLIN utilisation. Pigs from C sows received diets containing either 0% (CC group, n=92) or 2% exLIN (CL group, n=93); pigs from L sows were fed a diet containing 2% exLIN (LL group, n=92). No significant difference in sows' body condition at farrowing, prolificacy and weaning to oestrus interval was observed. In largest litters, the farrowing progress was significantly faster in the L than in the C and P sows. The survival rate of piglets weighing between 1.0 and 1.4 kg at birth was significantly improved in the L group. From 24 to 110 kg BW, neither pig's spontaneous daily feed intake, feed conversion ratio, or carcass fatness were significantly influenced by the treatment. Higher ADG between 24 and 70 kg and higher ultimate pH in *Semimembranosus* muscle were obtained in LL than in CC pigs. The effect of ω3 PUFA on reproductive hormone synthesis could partly explain differences in farrowing progress. Investigations on growing pigs bred in poorer sanitary conditions would be interesting taking into account the anti-inflammatory properties of ω3 PUFA.

INTRODUCTION

In France, consumers are incited to modify the nature of lipid intake toward increased PUFA intake with a ω6/ω3 PUFA ratio below 5. Increase of the ω3 PUFA intake without any change in the consumers' behaviour could be achieved through fortified traditional food items. In pork meat, the profile of fatty acid stored in adipose tissue reflects closely that of dietary supplies (Mourot and Hermier, 2001). Incorporation of linseed, which is rich in C18:3n-3 (ALA) precursor of the long-chain ω3 PUFA, in pigs' diets could help to reach this nutritional goal.

Beside their impact on the fatty acid profile, ω3 PUFA play also a key role in numerous physiological functions, such as the development of the nervous system, the fluidity of cell membranes, the synthesis of prostaglandins…, which can be involved in the vitality and/or the health of the newborn piglets (Papadopoulos et al., 2009).

The aim of the present experimental program was to investigate the effect of extruded linseed (exLIN) utilisation on sows', newborn piglets' and growing pigs' performance when diets with or without exLIN are formulated on the same net energy (**NE**) basis (INRA-AFZ Tables, 2004; Noblet et *al*., 2008).

1. MATERIALS AND METHODS

1.1. Experimental design

Trial 1 performed on sows. Four batches of 24 crossbred Large White x Landrace sows were used at the experimental station of IFIP (Romillé, 35, France) in order to evaluate the performance of the sow and its litter when exLIN was incorporated in diets from the 35th d of gestation until weaning. Dietary treatment with 3.5% exLIN (L treatment) was compared to a control treatment without extra addition of lipid (C treatment). In order to make the distinction between a specific exLIN effect and a lipid effect (Seerley, et al., 1974; Le Boyd et al., 1978; Gerfault et al., 1999; Quiniou et al., 2008), an additional treatment was studied that consisted in addition of the same amount of lipids like in L diet but through 1.4% palm oil (P treatment) that presented a high proportion of MUFA. Within each replication, three sows were chosen with regard to their parity, backfat thickness (BT) and body weight (BW) on the 28th d of gestation and from the 35th d of gestation onwards they were allocated to one of the 3 treatments. Dietary characteristics are presented in Table 1. The NE allowance during gestation was adjusted to the sows' body condition assessed from BW and BT measured after the artificial insemination. The feed allowance took into account the recovering of body reserves required to reach the target BW (function of parity) and BT (20 mm) at farrowing and the dietary NE content, as proposed by Dourmad et al. (2008).

Trial 2 performed on sows and piglets. The aim of this trial was to evaluate the interest of exLIN utilisation both in sows' and pigs' diets or only in pigs' diets. Three batches of crossbred pigs (Large White x Landrace) x (Piétrain x Large White) obtained only from C or L sows in Trial 1 were studied during the fattening period. At 63 days of age, the pigs were allocated to one of the three treatments depending on their BW and sex: pigs from C sows received diets containing either 0% (CC group) or 2% exLIN (CL group); pigs from L sows were fed a diet containing 2% exLIN (LL group). They were moved to three fattening units that differed with regard to the number of pigs per pen (6, 8 or 10 pigs), feeding systems (liquid feeding or dry feeding with pellets) and ambient temperature (18 or 24°C). Replications of three pens of mixed genders (gilts and barrows) were studied within each room.

