Influence of colostrum supply on *Salmonella* spp. seroprevalence in piglet rearing and possibilities to increase colostrum production by optimised feeding

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Abstract

A commercial farm study investigated whether colostrum production and antibody transfer can be improved by extra feeding in late pregnancy sows, and whether such improvements have an influence on disease status (measured as *Salmonella* spp. seroprevalence) in piglets, using a rapid and cost effective, ELISA-based estimation method (IDEXX Swine *Salmonella* spp. Ab Test). Four farms with established high *Salmonella* spp. seroprevalence were selected, and 16 sows in each farrowing group were selected over six farrowing cycles for the feeding experiment (n=368). One half (n=184) of the sows were fed a conventional feed following official nutrient recommendations concerning energy, amino acids and minerals when they entered the farrowing pen. The other half (n=184) received 1.25 kg of a test feed daily containing fibre rich cereals (barley, oats), a fibre component (soy husks) and potassium diformate in addition to the conventional feed until two days *post-partum*. Blood samples were taken from two light and two heavy piglets aged 2 d in each litter (n=1,469) and at the end of rearing (approximately nine weeks old; average body weight of 25 kg; n=588). In the test-fed group, piglet immunocrit value (as a measure of immunoglobulin transfer) was significantly improved ($P<0.0219$; K: 0.1226 ± 0.0437 ; V: 0.1278 ± 0.0406). A moderate correlation ($r=0.40935$; $P<0.0001$) was found between immunocrit value and *Salmonella* spp. antibodies at 2 d old. There was no correlation between immunocrit value and *Salmonella* spp. antibodies at the end of the rearing period ($r=0.09914$), when the pigs were around nine weeks of age. Despite better colostrum supply, the animals in the test group did not show a significantly lower prevalence of *Salmonella* spp. seroprevalence (test group optical density (OD) $9.8000\pm17.4954\%$; control group OD $8.9486\pm14.2426\%$; $P<0.5344$) at nine weeks of age. It could be shown that the colostrum supply can be optimised by providing sows with extra feed. The moderate correlation between immunocrit and *Salmonella* spp. antibodies on the second day of life suggests that measuring antibodies by rapid, cost effective ELISA could be a practical tool to for the estimation of colostrum supply and the corresponding health of piglets. A suspected effect of reduced colostrum supply on the *Salmonella* spp. seroprevalence at the end of piglet rearing was not detectable. Other effects (e.g. hygiene) seem to be more significant.

Keywords: fertility, nursing, colostrum, immunocrit

1. Introduction

National piglet producers have demonstrated an enormous increase in reproductive performance in recent years

(AHDB, 2017). This has resulted in special challenges. Across the board, it can be observed that the number of born piglets correlates negatively with birth weight, and the number of underweight (<1 kg) and uneven-sized piglets

is increasing (Ferrari *et al.*, 2014; Quesnel, 2011; Vallet *et al.*, 2015). In many cases, this poses a problem because birth weight is a critical factor for individual survival (Fix *et al.*, 2010; Milligan *et al.*, 2002). One of the causes is an insufficient colostrum supply to underweight piglets (Ferrari *et al.*, 2014; Quesnel, 2011; Vallet *et al.*, 2013). A further complicating factor is that litter size is not directly related to the absolute amount of colostrum produced (Quesnel, 2011). Rather, the amount of colostrum provided by the sow varies individually between 2.8 kg/d and 8.5 kg/d (Vadmand *et al.*, 2015). Ferrari *et al.* (2014) demonstrated an increase in the average mortality rate from 4.7 to 23.1% in piglets that had consumed less than 150 g of colostrum instead of the required 250 g.

Ensuring an adequate supply of colostrum with the aim of maintaining a high health status in piglet rearing is a task frequently addressed in practice and science. In essence, ways for increasing colostrum supply have concentrated on three main areas: management, breeding and feeding (Knauer, 2018). The described trend towards ever larger litters, which, in many cases, goes hand in hand with human consumer demands, would not be possible without efficient management. This includes optimised measures to increase colostrum supply, cross-fostering to compensate for unbalanced litters and split nursing to ensure colostrum intake by small litter siblings with weak constitution, which have proven their effectiveness in research and practice (Calderón Díaz *et al.*, 2018; Heim *et al.*, 2012). However, such management measures are almost always accompanied by high personnel and time expenditure.

