Preventive Veterinary Medicine 205 (2022) 105678

Contents lists available at ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed

A field trial on the effect of cross-fostering on performance, clinical health and antibiotic usage during the suckling period of pigs

Cecilie Liv Nielsen *, Mogens Agerbo Krogh, Jan Tind Sørensen, Hanne Kongsted

Department of Animal Science, Aarhus University, Blichers Alle 20, DK-8830 Tjele, Denmark

ARTICLE INFO

Keywords:
Cross-fostering
Antibiotic usage
Pigs
Disease
Suckling period
Weaning age

ABSTRACT

Cross-fostering is a common nursing strategy in pig production, but there is sparse evidence on its effect on antibiotic usage and disease occurrence in piglets. The objective of this study was to compare the effect of two nursing strategies on antibiotic usage, disease occurrence, weight gain and mortality in piglets. A 2×2 randomized factorial experiment was conducted in three Danish commercial pig production herds. The factors were nursing strategy (cross-fostering allowed (CF) vs. cross-fostering not allowed after initial litter equalisation (non-CF)) and weaning age (four vs. five weeks). In CF litters, the herd's usual cross-fostering strategy was applied. Piglets were followed individually from birth until weaning. Data was collected on antibiotic usage, mortality, weight gain and clinical disease. Only individual antibiotic treatments were allowed. At litter level, the effect of nursing strategy (CF vs. non-CF) on average daily gain, mortality, antibiotic treatment, clinical disease, face wounds and carpal wounds was analysed. In total, 241 litters were used for the data analysis. Approximately 30% of the CF litters were cross-fostered (either given a nurse sow, mingled with non-siblings or both) during the nursing period. The odds for antibiotic treatment during the suckling period were 1.58 times higher for CF litters compared to non-CF litters ($P < 0.001$). Across experimental groups, 60.8% of antibiotic treatments were administered for leg diseases. In CF litters, 15.7–21.3% of the antibiotic treatments were directed against diarrhoea, whereas in non-CF litters this was the case for less than 1%. In CF litters, the odds for carpal wounds were 1.40 times higher than in non-CF litters ($P = 0.005$). There was a tendency towards a higher occurrence of face wounds ($OR = 1.30$, $P = 0.095$) and clinical disease ($OR = 1.25$, $P = 0.059$) at weaning in CF litters compared to non-CF litters. There was no difference in average daily gain and mortality from birth to weaning between CF and non-CF litters. The results show that cross-fostering increases antibiotic usage in piglets during the nursing period and tends to affect the clinical health at weaning negatively.

1. Introduction

There is a need for management strategies that improve health and reduce antibiotic usage in pig production. In commercial pig production, weaning is a stressful transition (Pluske et al., 1997), making pigs vulnerable to disease (Heo et al., 2013). Furthermore, management strategies for the nursing period are required to increase disease resilience around weaning (Prunier et al., 2010). Disease resilience is defined as the ability of animals to maintain performance and health when exposed to challenges (Albers et al., 1987).

In pigs, cross-fostering is a management intervention where some or all nursing piglets are removed from their birth sow and moved to a nurse sow. Piglets may also be exchanged between sows (Baxter et al., 2013). Cross-fostering is widely used in herds with hyper-prolific sows because the number of live born piglets often exceeds the number of functional teats in the sows (Straw et al., 1998; Rutherford et al., 2013). Cross-fostering is performed to enhance survival and growth of the piglets during the nursing period and to decrease piglet size variation within litters (Baxter et al., 2013; Alexopoulos et al., 2018). Early cross-fostering, just after the colostrum intake period, seems not to affect piglet growth or mortality (Heim et al., 2012; Schmitt et al., 2018). However, cross-fostering done later, and maybe several times during the nursing period, has been associated with reduced weight gain and increased mortality (Giroux et al., 2000; Robert and Martineau, 2001; Calderon Diaz et al., 2018).

During the first days post-partum piglets develop preference for a

Abbreviations: CF, cross-fostering allowed; non-CF, litters without cross-fostering after initial litter equalisation.

* Corresponding author.
E-mail address: cecilie.liv@anis.au.dk (C.L. Nielsen).

https://doi.org/10.1016/j.prevetmed.2022.105678
Received 3 November 2021; Received in revised form 9 May 2022; Accepted 13 May 2022
Available online 16 May 2022

specific teat or teat pair which they suckle throughout the nursing period (McBride, 1963). The stability of the teat order is disturbed if cross-fostering is performed after its establishment which results in competition and teat fighting to re-establish the teat order (Horrell and Bennett, 1981). Cross-fostered litters show more fighting and have an increased occurrence of skin lacerations compared to litters nursed by their mother (Robert and Martineau, 2001; Sorensen et al., 2016). Sows with cross-fostered litters spend less time lying on their lateral side and have more unsuccessful nursing episodes. This, may affect piglet growth (Robert and Martineau, 2001; King et al., 2020).

In a study by McCaw (2000), cross-fostering was reduced to a minimum to mitigate an acute outbreak of porcine reproductive and respiratory syndrome virus, which reduced pre-weaning mortality from approximately 15% to 10%. Moreover, Calderon Diaz et al. (2017) showed that cross-fostered piglets had a greater risk of pericarditis and heart condemnations at slaughter. No studies have compared the clinical health and antibiotic usage during the suckling period of pigs cross-fostered compared to pigs nursed by their mother.