Table 1: Nutritional characteristics of experimental diets. [1]

Physiological stage	Gestation			Lactation			Growing phase		Finishing phase	
Diet	C	P	L	C	P	L	C	L	C	L
Extruded linseed, %[2]	0	0	3.5	0	0	3.5	0	2.0	0	2.0
Palm oil, %	0	1.4	0	0	1.4	0	-	-	-	-
Dry matter, g/kg	860	863	863	858	861	861	863	864	863	864
Crude protein, g	143	141	139	145	146	144	162	162	155	155
Crude lysine, g	6.3	6.2	6.2	9.5	9.5	9.4	9.3	9.4	8.4	8.5
Digestible lysine, g	5.0	5.0	5.0	8.5	8.5	8.5	8.3	8.3	7.4	7.4
Crude fiber Weende, g	63	59	51	49	45	37	38	43	42	47
Starch, g	375	377	413	416	414	451	437	420	445	728
Crude fat, g/kg	18	32	31	20	34	33	16	23	16	24
SFA[2]	213	503	313	238	669	368	213	309	198	178
MUFA[2]	225	453	386	261	623	495	189	348	172	195
PUFA[2]	636	643	1084	687	877	1347	537	1092	615	683
[illegible]	569	583	701	629	803	896	465	730	529	440
ω 3	64	57	380	57	69	449	71	358	81	239
ω 6/ ω 3	9	10	2	11	12	2	7	2	7	2
C18:2/C18:3	10	11	2	12	13	2	7	2	7	2
Net energy, MJ/kg	9.3	9.3	9.3	9.6	9.6	9.6	9.3	9.3	9.3	9.3

1. Calculated from the nutritional characteristics of feedstuffs assessed from their chemical composition and Evapig® software.

2. Results of chemical analyses performed in the INRA laboratory (mg/100 g fat tissue) SFA: saturated, MUFA: monounsaturated, PUFA: polyunsaturated fatty acids.

Experimental diets: At each physiological stage, the different diets were formulated on the same NE bases (gestation: 9.3, lactation: 9.6, growing/finishing periods: 9.3 MJ/kg) and amino acid bases (5.0, 8.5, 8.3 and 7.4 g digestible lysine (LYSd), respectively). Other amino acids were supplied as a proportion of LYSd supply in agreement with the ideal protein concept. The incorporation rate of exLIN was performed from a commercial mixture of 50% exLIN and 50% fibre rich feedstuffs, called Croquelin®. During the post-weaning period, I;e., from 28 to 62 d of age, pigs were all fed with the same commercial diet.

1.2. Measurements

On sows: The sows were weighted and their BT was measured at 28 d of gestation (i.e., 7 d before the beginning of the trial), at farrowing and at weaning. The farrowing progress was studied through video recording. The parturition was not induced and little care as possible was supplied to new born piglets as long as farrowing was not completed. Within the 24 h after birth, the piglets were classified as born alive or still born and weighed. In case of death before weaning at 28 d of age, the day and weight was recorded. Sows were fed ad libitum from the 5th d of lactation until the day before weaning. Daily feed intake during lactation was individually measured. Weaning to oestrus interval (**WOI**) was observed from the 3rd d after weaning until the 18th.

