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The objectives of this study were to determine the effect of the chemical form of selenium (Se) fed to sows (1) on production and immune quality of colostrum and (2) on piglet response to a deterioration of sanitary conditions after weaning. Twenty-two pregnant sows were assigned to receive a diet supplemented with 0.3 ppm Se from either sodium selenite (inorganic Se) or Se-enriched yeast (organic Se as Sel-Plex®; Alltech Inc., Nicholasville, KY, USA). Dietary treatments were applied during the last month of pregnancy and lactation. Blood samples were collected on sows before dietary treatment, on the day of weaning and 6 weeks later, and on three to five piglets within litters at birth, at weaning and 6 weeks post weaning. Whole blood was analysed for Se concentration. Colostrum samples were collected at 0, 3, 6 and 24 h post partum *and milk samples on days 14 and 27 of lactation. Colostrum and milk were analysed for Se and immunoglobulin G (IgG) concentrations. At weaning, 40 pairs of littermate piglets were moved to rooms where sanitary conditions were good or purposely deteriorated. Piglets were reared individually and fed* ad libitum*. After 15 days, piglets and feed refusals were weighed and a blood sample was collected to measure plasma haptoglobin concentration. When sows were fed organic Se, Se concentrations were increased by 33% in colostrum ($P < 0.05$), 89% in milk ($P < 0.001$) and by 28% in whole blood of piglets at weaning ($P < 0.001$). Colostrum production during the 24 h after the onset of farrowing and IgG concentrations in colostrum and milk did not significantly differ between the two groups of sows. Weaned piglets reared in good sanitary conditions grew faster ($P < 0.001$) than piglets housed in poor conditions. Sanitary conditions did not influence mean plasma haptoglobin concentrations of piglets ($P > 0.1$). The source of Se fed to the dams did not influence piglet performance or haptoglobin concentrations after weaning. These findings confirm that, compared with inorganic Se, organic Se fed to the dam is better transferred to colostrum and milk, and consequently to piglets. They indicate that the Se source influences neither colostrum production nor IgG concentrations in colostrum, and that the higher Se contents of piglets does not limit the reduction of growth performance when weaning occurs in experimentally deteriorated sanitary conditions.*

Keywords: colostrum, immunity, pig growth, selenium, sow

Introduction

Selenium (Se) is an essential nutrient, necessary for adequate function of selenoproteins. These proteins include the antioxidant enzymes glutathione peroxidases (GSH-Px). As a consequence, Se plays a role in cell antioxidant defence, immune response and reduction of inflammation (Arthur *et al.*, 2003; Schomburg *et al.*, 2004). Feeding Se to pregnant or lactating females increases tissue Se content and GSH-Px activity in cows, ewes, sows and their offspring (Lacetera *et al.*, 1996 and 1999; Rock *et al.*, 2001; Mahan and Peters, 2004). It can stimulate antibody response to an antigen in calves and enhance immunoglobulin G (IgG) concentrations in colostrum produced by cows (Swecker *et al.*, 1995; Awadeh *et al.*, 1998). Moreover, greater colostrum yields have been reported when cows were treated with inorganic Se (Lacetera *et al.*, 1996). To our knowledge, no data were available in swine. The increase in Se content in the dams and their progeny is greater when Se is supplied as organic Se from an enriched yeast source, as compared with

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inorganic Se from sodium selenite (sows: Mahan and Kim, 1996; cows: Pehrson *et al.*, 1999; ewes: Rock *et al.*, 2001). Providing organic versus inorganic Se to sows has also been suggested to reduce pre- and post-weaning mortality of piglets (Lampe *et al.*, 2005a and 2005b). The present study was designed to compare the influence of organic and inorganic Se provided in sow diets during late gestation and lactation, with two objectives. Firstly, the influence of the Se source was investigated on colostrum production and immunoglobulin concentration. Given the nutritional and immunological importance of colostrum for newborn piglet survival (Rooke and Bland, 2002; Le Dividich *et al.*, 2005), we may wonder whether organic Se could improve piglet survival through an impact on colostrum quality or yield. Secondly, it was evaluated whether Se content of the piglets at weaning influences its response to a deterioration of sanitary conditions, as may occur in the post-weaning facilities.