Targeted breeding or changes in feed composition and quantity seem to be particularly effective for keeping animals healthy and optimising colostrum supply. Individual, as well as breed differences, in colostrum and milk production have already been described and can be expected have an influence on breeding development in the future (Declerck *et al.*, 2015; Fahmy, 1972). Performance-related feeding for sows, particularly in the peripartum period to increase the colostrum milk quantity and milk composition to supply to all piglets in increasingly large litters has been the objective of numerous studies. Nuntapaitoon *et al.* (2018) investigated the effect of different concentrations of L-arginine in the ration of highly pregnant sows. In addition to increased placenta size and live weight, (piglets with a birth weight above 1.35 kg) the L-arginine-supplemented sow group had increased immunoglobulin (Ig)G concentrations in their colostrum. Vanklompenberg *et al.* (2013) tested whether milk yield could be increased by increasing the epithelial diameter in the udder parenchyma of the sows. This was achieved by regulating the release of prolactin during high pregnancy by means of the dopamine antagonist domperidone (DOM), and led to increased milk quantity and higher piglet weight gains. In another study, Kulüke (2018) was able to prove

that, when comparing different feeding strategies, sows fed *ad libitum* during lactation ingested a higher amount of feed than the restrictively fed animals in the comparison group. This resulted in higher daily gains and weaning weights for the piglets.

In terms of survival rates in new-born piglets, colostrum is of enormous importance as an energy source in the first hours of life, and for ingested Igs and cellular components which protect the piglets from infections for several weeks (Nguyen *et al.*, 2007; Quesnel *et al.*, 2012). In field studies, evidence shows that colostrum supply can be a critical factor on farms that have high *Salmonella* spp. seroprevalence in piglets ready for sale (Schulte zu Sundern *et al.*, 2017; 2018). A comparison of *Salmonella*-conspicuous (SC; i.e. the higher number of *Salmonella* spp. positive animals in a routine serological screening) with *Salmonella*-inconspicuous (SI) farms showed that the lightweight piglets on the SC farms had a significantly worse supply of colostrum than comparable piglets on SI farms. Furthermore, farms with very high fertility performance showed an increased prevalence of *Salmonella* spp. seroprevalence in piglets ready for sale, compared to average farms (Schulte zu Sundern *et al.*, 2017).

The aim of the present field study was to investigate a fundamental correlation between the level of colostrum supply and an increased *Salmonella* spp. seroprevalence in piglet rearing. Furthermore, an attempt was made to raise colostrum production by providing a special birth preparation feed to sows prepartum. By reducing the proportion of piglets with colostrum deficiency, the prevalence of *Salmonella* spp. seroprevalence in piglet rearing was expected to be reduced accordingly. In addition, the experimental feed had an increased L-arginine content, which was expected to have a positive effect on the blood circulation of the milk ridge parenchyma and, ultimately, on the amount of colostrum produced.

2. Materials and methods

Animal experiments were performed in accordance with the German rules and regulations and approved by the Ethics Committee of Lower Saxony for Care and Use of Laboratory Animals (LAVES) (Niedersächsisches Landesamt fuer Verbraucherschutz und Lebensmittelsicherheit; reference: 33.19-42502-05-17A107).

The study was carried out in cooperation with EVH-Select GmbH, an association of six Northern German piglet producer communities in which more than 250 piglet producers are involved. Under the organisation of EVH-Select GmbH, a voluntary health screening has been taking place on the farms every six months since 2014. For each screening, ten piglets ready for sale (weighing approximately 25 kg) are randomly selected for sampling.

The screening, aims to give potential buyers an overview of pig health status, includes the detection of *Salmonella* spp. lipopolysaccharide (LPS) antibodies. This detection was performed by ELISA Herdcheck® (IDEXX Laboratories B.V., Hoofddorp, the Netherlands, approved test MA No. BGVV-B 305). On the basis of the available results, four farms (n=4) were selected, which had been known to have an increased established prevalence of *Salmonella* spp. seroprevalence in piglets ready for sale (Figure 1).