On pigs: The animals were weighed at birth, at weaning (28 d of age), at 63 d (beginning of the fattening period) and periodically until slaughter around 115 kg. The total feed intake per pen was recorded between two weightings. At slaughter, the carcass was weighed immediately after slaughter (warm weight) and 24 h later (cold weight) in order to calculate the chilling losses. The carcass lean meat content was estimated from the backfat depth measured between the 3rd and 4th last ribs (**F34**) and the Longissimus dorsi muscle depth between the 3rd and 4th last ribs (**M34**) according to the following equation: 62.19 - 0,729 x G2 + 0,144 x M2. The pH in *Semi Membranosus* muscle was taken immediately after slaughter (pH1) and 24 h post-mortem (pHu). The colour of the meat was assessed on *Gluteus Medius* muscle, immediately after the separation of the ham and the loin, through the 3 coordinates **L***, **a***, and **b*** of the CIELAB colour space using a Minolta CR-309 photocolourimeter.

1.3. Calculations and statistical analyses

The average daily feed intake (**ADFI**) was calculated for sows as the ratio between the total feed intake during lactation and the lactation duration and for pigs on a pen basis as the ratio between the cumulated feed intake, the fattening duration and the group size. Pigs that died during the trial were taken into account on a *prorata temporis* basis. The average daily gain (**ADG**) was calculated as the ratio between the BW gain and the duration either on a individual basis (growing pigs) or on a litter basis (piglets).

Data obtained on sows were submitted to a variance analysis with the treatment (**T**, n=3) and the replication within the batch (**R**, n=29) as main effects. Litter size was introduced as a covariate in order to study litters' performance. The individual data obtained on pigs were submitted to a multifactorial variance analysis with T (n=3), B (n=12), the sex (**S**, n=2), and the interaction TxS as main effects, and the pen as the experimental unit (proc GLM, SAS 1998). For data recorded on a pen basis, a variance analysis with T, S and B was performed. Slaughter weight was introduced as a covariate in order to analyse data recorded at slaughter.

2. RESULTS - DISCUSSION

2.1. Sows' performance (Trial 1)

Data were available from 29 replications. The average birth weight was not significantly influenced by the type of energy provided during the gestation (1.36 kg), in agreement with Farmer *et al*. (2008) and Quiniou *et al*. (2008). The dietary treatment influenced neither the litter size, the ADFI during lactation, the milk production assessed through the litter's ADG, nor the WOI (5 d for the 3 groups).

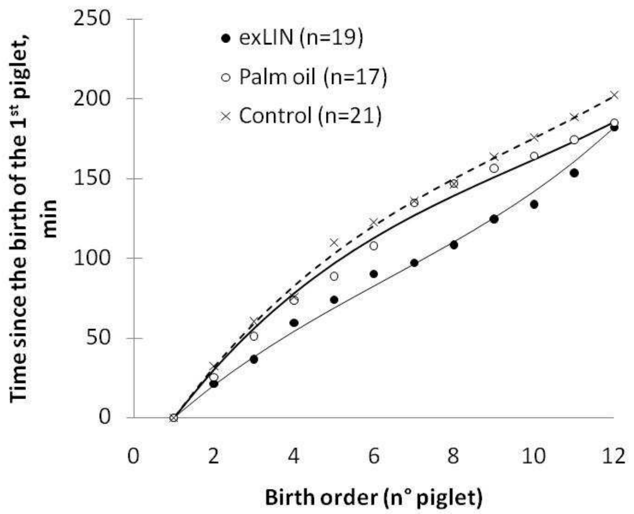

Figure 1: Effect of the treatment on the farrowing progress in litters of 12 piglets and more.

In the largest litters (12 total born piglets or more), the farrowing progress was significantly affected by the diet. In L sows, the farrowing progressed significantly more rapidly than in C (Figure 1). It does not seem to be related to the lipid supply as the kinetic obtained on P and C sows were not significantly different. The exLIN specific FA profile explains probably this difference. Indeed, amongst the physiological function of ω3 PUFA, their implication in the prostaglandins synthesis is well documented (Wathes *et al*., 2007). However, the physiological impact induced by a change in the balance between the different prostaglandins is still presently unknown, especially during parturition. Other components of exLIN may also contribute to farrowing progress, such as the fibrous fraction.