Material and methods

Animals, experimental design and sow feeding

The experiment was carried out at the INRA experimental herd (UMR SENAH, Saint-Gilles, France). It was conducted in two replicates on 22 crossbred LR $\times$ LW sows from parity one to parity four and their piglets (PP $\times$ (LR $\times$ LW)). Parities were balanced across treatment. Littermate sows were allocated to one of two feeding regimens at 85 days of pregnancy. During the last month of pregnancy (beginning at day 88) and during lactation, sows were fed experimental diets for gestating and lactating sows, respectively, supplemented with organic Se (group OSe, $n = 11$) or inorganic Se (group ISe, $n = 11$), provided at a dose of 0.3 ppm (Table 1). Inorganic Se was supplied as sodium selenite and organic Se as Sel-Plex® (Alltech Inc., Nicholasville, KY, USA), an Se-enriched yeast product that contains at least 98% selenium in the form of organo-selenium compounds. The experimental diets contained 45 IU/kg of vitamin E, as standard diets. They contained the same concentration of digestible energy and Se for the ISe and OSe sows (Table 1). During the last month of pregnancy, sows received 2.7 kg of feed daily. On the day of farrowing and on the first day of lactation, sows were fed 2.7 kg and then the feed supply was progressively increased to reach 5.5 kg by day 4, then 6.5 kg/day at the end of lactation. Feed supply was limited to prevent variation in feed consumption between sows. Throughout the experimental period, feed refusals were weighed daily. From insemination to day 87 of pregnancy and after piglet weaning, sows were fed a conventional diet for gestating sows supplemented with 0.25 ppm of inorganic Se (Table 1).

Management of sows and litters

Sows were housed in individual stalls or crates. They were moved from the gestation to the farrowing rooms on day 104 ± 1 of gestation. Parturition was induced on day 114 of gestation. During farrowing, oxytocin was injected and piglets were manually extracted if necessary. At birth, each piglet was identified with an ear clip. Each piglet was weighed at birth (umbilical cords were cut to limit biased measurements) and 24 h later. Because standardizing litter size at birth was not possible in practice, the original litter was kept under the sow during the first 24 h after birth. This procedure should not influence litter weight gain from birth to 24 h of age and colostrum yield, as these parameters have been shown to be independent of litter size (Le Dividich *et al.*, 2005). Litters were not standardized thereafter but, when the litter was large, litter size was reduced to the number of functional teats minus one. Castration, iron injection and tattoos were performed after 24 h. During lactation, piglets received no creep feed but had free access to water and to the sow trough. Piglets were weighed and weaned at 26 ± 1 days of age. Before and after weaning, diarrhoea incidence was registered and treated.

Management of weaned piglets

Some piglets were submitted to an experiment to evaluate the impact of Se source on growth performance when weaning occurs either in good or in poor sanitary conditions, according to a procedure previously validated (Le Floc'h *et al.*, 2006). Within each litter, two pairs of piglets were selected on a live-weight basis. Within each pair, one piglet was assigned to a high sanitary status (HSS) and the other to a low sanitary status (LSS). The high sanitary conditions were obtained by cleaning and disinfecting rooms before piglet arrival. These rooms housed 10 experimental piglets. For the low sanitary conditions, rooms were neither cleaned nor disinfected after previous occupation by pigs from the same herd. They housed 10 experimental piglets mixed with 10 non-experimental piglets in order to increase the microbial pressure. All piglets were individually reared. They were fed *ad libitum* phase I diet (Table 1). An antibiotic was added to the diet for HSS piglets only (avilamycin, 4 g/kg of feed). Antibiotic treatment was used to improve the sanitary status of the piglets housed in the clean environment. The experiment lasted for 15 days. Fasted piglets and feed refusals were weighed at the end of the experiment.

Piglets not used in the previous trial were moved to the post-weaning facilities. They were housed in groups of 10, on slatted floors. All weaned piglets were fed conventional diets, phase I diet for 2 weeks and then phase II diet for 4 weeks. Feed was offered for *ad libitum* intake. These conventional diets contained Se provided at 0.3 ppm as sodium selenite (Table 1). Piglets were weighed after 6 weeks post weaning.

Sampling

Single blood samples were collected from sows, by puncture in the jugular vein, 2 h after the morning meal on day

Table 1 *Composition of conventional and experimental diets*

	Conventional diets			Experimental diets			
	For piglets			Gestation		Lactation	
	Phase I	Phase II	Gestation	Ise	OSe	ISe	OSe
Ingredients (%)							
Wheat	–	23.2	22.1	22.1	22.1	22.7	22.7
Yellow corn	–	–	10.0	10.0	10.0	12.0	12.0
Barley	41.8	17.8	33.7	33.7	33.7	25.6	25.6
Wheat bran	–	–	15.0	15.0	15.0	10.0	10.0
Soybean bran	21.4	26.6	9.0	9.0	9.0	21.0	21.0
Soybean proteins	2.5	–	–	–	–	–	–
Sunflower oil	2.3	0.4	2.0	2.0	2.0	2.0	2.0
Sugar-beet molasses	–	–	–	–	–	3.0	3.0
Sugar-beet pulp	–	–	5.0	5.0	5.0	–	–
Lactoserum	20.0	–	–	–	–	–	–
Dried skimmed milk	8.0	–	–	–	–	–	–
Calcium carbonate	1.14	0.69	1.90	1.90	1.90	1.10	1.10
Dicalcium phosphate	0.99	1.11	0.30	0.30	0.30	1.30	1.30
Salt	–	0.40	0.45	0.45	0.45	0.45	0.45
Premix[a,b]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Composition (%)							
Dry matter	90.4	–	–	87.3	87.2	87.6	87.6
Ash	8.4	5.5	5.9	5.2	5.3	5.6	5.6
Protein	19.2	19.5	13.5	13.5	14.1	17.2	17.2
Lipids	6.7	2.7	4.2	4.2	4.2	4.1	4.1
Crude fibre	2.9	3.4	4.9	4.9	4.9	4.1	4.1
Starch	22.7	41.8	40.6	40.6	40.6	37.1	37.1
Energy[c] (MJ/kg)							
Digestible	14.5	13.7	13.2	13.2	13.2	13.7	13.7
Net	10.5	9.7	9.5	9.5	9.5	9.6	9.6
Selenium (ppm)							
Added	0.30	0.30	0.25	0.30	0.30	0.30	0.30
Total levels[d,e]	ND	ND	ND	0.35	0.37	0.37	0.37