Animals

All participating farms (n=4) were located in the federal state of Lower Saxony, Germany in the districts of Emsland and County of Bentheim. Only one of the four farms fattened its own piglets (Table 1). The other three farms were solely piglet producers. A total of 367 litters (farm A: 95, B: 92 C: 85, D: 95) were recorded on the four experimental farms. A total of 1,469 suckling piglets were sampled (farms A: 380, B: 368, C: 341, D: 380). Another sampling at the end of rearing was carried out on a total of 558 piglets (farms A: 114, B: 154 C: 142, D: 148).

Table 1. Characterisation of farms in terms of size, genetic background of sow breeds and management system in sows.

	Farm A	Farm B	Farm C	Farm D
Sows	720	200	590	270
Number of flatdeck places	3,200	800	2,800	1,100
Sow breed	DanAvi	PIC	DanAvi	Topigs
Weekly batch farrowing (weeks)	1	2	4	2
Lactation period (days)	26	25	24	26

Feed

On the four farms, the use of a commercial farrowing preparation feed was tested over six farrowing cycles (Figure 1). The sows were transferred to the farrowing pens about seven days before the calculated farrowing day. Per cycle, 16 sows in a farrowing group were selected. It was decided not to adjust the feed quantities between the farms before the start of the studies, because this was the preferred feed quantity for each farm in terms of performance. This had been established for a long time and could not be changed. One half (n=8) was fed in accordance with the farm's usual feeding curve and diet. The sows on farm A were fed 4 kg when moved to the farrowing shed. The amount was reduced to 2.2 kg until farrowing. On farm B, the sows were

Table 2. Composition of the experimental diet additionally given to the sows in the test group above.

Ingredient	%
Barley	54.80
Oats	20.00
Soy husks	17.25
Potassium diformate	2.50
Rapeseed oil	2.00
Calcium formate	1.00
L-arginine	1.00
Monocalcium phosphate	0.75
Salt	0.50
Propionic acid	0.20
Total	100.00

initially fed 3 kg and then 1.5 kg for the planned farrowing. Farms C and D fed 2.8 kg during the period from housing to farrowing. In the other 50% (the experimental group), the sows (n=8) received 1.25 kg of the test feed once a day in addition to the conventional ration. As the feeding trial was carried out in conventional farms, only the ration for the test group was adapted so as not to further disturb the operating process. The feed was manually dispensed into the feeding trough, not *via* the automatic feeding system. The feed was given when the sows were placed in the farrowing pen (seventh day *ante-partum*) until the second day *post-partum*. The amount of conventional feed (control) was not reduced in the experimental group, unless the feed from the previous meal was not consumed. Where this occurred, the amount of conventional feed was reduced accordingly.

The test diet was manufactured by a feed compounder (Rothkötter Mischfutterwerk GmbH, Meppen, Germany) as a crumbed product, supplied bagged and produced as a single batch. The control feed, which served as a basis for sows in both groups, was a commercial gestation ration (Rothkötter Mischfutterwerk GmbH; Bröring GmbH & Co. KG, Dinklage, Germany) used as standard on the farms, and was not changed during the trial. All four farms used dry feeds in the farrowing pens. The ingredients used in the test feed were selected in such a way that the increase in feed had no negative effects on the birth process (balanced for minerals and rich in fibre). For this reason, among others, components rich in crude fibre were selected (Table 2) to encourage fermentation in the hindgut which prevents constipation. In addition, Loisel *et al.* (2013) findings suggest that crude fibre-rich diets at the end of pregnancy can influence colostrum composition. Potassium diformate (FORMI®, Addcon GmbH, Bitterfeld-Wolfen, Germany), which has an inhibitory effect on *Salmonella* spp. in the gastrointestinal tract, was added to the experimental diet.

Sample collection

All four farms were monitored over six farrowing cycles, depending on their production cycle, and measurements were initially taken 24-48 h after the main farrowing day. For sampling, two piglets from the sows on the control feed and two piglets from sows that received the extra test feed were selected, to measure effects in the extremes of body weight in each pen (two light-weight and two heavy piglets; Figure 1). The piglets were aged between 12 h and 48 h at the time of sampling. The minimum weight of the selected piglets was 1.0 kg. The body weight of the selected piglets, the number of live piglets per litter at the time of sampling and the parity of the sow were recorded. Blood was collected from each of the selected piglets using serum monovettes (Monovette 9 ml, Sarstedt AG & Co., Nümbrecht, Germany) containing a coagulation activator. The blood samples were refrigerated for transportation to the laboratory and centrifuged at 2,000×g for 10 min. The extracted serum was stored at -20 °C until further analysis. Electronic transponder ear tags were used to individually identify the sampled piglets. Another blood sample was taken at the end of rearing, shortly before sale, when body weight was approximately 25 kg. On farms A, C and D, only the piglets from cycles 1, 2 and 3 were resampled because cycles 4, 5 and 6 were being used for other feeding trials.