A shortened time interval between the beginning of the farrowing and the birth of the n^{th} piglet allows the n^{th} piglet to consume a better colostrum, with regard to its immunoglobulin content, which is associated with improved survival rate (Devillers *et al*., 2005). Indeed, A significant improvement of the survival rate at weaning was observed on LL piglets weighing between 1.0 and 1.2 kg at birth (86% vs. 74-C et 68-P % of total born piglets). For slightly heavier piglets, i.e., weighing between 1.2 and 1.4 kg, the survival rate tended to be higher in L and P piglets when compared to C ones (P=0.06, 89 vs 76%). Above these birth weight ranges, no effect of the dietary treatment was observed, which was not surprising taking into account the higher survival rate of these heavier piglets (Quiniou et al., 2002). Below 1 kg birth weight, the potential effect of the diet was not sufficient to influence the survival rate that was very low.

Table 2: Sows' performance.

Treatment	C	P	L	RSD	Stat.[1]
Parity	2.5	2.5	2.5	0.7	R*
Body weight, kg					
at 28 d of gestation	202	198	202	15	R***
after farrowing	245	246	248	12	R***
at weaning	219	215	216	17	R***
Backfat thickness, mm					
at 28 d of gestation	17	17	17	1	R***
at farrowing	18	19	19	2	R***
at weaning	16	15	15	2	R***
ADFI during lactation, kg[3]	6.7	6.4	6.5	0.8	R**
Litter size					
total born piglets (N_T)	15.1	15.1	14.6	3.3	
suckled piglets (Ns)	11.7	12.3	12.1	3.1	-
at weaning	11.6	12.0	11.9	2.0	
Piglets' body weight, kg[3]					
at birth	1.33	1.36	1.40	0.18	N_T*
at weaning	8.7	8.8	8.8	0.8	Ns***
ADG, kg/d/litter[3]	3.1	3.1	3.2	0.3	Ns***

1. Variance analysis with Treatment and Replication as main effects.

2. Data used only when no spillage was observed (n=21, 23, 24 for C, P and L groups).

3. Litter size was taken into account as a covariate in the statistical model.

Table 3: Pigs' growth performance.

Treatment	CC	CL	LL	RSD	Stat.
N. pigs	92	93	92		
Body weight, kg[1]					
initial (63 d)	24	24	24	3	
final (155 d)	109	109	110	7	S**
ADG, g/d[1]	922	921	941	79	S**
below 70 kg[2]	894[ab]	890[a]	922[b]	93	L** S**
above 70 kg[2]	956	963	968	116	
N. pens	12	12	12		
ADFI, kg[3]	2.46	2.44	2.47	0.09	
below 70 kg[2]	2.06	2.04	2.08	0.08	
above 70 kg[2]	2.99	2.98	2.96	0.15	
FCR[3]	2.67	2.65	2.64	0.09	
below 70 kg[2]	2.31	2.30	2.28	0.07	
above 70 kg[2]	3.11	3.09	3.08	0.18	

*1. Model 1 - Split-plot variance analysis with the **T**reatment, the **S**ex, TxS interaction, the **R**eplication (always significant, P<0.05%) within batch as main effects and the pen as the experimental unit.*

2. Growing phase: below 70 kg, Finishing phase: above 70 kg BW.

3. Model 2 - Variance analysis with T and B as main effects.

2.2. Pigs' performance (Trial 2)

In a situation where dietary NE content was the same for all diets, no significant difference was observed on growth performance between pigs fed with exLIN or not (Table 4). Indeed, similar ADFI and ADG were observed for both CC and CL pigs. Their feed conversion ratio (**FCR**) was not significantly different, which was in agreement with a similar lean content at slaughter. An earlier exLIN supply, i.e., in sows' diet (LL pigs), did not bring any additional difference on these criteria. A significant difference was observed only during the growing phase on ADG that was higher in LL pigs when compared to other groups. Most investigations would be required in order to determine whether this improved growth rate would result from a better adaptation capacity to new breeding conditions induced by the anti-inflammatory properties of ω3 PUFA stored in LL pigs during gestation and lactation, or not.