[a]Supplied the following amounts/kg of diet, for sows: vitamin A, 10 000 IU; vitamin D_3, 1500 IU; vitamin E 45 mg, vitamin K_3, 2 mg; thiamine, 2 mg; riboflavin, 4 mg; nicotine acid, 15 mg; d-pantothenic acid, 10 mg; pyridoxine 3 mg; d-biotin, 0.2 mg; folic acid, 3 mg; vitamin B_{12}, 0.02 mg; choline, 500 mg; Fe, 80 mg; Cu, 10 mg; Mn, 40 mg; Zn, 100 mg; Co, 0.1 mg; and I, 0.6 mg. For conventional diets, Se was provided as sodium selenite at 0.3 mg/kg of diet for piglets and 0.25 mg/kg for gestating sows.
[b]The premix used for the experimental diets did not contain Se.
[c]Calculated values based on INRA-AFZ (2004).
[d]ND = not determined.
[e]Total Se levels were determined by ICP-MS (0.35 ± 0.04; 0.37 ± 0.04; 0.37 ± 0.08 and 0.37 ± 0.01 ppm).

85 of pregnancy, on the day of weaning and 6 weeks later. Blood samples were taken from the same three to five piglets in each litter, at birth, at weaning and 6 weeks later. Blood samples were not centrifuged and were immediately frozen at −20°C. Blood samples were also collected from piglets submitted to the sanitary experiment, at the end of the experiment. They were collected on EDTA, centrifuged for 15 min at 3500 × **g** at 4°C. Plasma was aliquoted and stored at −20°C.

Colostrum was obtained just after birth of the first piglet and 3, 6 and 24 h later (*t*0, *t*3, *t*6 and *t*24, respectively). This *t*24 time was calculated by adding 24 h to the mid-duration of farrowing. Milk was collected on day 14 of lactation and on the day of weaning before piglet removal. Colostrum and milk were immediately filtered on gauze, sampled and stored at −20°C.

Biological analyses

IgG in colostrum and milk were analysed using a commercial kit (Pig IgG ELISA Quantitation kit; Bethyl Laboratories, Montgomery, USA, ref. E100-104), according to an adaptation by I. Oswald (UR66 Pharmacologie-Toxicologie, INRA, Toulouse, France). The validated procedure was described by Devillers *et al.* (2004a). Colostrum was diluted at 1/500 000 (*t*0, *t*3 and *t*6 samples) or at 1/100 000 (*t*24 samples) and milk was diluted at 1/5000 (mid-lactation) and 1/2000 (late lactation). Each dilution was measured twice in duplicate and data are the means of four values. To prevent plate-to-plate variation in the IgG assay, the two treatments were represented on each plate. The coefficients of variation between and within plates were 14% and 5.8%, respectively, for a colostrum sample containing 67 mg/ml of IgG.

The plasma concentration of haptoglobin, used as an indicator of inflammatory response (Eckersall *et al.*, 1996), was measured by a colorimetric assay (Phase Haptoglobin Assay; Tridelta Development Limited, Wicklow, Ireland).

The Se content in experimental diets and blood samples was analysed by ICP-MS (Inductively Coupled Plasma Mass Spectrometry) in the UT2A laboratory (Ultra Traces Analyses Aquitaine, Université de Pau et des Pays d'Adour, France).

Calculations and statistical analyses

Individual colostrum intake by newborn pigs during the first 24 h of life was estimated from piglet weight variation between birth and 24 h. The equation was proposed by Devillers *et al.* (2004b):

$$\begin{aligned} CI = &-217.4 + 0.217 \times t + 1861019 \times BW/t \\ &+ BW_b \times (54.8 - 1861019/t) \\ &\times (0.9985 - 3,7 \times 10^{-4} \times t_{fs} \\ &+ 6.1 \times 10^{-7} \times t_{fs}^2) \ (R^2 = 0.9), \end{aligned}$$

where CI = colostrum intake (g), BW = pig body weight at 24 h (kg), BW_b = pig body weight at birth (kg), t = time elapsed from birth to weighing around 24 h (min) and t_{fs} = time elapsed from birth to first suckling (min). According to Devillers *et al.* (2004b), the interval elapsed between birth and first suckling (t_{fs}) can be estimated between 15 and 30 min without major error. In the present experiment, an average interval of 20 min was chosen. When piglets lost much body weight during the first day of life, CI value was negative. We considered that these piglets had not consumed colostrum and that the CI value was nil. Colostrum production by sows during the 24 h after farrowing commenced was calculated by summing colostrum intakes of all the piglets in the litter.