Analysis

The serological examination of the blood samples was performed uniformly under standardised methods in an accredited laboratory (IVD Gesellschaft für Innovative Veterinärdiagnostik mbH, Seelze, Germany). The detection of *Salmonella* spp. LPS antibody was performed using an IDEXX Swine *Salmonella* spp. Ab Test (IDEXX Laboratories B.V., Hoofddorp, the Netherlands, approved test MA No. BGVV-B 305;). Samples collected at 2 d of age were not classified as ‘serologically positive’ or ‘serologically negative’. For the samples taken at the end of rearing, the cut-off for differentiating between ‘serologically negative’ and ‘serologically positive’ piglets were determined at a threshold optical density (OD)≥10% (Farzan *et al.*, 2007). The quantification of the colostrum supply to the piglets was carried out by the Ig-Immunocrit method (Vallet *et al.*, 2013), which was developed to allow rapid and simple measures of Ig levels and validated using conventional SDS-PAGE analysis. For this purpose, 50 µl serum was mixed with 50 µl of 40% ammonium sulphate, so that IGs present in the serum were precipitated. Centrifugation at 12,000×g in a disposable microhaematocrit capillary tube (75 mm/75 µl, Hirschmann Laborgeräte GmbH & Co.KG, Eberstadt, Germany) was carried out for 10 min. Haptoglobin in piglet serum was calorimetrically tested in an accredited laboratory (BioCheck-Labor für Veterinärdiagnostik und Umwelthygiene GmbH, Leipzig,

Germany) using the Haptoglobin Assay Cat. No. TP-801 (Tridelta Development Ltd., Maynooth, Ireland).

Statistical analysis

The statistical analysis of the data was performed using SAS®9.4 for Windows, using the SAS® Enterprise Guide®, Client Version 7.1 (SAS Institute Inc., Cary, NC, USA). By means of the Shapiro-Wilks test, the quantitative parameters were checked for normal distribution. The standard deviation is indicated in parenthesis in the tables. For correlation analysis of normally distributed data, Pearson's coefficient was used. For non-normally distributed data sets, the Spearman rank correlation coefficient was calculated. The interpretation of the correlation coefficient Rho was determined as $0.0 < r \leq 0.2$ = no to low correlation; $0.2 < r \leq 0.5$ = weak to moderate correlation; $0.5 < r \leq 0.8$ = clear correlation; $0.8 < r \leq 1.0$ = high to perfect correlation. Significance level was set at 5% confidence limits ($P < 0.05$).

3. Results

Results from the farms concerning reproductive performance, immunocrit and haptoglobin values in blood are shown below. Table 3 shows the typical characteristics specific to each farm (live born per litter, litter number, birth weight) before the test diets were included.

Colostrum supply

A moderate correlation ($r = 0.40935$; $P < 0.0001$) was demonstrated between immunocrit, as a measure of colostrum supply (i.e. Ig quality) to piglets and *Salmonella*

spp. antibodies at 2 d old. However, this effect was no longer detectable at the end of rearing, with a *Salmonella* spp. antibodies correlation of $r = 0.09914$. Piglets which were well-supplied with colostrum did not show a significantly lower prevalence of *Salmonella* spp. seroprevalence, compared to poorly supplied individuals. No correlation was found between body weight of the piglets at 2 d and the determined immunocrit ($r = -0.018425$) or between measured antibody titres at 2 d or and at the end of rearing ($r = 0.03333$). Additionally, no correlation between haptoglobin (measured in serum on the second day of life) and *Salmonella* spp. seroprevalence at the end of rearing was seen ($r = -0.01353$). A weak to moderate relationship was found between birth weight and haptoglobin ($r = 0.2924$).

Performance, immune and disease status in piglets

Significant benefits were seen in immunocrit from piglets from the test group for all farms (Table 4).