Despite the effect of the dietary lipid supply in the gestation diet on the potential lipid deposition rate during the growth phase (Gerfault et *al.,* 1999), no significant difference was observed on the FCR and the carcass leanness between LL et CC pigs.

No significant effect of the treatment was observed on pH1, chilling losses (in agreement with Vorin et *al*., 2003), or on meat colour (in agreement with Wilfart et *al*., 2004). The pHu was significantly higher in LL pigs than in CC ones (+0.05, P<0.05); however the particularly high homogeneity of values obtained for this criteria in the present study should be notified (RSD=0.14).

Table 4: Carcass and meat characteristics.

Treatment	CC	CL	LL	RSD	Stat.
Warm carcass, kg[1]	86	85	87	6	S*
Dressing, %[2]	78.7	78.7	78.4	1.8	
F34, mm[2,3]	13	13	14	2	S**
M34, mm[2,3]	57	56	56	5	S*
Lean content, %[2]	61.0	60.7	60.3	1.8	S**
Chilling loss, %[2,4]	-	-0.4	-0.1	2.0	
pH1[5]	6.46	6.46	6.46	0.19	
pHu[5]	5.63^{a}	5.65^{ab}	5.68^{b}	0.14	L* D*
Colour[5]					
L*	50.7	50.9	50.5	3.3	D*
a*	7.1	7.3	7.3	1.4	S* D**
b*	4.7	4.8	4.7	1.0	D**

1. See Model 1 below Table 3.

2. The BW at slaughter was introduced in Model 1 as a covariate. It was significant (P<0.01).

3. F34 and M34 corresponded to fat and muscle depths measured between the 3rd and 4th last ribs, respectively.

4. Difference between the values obtained for CL and LL groups and the value obtained for the CC group.

5. The slaughter day was introduced as a main effect in Model 1.

CONCLUSION

To our knowledge, the present trial seems to be the first one performed on extruded linseed with diets prepared on the basis of the net energy content of feedstuffs. In addition, experimental conditions were chosen so that linseed was used at levels close to those applied on field, and compared to other sources of fatty acids.

With diets that presented the same net energy content at each physiological stage, similar average daily feed intake was observed during lactation or during the fattening period, whether energy was provided mainly from starch (C diets), from lipids(P diet) or from a feedstuff rich in lipids (L diets). In other words, incorporation of extruded linseed seems to have no impact on the palatability of the diet, in contrast with what was observed with linseed oil (J. Mourot, personal communication).

According to our results, it is possible to manage sow's body condition at farrowing through the feed allowance when the diet contains oil or extruded linseed or not, as far as the net energy system is used as the reference. However, differences were observed amongst treatments on farrowing progress and survival rate before weaning, with improved values obtained in sows fed with extruded linseed. Shorter birth intervals were associated with a better survival rate, mainly in small piglets. The benefit was not only due to the type of energy (lipid vs. starch) provided as results obtained in sows fed with palm oil were not significantly different from results obtained in control sows. The high content in ω3 PUFA in linseed, but also maybe its fibrous components, is probably involved in differences observed between sows fed with palm oil and linseed but mechanisms involved still need to be investigated.

During the fattening period, in most cases, the incorporation of extruded linseed is performed to meet the restrictions defined in specifications toward the production of meat that presents a higher nutritional value for human beings. Our results indicate that the extra-feed cost induced by these specifications, as far as linseed is concerned, can not be compensated by improved growth performance, as the only significant difference was observed on the ADG at the beginning of the fattening period and on the pHu when linseed was incorporated both in sows' and pigs' diets. Subsequently, payment of the carcasses should be adapted.

With regard to the implication of ω3 PUFA on the influence of the immune response through their role as precursors of eicosanoïdes (Fritsche et al., 1993), a complementary study performed in poorer sanitary conditions would be interesting.

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