The data were submitted to an analysis of variance using the GLM procedure of SAS (SAS, 1996). All models included the effects of the treatment (organic versus inorganic Se) and of the replicate and the interaction between these two factors. For piglet performance, a split-plot design was used with treatment, replicate and the interaction, and sow nested within group (error to test the effects of treatment, replicate and the interaction). For Se in sow blood and Se and IgG in colostrum and milk, the repeated procedure of SAS was used. For Se in pig blood, the general model showed a significant interaction between treatment and day of sampling effects. Therefore, the analysis was performed day by day, using a split-plot design with the sow nested within group as an error term. For sanitary challenge, the experimental treatments (ISe *v.* OSe and HSS *v.* LSS) were compared within pairs using the interaction treatment × pair as the error term.

One of the 22 sows allocated to the experiment farrowed at 112 days of gestation without annunciating signs. Therefore, data on piglets at birth and on colostrum are available only for 21 sows (10 in the group OSe and 11 in the group ISe).

Results

Sow and litter performance

Sows from the two groups consumed the same amount of experimental diets (76.7 ± 0.3 kg during the last 28 days of pregnancy and 129.8 ± 0.7 kg during lactation).

Litter size did not significantly differ between the two groups of sows (Table 2). Nevertheless, the total number of piglets born and the number of piglets born alive were higher by two piglets, on average, for the ISe than for the OSe sows. The proportion of stillborn piglets did not differ between groups and averaged 7.2% of total piglets. Litter weight at birth and at 24 h tended to be higher in the ISe group ($P < 0.1$). Litter weight gain varied from −654 to +1982 and averaged 884 ± 161 g ($P > 0.1$). No effect of Se source was found on piglet weight at birth and at 24 h, as well as on weight gain (Table 2).

During lactation, growth performance of litters and individual performance of piglets did not differ between the two groups of sows (Table 3). At weaning, the piglets from the

Table 2 *Influence of selenium sources in sow diet on litter size and piglet growth during the first 24 h of life (mean ± s.e.)*

	Selenium		
	Inorganic	Organic	*P* value
Litter size			
Total born	16.1 ± 0.8	14.1 ± 0.9	0.140
Born alive	14.9 ± 0.8	13.1 ± 0.8	0.153
Stillborn, *n* (%)	1.2 ± 0.4 (7.3)	1.0 ± 0.4 (7.1)	0.845
Litter weight			
At birth (kg)	21.0 ± 1.3	17.8 ± 1.2	0.090
At 24 h (kg)	21.9 ± 1.3	18.6 ± 1.1	0.087
Gain (g)	912 ± 264	852 ± 188	0.989
Piglet weight			
At birth (kg)	1.41 ± 0.05	1.36 ± 0.05	0.399
At 24 h (kg)	1.48 ± 0.07	1.43 ± 0.05	0.531
Gain (g)	66 ± 20	71 ± 15	0.750

Table 3 *Influence of selenium sources in sow diet on litter and piglet performance during lactation (mean ± s.e.)*

	Selenium		
	Inorganic	Organic	*P* value
Piglet number at 24 h[a]	13.5 ± 0.4	12.9 ± 0.7	0.482
Weaned piglets	11.6 ± 0.6	11.2 ± 0.6	0.666
Litter weight (kg)			
At 24 h[a]	18.1 ± 1.2	16.9 ± 0.9	0.531
At weaning	81.4 ± 3.2	82.0 ± 3.5	0.910
Daily gain	2.50 ± 0.09	2.55 ± 0.10	0.709
Piglet weight			
At 24 h[a] (kg)	1.54 ± 0.06	1.52 ± 0.05	0.781
At weaning[b] (kg)	7.08 ± 0.27	7.43 ± 0.29	0.418
Daily gain[c] (g/day)	218 ± 10	232 ± 10	0.360
Piglet mortality, *n* (%)	2.0 ± 0.7 (14.8)	1.7 ± 0.5 (13.2)	0.696

[a]After reduction of litter size to the number of teats minus one.
[b]After adjustment for litter size, $P = 0.65$.
[c]After adjustment for litter size, $P = 0.73$.

Table 4 *Production of colostrum by sows fed inorganic or organic selenium, and colostrum concentrations of immunoglobulins G (mean ± s.e.)*

	Selenium		
	Inorganic	Organic	*P* value[a]
n	11	10	
Colostrum production[b] (kg)	4.01 ± 0.35	3.48 ± 0.21	T:0.296
Colostrum production[b] (kg/kg litter)	0.19 ± 0.02	0.20 ± 0.02	T:0.621
Concentrations of immunoglobulins G (mg/ml)			
At *t*0	71.35 ± 4.35	61.86 ± 6.13	T:0.176
At *t*3	61.41 ± 4.34	51.74 ± 5.52	S:<0.001
At *t*6	53.06 ± 3.75	51.04 ± 6.81	T × S:0.394
At *t*24	10.47 ± 2.72	7.66 ± 1.64	

[a]T = dietary treatment effect; S = time of sampling effect; T × S = treatment × sampling interaction.
[b]Estimated production during 24 h after the onset of farrowing.