The nursing piglets in the control group ($n = 705$) had an immunocrit of $0.1227 (\pm 0.0438)$. The piglets ($n = 695$) whose dams had received the test feed had a significantly higher ($P < 0.0219$) immunocrit of 0.1279 ± 0.0407 (Table 5).

In line with this result, there was a significant difference ($P < 0.0007$) in *Salmonella* spp. seroprevalence in 2 d old piglets between individuals in the control ($n = 725$) and the experimental group ($n = 733$). Thus, the average OD (in %) in the control group was $25.4469 (\pm 22.3101)$ compared to $29.8718 (\pm 27.0617)$ in the experimental group. There was a difference in the body weights of the 2 d old piglets, which was $1.7749 \text{ kg} (\pm 0.5396)$ in the control

Table 3. Typical reproductive performance, immunocrit and haptoglobin values in blood without additional test feed.

Parameter	n	Live born per litter	Litter number	Birth weight	Immunocrit	Haptoglobin
Farm A	380	15.86 ± 2.37	4.21 ± 2.14	1.59 ± 0.37	0.145 ± 0.046	0.369 ± 0.319
Farm B	368	12.06 ± 1.68	4.61 ± 2.32	1.82 ± 0.49	0.099 ± 0.030	0.911 ± 0.684
Farm C	341	14.42 ± 2.05	5.56 ± 2.59	1.59 ± 0.38	0.142 ± 0.036	0.378 ± 0.469
Farm D	380	13.02 ± 1.43	5.26 ± 2.62	1.96 ± 0.63	0.110 ± 0.034	0.759 ± 0.713

Table 4. Reproductive performance, immunocrit and haptoglobin values in blood with division in the control (C) and test (T) groups for 2 d old piglets.¹

Parameter		Live born per litter	Litter number	Birth weight	Immunocrit	<i>Salmonella</i> -OD (%)	Haptoglobin
Farm A	C (n=189)	15.58 ± 2.63	4.23 ± 2.34	1.59 ± 0.39	0.142 ± 0.050	22.624 ± 17.690	C (n=48) 0.342 ± 0.272
	T (n=191)	16.15 ± 2.04	4.19 ± 1.94	1.58 ± 0.368	0.147 ± 0.040	26.431 ± 21.602	T (n=42) 0.400 ± 0.366
Farm B	C (n=163)	12.30 ± 1.59	4.58 ± 2.03	1.83 ± 0.48	0.102 ± 0.033	16.405 ± 17.578	C (n=48) 0.938 ± 0.668
	T (n=180)	11.84 ± 1.72	4.63 ± 2.58	1.80 ± 0.49	0.097 ± 0.027	17.577 ± 17.184	T (n=48) 0.882 ± 0.706
Farm C	C (n=191)	14.49 ± 1.55	5.20 ± 2.55	1.59 ± 0.37	0.139 ± 0.038	44.712 ± 22.573	C (n=49) 0.390 ± 0.554
	T (n=188)	14.36 ± 2.46	5.94 ± 2.59	1.59 ± 0.39	0.146 ± 0.036	45.203 ± 26.876	T (n=46) 0.367 ± 0.374
Farm D	C (n=192)	12.95 ± 1.27	4.91 ± 2.72	2.07 ± 0.68	0.103 ± 0.033	16.265 ± 17.222	C (n=47) 0.909 ± 0.821
	T (n=192)	12.95 ± 1.27	4.91 ± 2.72	2.07 ± 0.68	0.103 ± 0.033	29.869 ± 32.709	T (n=48) 0.909 ± 0.821
Average	C (n=735)	13.83 ± 1.76	4.73 ± 2.41	1.77 ± 0.48	0.1226 ± 0.0437^a	25.446 ± 22.310^a	C (n=192) 0.648 ± 0.670
	T (n=751)	13.82 ± 1.87	4.92 ± 2.46	1.76 ± 0.48	0.1278 ± 0.0406^b	29.872 ± 27.062	T (n=184) 0.566 ± 0.558

¹ Columns not sharing a letter differ significantly $P < 0.05$.