OSe sows were 0.35 kg heavier than those from the ISe sows, but the difference did not reach the level of significance. Piglet mortality throughout lactation averaged 14% and was not influenced by treatment ($P > 0.1$). The ISe and OSe sows weaned 11.4 piglets on average. During the 6 weeks after weaning, piglets gained 499 ± 81 g daily and growth rate was not influenced by sows' regimens ($P > 0.1$).

Colostrum, milk and immunoglobulin G

Estimated colostrum production during 24 h was highly variable among sows, varying from 1.6 to 5.4 kg. The ISe sows produced on average 500 g more than the OSe sows, but the difference was not significant ($P > 0.1$; Table 4). When colostrum production was expressed per kg of litter, it was similar in the two groups. Colostrum production was not significantly correlated with litter size ($r = 0.28$, $P = 0.22$) or litter weight ($r = 0.42$, $P = 0.06$).

Averaged concentrations of IgG decreased progressively during the 24 h after farrowing commenced ($P < 0.001$; Table 4). They further decreased in milk where they were very low (3.1 ± 1.1 and 1.7 ± 1.0 mg/ml in mid- and late lactation, respectively). No Se treatment effect was found on IgG concentrations in colostrum and milk.

Concentrations of Se in sows, colostrum, milk and piglets

The source of Se had no effect on Se concentrations in sow whole blood (Table 5). Concentrations were lower ($P < 0.001$) in late pregnancy than on the day of weaning and 6 weeks after. Concentrations of Se in colostrum were higher ($P < 0.05$) in the OSe than in the ISe group at the onset of farrowing, 3 and 6 h later but the difference was no longer observed at 24 h (Table 5). They were significantly higher ($P < 0.05$) during the first 6 h following the onset of farrowing than 24 h later. In mid- and late lactation, milk produced by the OSe sows contained higher levels of Se (Table 5). Feeding sows organic Se instead of inorganic Se increased average Se concentration by almost 35% in colostrum and 90% in milk.

At birth, piglets born from sows fed organic Se tended to have higher concentrations of Se in blood than piglets from the ISe sows (Table 5). The difference was markedly accentuated at weaning and was completely erased 6 weeks after weaning (Table 5).

Table 5 *Influence of dietary selenium source on selenium content in sow and piglet whole blood, colostrum and milk (mean ± s.e.)*

	Selenium		
	Inorganic	Organic	*P* value
Sow whole blood (ng/g)			
Day 85 of pregnancy	246 ± 6	232 ± 11	0.339
Day of weaning	281 ± 12	279 ± 10	0.920
Weaning + 6 weeks	280 ± 9	284 ± 6	0.705
Colostrum (ng/g)			
*t*0	242 ± 25	323 ± 29	0.010
*t*3	235 ± 22	313 ± 29	0.017
*t*6	201 ± 23	273 ± 32	0.026
*t*24	88 ± 16	106 ± 14	0.426
Milk (ng/g)			
Day 14	45 ± 3	75 ± 3	<0.001
Day 27	42 ± 1	87 ± 2	<0.001
Piglet whole blood (ng/g)			
Birth	140 ± 4	159 ± 5	0.077
Weaning	188 ± 4	240 ± 6	<0.001
Weaning + 6 weeks	306 ± 5	300 ± 5	0.355

Performance of weaned piglets in response to depressed sanitary conditions

Weaned piglets reared for 15 days in good sanitary conditions ate more ($P < 0.001$) and gained 1.1 kg more than piglets reared in non-sanitized rooms ($P < 0.001$; Table 6). Their feed conversion ratio was better ($P < 0.01$). Sanitary conditions did not influence mean plasma haptoglobin concentrations ($P > 0.1$). The source of Se fed to the dams did not influence piglet performance or haptoglobin concentrations (Table 6).

Discussion

The source of Se did not significantly influence pig and litter growth rate, during lactation and during the 6 weeks after

Table 6 *Influence of selenium source fed to the dams on piglet response to a deterioration of sanitary conditions in post-weaning room (mean ± s.e.)*

	Selenium		*P* value[a]	
	Inorganic	Organic	Se source	Sanitary conditions
Initial piglet weight (kg)				
HSS[b]	7.58 ± 0.23	7.62 ± 0.23	0.737	0.861
LSS[b]	7.62 ± 0.24	7.60 ± 0.22		
Final piglet weight (kg)				
HSS	11.16 ± 0.34	11.28 ± 0.37	0.938	<0.0001
LSS	10.18 ± 0.36	10.09 ± 0.40		
Weight gain (kg)				
HSS	3.58 ± 0.21	3.64 ± 0.21	0.975	<0.0001
LSS	2.56 ± 0.18	2.49 ± 0.23		
Total feed intake (kg)				
HSS	5.35 ± 0.23	5.17 ± 0.19	0.150	<0.0001
LSS	4.38 ± 0.21	4.09 ± 0.18		
Feed conversion ratio				
HSS	1.53 ± 0.04	1.43 ± 0.05	0.929	0.002
LSS	1.80 ± 0.09	1.88 ± 0.19		
Plasma haptoglobin concentration (mg/ml)				
HSS	1.11 ± 0.15	1.11 ± 0.17	0.775	0.270
LSS	1.33 ± 0.14	1.24 ± 0.19		