Table 5. Immunocrit, haptoglobin and *Salmonella* status in piglets from sows fed the control or test diets (including piglet numbers per analysis).¹

Parameter	Control	Test
No. birth weight	734	735
Birth weight	1.7749±0.5396 ^b	1.7035±0.4723 ^a
No. immunocrit	705	695
Immunocrit	0.1226±0.0437 ^a	0.1278±0.0406 ^b
No. haptoglobin	192	184
Haptoglobin	0.648±0.670	0.566±0.558
No. OD	725	733
Seroprevalence by OD (%)	25.446±22.310 ^a	29.871±27.061 ^b

¹ Rows not sharing a letter differ significantly $P<0.05$.

group (n=734) which was significantly ($P<0.0071$) higher (± 0.0071) than the experimental group (n=735) at 1.7035 kg (± 0.4723). This was difficult to explain regarding the test diets, and may have been due to management on the farms, as no differences in haptoglobin or *Salmonella* spp. seroprevalence was observed between the control and experimental groups at the end of rearing ($P<0.1758$ and $P<0.2977$, respectively; Table 6).

4. Discussion

Relevance of colostrum supply

The idea for this commercial trial was inspired by a study carried out on Northern German piglet production farms (Schulte zu Sundern *et al.*, 2017). For this purpose, the results from health screening piglets at 84 participating farms were compared with the corresponding sow production. Sows with an above-average fertility performance (more piglets born alive or weaned) often were not on farms with the lowest *Salmonella* spp. seroprevalence. Furthermore, the number of weaned piglets had a stronger relationship with the farm *Salmonella* spp. seroprevalence than number of piglets born alive (Schulte zu Sundern *et al.*, 2017). This led to the assumption that management decisions to control *Salmonella* spp. seroprevalence could be made in the period from birth to weaning. Hence, the colostrum supply of the

Table 6. *Salmonella* antibodies (OD in %) at the end of piglet rearing on farms.¹

Seroprevalence	<i>Salmonella</i> -OD (%)
Farm A	
C (n=53)	3.037±3.912
T (n=61)	3.852±11.628
Farm B	
C (n=59)	3.400±7.073
T (n=94)	2.446±5.167
Farm C	
C (n=67)	11.560±13.369
T (n=76)	14.394±18.434
Farm D	
C (n=74)	15.351±19.782
T (n=74)	19.324±23.816
Average	
C (n=253)	8.9486±14.2426 ^a
T (n=305)	9.8000±17.4954 ^b

¹ Columns not sharing a letter differ significantly $P<0.05$.

piglets was examined in twelve SC (i.e. higher number of *Salmonella* spp. positive animals from a routine serological screening) and twelve SI piglets.

At comparable weights, a significant difference in the colostrum supply to the lightest piglets between the SC and SI farms was found (Schulte zu Sundern *et al.*, 2018), hence four farms were selected from the twelve SC farms. On these farms, no correlation could be established between the quantity of colostrum supply (estimated by immunocrit) and *Salmonella* spp. seroprevalence at the end of rearing ($r=-0.00934$). Similar results were obtained in a follow-up study investigating the *Salmonella* spp. seroconversion of piglets on three French farrow-to-finish farms (Cevallos-Almeida *et al.*, 2019). Maternal antibodies in piglets could be detected up to ten weeks of age, and the levels measured correlated with those of the sows at the time of farrowing. However, the timing of seroconversion was different on these three farms. On average, seroconversion occurred at 137 ± 2.2 days of life, i.e. during the last third of the fattening period. In addition to the significant differences seen between the farms, variations between pens and houses were observed. Seroconversion was measured in piglets aged between 10 and 14 weeks, corresponding to the end of the starter/grower period (approx. 30-50 kg body weight). The authors concluded that medication programme, husbandry and management was more important for the timing of *Salmonella* spp. infection than individual animal factors. Other follow-up studies have shown a similar trend (Beloeil *et al.*, 2003; Merialdi *et al.*, 2008).

Despite these results, the efficacy of maternally transmitted antibodies against *Salmonella* spp. has been demonstrated. Both Matiasovic *et al.* (2013) and Roesler *et al.* (2006) were able to reduce the *Salmonella* spp. prevalence in piglets by sow vaccination (with inactivated vaccine) during pregnancy. However, the large body of published studies that have dealt with such causes and countermeasures do not always complement each other.