[a]Effects of Se source and sanitary conditions, respectively. For all criteria, the Se source × sanitary conditions interaction was not significant.
[b]Piglet sanitary status, high (HSS) or low (LSS), was obtained by rearing weaned piglets in good or poor sanitary conditions.

weaning, in agreement with published data (Mahan and Kim, 1996; Yoon and McMillan, 2006). The two extra piglets born alive when sows were fed inorganic Se were not related to a reduced incidence of stillbirths but to a greater whole litter size, which was established before dietary treatments started. The difference in litter sizes cannot therefore be attributed to treatment. Piglet mortality rate was similar to the average mortality (14.4%) in French herds, calculated from the national database of sow performance in 2006. Because of the limited number of females and unequal litter sizes, the present experiment was not designed to investigate the effect of Se source on pig mortality.

Short-term effects on Se concentrations in sows, piglets, colostrum and milk

The chemical form of Se provided to pregnant females has been reported to significantly affect Se content in various tissues of the dams, but not in serum (in sows: Mahan and Kim, 1996; Yoon and McMillan, 2006; cows: Awadeh *et al*., 1998; ewes: Rock *et al*., 2001). In the present study, we chose whole blood as an indicator of circulating Se because more than 50% of Se in circulation is present in erythrocytes, mainly bound to haemoglobin (Butler *et al*., 1990; Giguère *et al*., 2005). The form of Se fed to sows did not alter blood Se concentration, which is consistent with findings in ewes (Rock *et al*., 2001). In contrast, a 16% increase in whole-blood Se concentration was reported in sows fed organic Se versus inorganic Se for 3 months (Fortier *et al*., 2004). In cows, organic Se was more effective in increasing blood Se concentrations than sodium selenite after 22 months of supplementation, but not before (Awadeh *et al*., 1998). It is likely that the effect of Se source on blood Se content depends on the duration of supplementation. Because Se in the Se-enriched yeast source is essentially provided as selenomethionine, the greater blood Se content may be related to the non-specific incorporation of selenomethionine to blood proteins.

The non-specific incorporation of selenomethionine to proteins has also been proposed to explain the better transfer of organic Se through placenta to foetuses, as compared to inorganic Se. Indeed, feeding organic Se to pregnant sows is reported to increase the Se content of piglets at birth, by 50% to 130% depending on tissues (liver, loin, whole body; Mahan and Kim, 1996; Mahan and Peters, 2004). Effects on Se content in blood or serum seem to be more moderate. Yoon and McMillan (2006) observed a 28% increase in serum and our results indicated only a trend towards a marginal increase in blood of neonates. Therefore, the only measurements of Se in blood or serum may not be adequate to assess piglet Se content, at least at birth.

The greater Se concentration in colostrum and milk when sows were fed organic Se is consistent with previous findings (Mahan, 2000; Mahan and Peters, 2004; Yoon and McMillan, 2006). This confirms that Se is better transferred to colostrum and milk when it is provided as organic Se. As suggested by Mahan (2000), the organic Se could be non-specifically incorporated to milk proteins as selenomethionine. As a consequence of better Se transfer to milk, blood Se contents of piglets at weaning were higher by nearly

30% in the OSe than in the ISe group, in agreement with previous observations in serum and tissues of weaned pigs (Mahan and Kim, 1996; Mahan and Peters, 2004).

Colostrum production and immunity

Our results indicate that the source of Se fed to the sows had no influence on litter growth and colostrum production during the 24 h *post partum*. In agreement with previous findings (Le Dividich *et al*., 2005), estimated colostrum production was not significantly correlated with litter characteristics at birth. Similarly, Se source had no influence on IgG concentration in colostrum and milk. This is consistent with previous findings, showing no effect of the chemical form of Se given to pregnant ewes on concentrations of IgG in colostrum (Rock *et al*., 2001). In antioxidant activities and immune modulation, selenium and vitamin E appear to work together (Oldfield, 2003). In the present experiment, diets for sows contained 45 IU/kg of vitamin E, as recommended by the National Research Council (NRC, USA) (standard diets). It seems therefore that supplementing diets with 0.3 ppm of Se supplied as sodium selenite, together with vitamin E, provides adequate levels of Se (and vitamin E) with regard to the IgG concentration of colostrum.

Weaned piglet response to depressed sanitary environment

Deterioration of sanitary conditions in post-weaning facilities has been shown to impair nutrient utilization and pig growth performance by inducing a moderate inflammatory response (Schneider and Bronsch, 1973; Le Floc'h *et al*., 2006). This immune response can be evidenced by increased plasma concentrations of haptoglobin, a major acute-phase protein in pigs (Le Floc'h *et al*., 2006). The experimental design we used has been proposed as a reliable model to investigate changes in nutrient requirements induced by deterioration of sanitary status and health (Le Floc'h *et al*., 2006). Indeed, conditions challenging the immune system are known to induce changes in nutrient metabolism. In these circumstances, requirements for nutrients involved in body defences, such as Se, would be theoretically increased. In the present study, as expected, growth rate and feed conversion were depressed when piglets were housed in bad sanitary conditions. The lack of difference in mean haptoglobin concentrations between LSS and HSS piglets was unexpected due to the difference in growth performance between the two groups. This could be due to the fact that several piglets reared in the clean room, which had unexplained great concentrations of haptoglobin (i.e. $>$1.5 g/L) without exhibiting lower growth rate and any clinical signs of disease compared to piglets housed in the same conditions. These piglets were equally distributed in the ISe and OSe groups. As a consequence, average haptoglobin concentrations in the HSS group were greater than previously described (Le Floc'h *et al*., 2006). Our results also indicate that piglet response to sanitary conditions was not influenced by the source of Se fed to the dams, despite the higher Se contents of piglets born from sows fed organic Se. These piglets may not have a better antioxydative capacity, as suggested by Mahan and Peters (2004). These authors reported that GSH-Px activities seemed to plateau when Se was provided at a 0.15 ppm level irrespective of the form. In the present study, weaned piglets were fed a first-stage diet supplemented with 0.3 ppm of inorganic Se, according to the current practice in French herds. Our findings suggest therefore that, in herd conditions, the higher Se content as determined by whole-blood Se levels of piglets at weaning, when the dams were fed organic Se, would not prevent short-term reduction of growth performance due to depressed sanitary conditions.

Long-term effects on blood Se concentrations in sows and piglets

Whole-blood Se concentrations did not decrease in sows during the 6 weeks after weaning. During this period, the sows were no longer fed the experimental diets, but a conventional diet supplemented with only 0.25 ppm of inorganic Se. This supports previous findings showing no influence of Se level beyond 0.25 ppm of supplementation (Mahan and Peters, 2004). In piglets, the influence of the Se source on blood Se concentrations was no longer observed 6 weeks after weaning. Standard diets for weaned pigs supplemented by 0.3 ppm of inorganic Se could therefore be adequate regarding pig Se content, as previously reported (Meyer *et al*., 1981). However, Se measurements in tissues are necessary before concluding on the actual Se content of pigs 6 weeks after weaning.

Independent of dietary treatments, blood Se contents in pigs increased by 40% between weaning and 10 weeks of age. This increase is consistent with previous findings (Meyer *et al*., 1981) and may be related to an active synthesis of selenoproteins by growing pigs. In sows, also, blood Se concentrations varied over time, being lower in late pregnancy. A decline in serum Se contents was previously reported in sows, with lower contents at 90 and 110 days of pregnancy (Mahan and Kim, 1996; Mahan and Peters, 2004). This decline in Se contents may be related to an active transfer of Se to foetuses, as suggested by Mahan and Kim (1996), and also to an increase in blood volume during pregnancy (Matte and Girard, 1996).

In conclusion, our findings confirm that, as compared with inorganic Se, organic Se fed to the dam is better transferred to colostrum and milk, and consequently to piglets. They indicate that Se source influences neither the quantity of colostrum produced by the sows nor the IgG concentration in colostrum and milk. Finally, they show that the higher Se content of piglets at weaning does not limit the reduction of growth performance when weaning occurs in deteriorated sanitary conditions. Therefore, under these experimental conditions, organic Se did not improve immune response as compared with non-organic Se.

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References

Arthur JR, McKenzie RC and Beckett GJ 2003. Selenium in the immune system. Journal of Nutrition 133, 1457S–1459S.

Awadeh FT, Kincaid RL and Johnson KA 1998. Effect of level and source of dietary selenium on concentrations of thyroid hormones and immunoglobulins in beef cows and calves. Journal of Animal Science 76, 1204–1215.

Butler JA, Whanger PD, Kaneps AJ and Patton NM 1990. Metabolism of selenite and selenomethionine in the Rhesus monkey. Journal of Nutrition 120, 751–759.

Devillers N, Farmer C, Mounier AM, Le Dividich J and Prunier A 2004a. Hormones, IgG and lactose changes around parturition in plasma, colostrum or saliva of multiparous sows. Reproduction, Nutrition, Development 44, 381–396.

Devillers N, van Milgen J, Prunier A and Le Dividich J 2004b. Estimation of colostrum intake in the neonatal pig. Animal Science 78, 305–313.

Eckersall PD, Saini PK and McComb C 1996. The acute phase response of acid soluble glycoprotein, a_1-acid glycoprotein, ceruloplasmin, haptoglobin and C-reactive protein, in the pig. Veterinary Immunology and Immunopathology 51, 377–385.