The findings from the present study indicated that the effects of good Ig supply from colostrum were not sufficiently large enough to give piglets effective protection against *Salmonella* spp. infection on SC farms until the end of rearing. However, due to the constraints of the commercial setting of the trial, it was not possible to make a comparison between SI and SC farms. Hence, further research is needed to specifically identify which role maternal antibodies play at different piglet ages regarding *Salmonella* spp. infection on-farm.

In the present commercial production study, other factors (e.g. hygiene, use of medication) appeared to play a greater role than individual colostrum supply. The list of potential risk factors is long, and has been the subject of numerous studies (Argüello *et al.*, 2018; Beloeil *et al.*, 2003; Wong *et*

al., 2004). Besides feeding, gaps in hygiene seem to play the most important role. However, none of these studies have provided an explanation for why highly productive farms (that are assumed to be well managed) appear to have high *Salmonella* spp. seroprevalence and why such infections are not limited to farms with poor management and obvious deficiencies in hygiene. For this reason, the identification of other key co-factors, which may include colostrum supply, should be the aim of further studies.

Influence of feeding on the colostrum supply

Providing extra feed to sows in the experimental group significantly improved colostrum and Ig supply to piglets. Measuring immunocrit ($P < 0.0219$) to evaluate Ig transfer (Vallet *et al.*, 2013) and *Salmonella* spp. antibodies ($P < 0.00007$), which must be maternally transmitted *via* ingested colostrum in 2 d old piglets, can be a good guide for on-farm use. It should be noted that in previous studies (Schulte zu Sundern *et al.*, 2018) the four experimental farms appeared to be conspicuous in connection with *Salmonella* spp. and, for this reason, were selected for the current trial in the first place. The results from previous studies indicated that the lightest piglets in litters on farms suspected of being SC were significantly worse off than comparable piglets on SI farms. It may be that colostrum supply was only significantly improved due to sow feeding at the time of farrowing, which may be a specific problem on SC farms. Further studies are required to investigate the effectiveness of the feed in SI farms as a comparison.

When considering the composition of the test feed, several concepts for increasing colostrum production were combined, with the aim of achieving the greatest possible effect in practice. Firstly, the absolute feed quantity in the test group was increased. Decaluwé *et al.* (2014) were able to show that the colostrum quantity was highest in sows with a moderate back fat thickness at housing in the farrowing area, and high peripartum feed quantity. Secondly, using soya husks in the experimental feed increased the crude fibre content, to meet two objectives. Firstly, there should be no adverse effects from the increase in feed quantity, and higher crude fibre content resulted in more rapid intestinal passage and prevented constipation. Secondly, there is already evidence that additional crude fibre intake at the end of pregnancy could have an influence on colostrum supply. Loisel *et al.* (2013) demonstrated the ability to change colostrum composition with the aid of a high-fibre experimental feed. Their feed contained soya husks and was fed to sows during late pregnancy, although this did not affect absolute colostrum quantity. This had a positive influence on the colostrum supply to the smallest piglets in the litter. Another important point was the supplementation of arginine in the experimental feed. The benefits of this have been contradictory from research results to date. Nuntapaitoon *et al.* (2018) observed the

effectiveness of arginine in increasing IgG concentration in colostrum, but Krogh *et al.* (2016) did not report an such increase. Ultimately, the combination of different feed concepts meant that it was not possible to evaluate whether individual components (barley, arginine, soya husks, FORMI), high crude fibre content or the increase in feed intake had the greatest influence on the amount of colostrum.

5. Conclusions

This commercial trial showed that, while it may be possible to increase colostrum supply and Ig to new-born piglets, it was not sufficient to protect individuals from *Salmonella* spp. infection in the long term, i.e. until the end of rearing. Other management factors (e.g. hygiene or use of medication) seem to be far more important for infection status in the herd. Nevertheless, the feeding trial carried out showed that there is potential to obtain benefits by increasing sow feeding at the time of farrowing. Optimised sow feeding can raise the colostrum Ig supply to piglets and can be a positive factor for producing healthy piglets, especially with regard to those in larger litters. Furthermore, the moderate correlation between immunocrit and measured *Salmonella* spp. antibodies at 2 d of age suggested that measuring antibodies, using cheap and rapid methods can be used as a practical, albeit estimates, measure for colostrum intakes.

Conflict of interest

The authors declare no conflict of interest.

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