Fortier ME, Quesnel H, Giguère A, Bilodeau JF, Laforest JP and Matte JJ 2004. The importance of dietary selenium on antioxidant status and hormonal profile in post-pubertal gilts. ADSA-ASAS-PSA 2004 Joint Annual Meeting, July 25–29, St. Louis, Missouri, USA, 1p.

Giguère A, Fortier ME and Matte JJ 2005. Rapid, sensitive and versatile determination of selenium in different biological samples. Canadian Journal of Animal Science 85, 533–536.

Institut National de la Recherche Agronomique – Association Française de Zootechnie 2004. In Tables of composition and nutritional value of feed materials. Pigs, poultry, cattle, sheep, goats, rabbits, horses, fish (ed. D Sauvant, JM Perez and G Tran). INRA-AFZ, Paris, France.

Lacetera N, Bernabucci U, Ronchi B and Nardone A 1996. Effects of selenium and vitamin E administration during a late stage of pregnancy on colostrum and milk production in dairy cows, and on passive immunity and growth of their offspring. American Journal of Veterinary Research 57, 1776–1780.

Lacetera N, Bernabucci U, Ronchi B and Nardone A 1999. The effect of injectable sodium selenite on immune function and milk production in Sardinian sheep receiving adequate dietary selenium. Veterinary Research 30, 363–370.

Lampe J, Gourley G, Sparks J and Stumpf T 2005a. Prewean piglet survivability: Sel-Plex® verses sodium selenite as selenium source in sow diet. Journal of Animal Science 83(suppl. 2), abstract 205.

Lampe J, Gourley G, Sparks J and Stumpf T 2005b. Postwean piglet survivability: Sel-Plex® verses sodium selenite as selenium source in sow and nursery phase diet. Journal of Animal Science 83(suppl. 2), abstract 206.

Le Dividich J, Rooke JA and Herpin P 2005. Nutritional and immunological importance of colostrum for the newborn pig. Journal of Agricultural Science 143, 1–17.

Le Floc'h N, Jondreville C, Matte JJ and Seve B 2006. Importance of sanitary environment for growth performance and plasma nutrient homeostasis during the post-weaning period in piglets. Archives of Animal Nutrition 60, 23–34.

Mahan DC 2000. Effect of organic and inorganic selenium sources and levels on sow colostrum and milk selenium content. Journal of Animal Science 78, 100–105.

Mahan DC and Kim Y 1996. Effect of inorganic or organic selenium at two dietary levels on reproductive performance and tissue selenium concentrations in first-parity gilts and their progeny. Journal of Animal Science 74, 2711–2718.

Mahan DC and Peters JC 2004. Long-term effects of dietary organic and inorganic selenium sources and levels on reproducing sows and their progeny. Journal of Animal Science 82, 1343–1358.

Matte JJ and Girard C 1996. Changes in serum and blood volumes during gestation and lactation in multiparous sows. Canadian Journal of Animal Science 76, 263–266.

Meyer WR, Mahan DC and Moxon AL 1981. Value of dietary selenium and vitamin E for weanling swine as measured by performance and tissue selenium and glutathione peroxidase activities. Journal of Animal Science 52, 302–311.

Oldfield JE 2003. Some recollections of early swine research with selenium and vitamin E. Journal of Animal Science 81(E. Suppl. 2), E145–E148.

Pehrson B, Ortman K, Madjid N and Trafikowska U 1999. The influence of dietary selenium as selenium yeast or sodium selenite on the concentration of selenium in the milk of suckler cows and on the selenium status of their calves. Journal of Animal Science 77, 3371–3376.

Rock MJ, Kincaid RL and Carstens GE 2001. Effects of prenatal source and level of dietary selenium on passive immunity and thermometabolism of newborn lambs. Small Ruminant Research 40, 129–138.

Rooke JA and Bland IM 2002. The acquisition of passive immunity in the newborn piglet. Livestock Production Science 78, 13–23.

SAS, SAS User's Guide: Statistics, Version 6.11 Ed., SAS Inst. Inc., Cary, NC, 1996.

Schneider D and Bronsch K 1973. Einfluss des Stallbelegung nach des sog. Fliessband- und Rein-Raus Methode auf die Ferkelaufzucht. Züchtungskunde 45, 53–60.

Schomburg L, Schweizer U and Köhrle J 2004. Selenium and selenoproteins in mammals: extraordinary, essential, enigmatic. Cellular and Molecular Life Sciences 61, 1988–1995.

Swecker Jr WS, Thatcher CD, Eversole DE, Blodgett DJ and Schurig GG 1995. Effect of selenium supplementation on colostral IgG concentration in cows grazing selenium-deficient pastures and on postsuckle serum IgG concentration in their calves. American Journal Veterinary Research 56, 450–453.

Yoon I and McMillan E 2006. Comparative effects of organic and inorganic selenium on selenium transfer from sows to nursing pigs. Journal of Animal Science 84, 1729–1733.