Prior investigations of the effect of cross-fostering on weight gain, mortality and behaviour have been conducted either as observational studies without random allocation or as artificial cross-fostering scheme experiments. In the prior experiments, a fixed number of piglets was exchanged between predetermined pairs of litters at fixed time points. Hence, experimental studies comparing commonly applied cross-fostering strategies with fostering by the mother are lacking. The current field trial was conducted in commercial herds. The herds' normal strategies for cross-fostering were used for comparison.

The objective of the study was to investigate how nursing strategies that allow cross-fostering affect piglet disease resilience compared to nursing strategies not allowing cross-fostering after initial litter equalisation. Disease resilience was measured as: Clinical disease, antibiotic treatment, mortality and average daily gain in piglets. Furthermore, the occurrence of face wounds and carpal wounds, as indicators of fighting, were investigated.

2. Materials and methods

The study was conducted as a controlled field trial in commercial production herds as part of a larger experiment with a 2x2 factorial design. The factors were nursing strategy (cross-fostering allowed (CF) vs. cross-fostering not allowed (non-CF)) and weaning age (four weeks (4wk) vs. five weeks (5wk)) resulting in four experimental groups.

2.1. Herd selection and characteristics

Recruitment of the herds was done with two strategies: 1) 180 pig herds with minimum 500 sows, own production of weaners and located within one hour drive from the university (AU Foulum, Tjele, Denmark) were extracted from the Danish Central Husbandry Register (national register holding information on all pig herds in Denmark with location and number of animals (Stege et al., 2003)) and contacted by letter and phone and 2) Five veterinary practices specialised in pig production were asked to suggest herds for the project, which fulfilled the same inclusion criteria. Twenty-nine herds were suggested. 139 herds in total were reached by phone. At the phone calls, the project was explained to the herd owners including exclusion criteria, a number of questions regarding their production were asked and it was clarified whether the herd owners found the project interesting. Exclusion criteria were: use of medical zinc oxide to prevent post-weaning diarrhoea and vaccination of pigs against diarrhoea (*Escherichia coli* and *Lawsonia intracellularis*). The main reasons to refuse to participate were: Not possible to wean at five weeks of age or not willing to stop using medical zinc oxide. Other arguments for refusal to participate were: Current disease challenges, not willing to use the time needed, economy or lack of interest in the research questions. Three commercial conventional sow herds volunteered to participate in the field trial.

In the herds, lactating sows were housed crated in pens of variable size with a mixture of full slatted plastic floor, cast iron floor, a partly slatted floor made by a combination of plastic and concrete or cast iron and concrete. Piglets had access to a covered creep area with a heat lamp. All piglets were tail docked and supplemented with iron and toltrazuril and male piglets were castrated on day 3–4. All herds vaccinated sows against Porcine parvovirus, *Erysipelothrix rhusiopathiae*, *Haemophilus parasuis*, *Escherichia coli* and *Clostridium perfringens* type C. Additionally, sows were vaccinated against Influenza A virus (herd 1, 2), Porcine reproductive and respiratory syndrome virus (herd 2), *Actinobacillus pleuropneumoniae* (herd 3), *Mycoplasma hyopneumoniae* (herd 2, 3) and Porcine Circovirus Type 2 (herd 2, 3).

Table 1 shows characteristics of the three study herds. Cross-fostering was performed differently in the herds. In herd 1 and 2, piglets in excess of the sow's number of functional teats were moved to other sows shortly after birth when the piglets where expected to have received colostrum. In herd 3, sows nursed 17 piglets irrespective of the number of functional teats. Excess piglets where moved to nurse sows as described for herd 1 and 2. During the suckling period, un-thriving

Table 1
Herd characteristics of the three herds included in the study. Production parameters from internal production reports and management practised one year prior to the study period are presented in the table. Except for the number of nursed piglets, the management strategies presented in the table were also practiced during the field trial.

Herd	Herd 1	Herd 2	Herd 3
Study period	Jan 2019 - Jun 2019	Aug 2019 - Dec 2019	Dec 2020 - Jun 2021
SPF-status[a]	SPF +myc	SPF +myc, +PRRS2	SPF +myc, +PRRS1, +Ap2
Production parameters			
Herd size (sows)	1011	1308	721
Live born (stillborn)/litter	17.0 (1.6)	16.8 (1.4)	18.5 (1.3)
Piglet mortality (% of live born)	12.2	16.3	12.9
Piglets weaned/sow/year	33.1	29.9	35.6
Management			
Cross-fostering strategy			
Number nursed piglets	Functional teats	Functional teats	17
Litter standardisation[b]	Yes	No	No
Un-thriving piglets removed	Yes	Yes	Yes
Operation of farrowing unit	Continuous	Sectioned	Sectioned
Washing and disinfection	Yearly	Every batch	Every batch
Milk replacer sucklers	No	Yes	Yes
Creep feed for sucklers 4 times/day	From day 7	From day 10	From day 4

[a] SPF: Specific Pathogen Free – Danish surveillance programme for seven infectious diseases: PRRS, *M. hyopneumoniae (myc), A. pleuropneumoniae (Ap), P. multocida* toxin, *B. hyodysenteriae, Sarcoptes scrabei* and *Haematopinus suis*. SPF +myc means that the herd is declared free from all SPF diseases except *M. hyopneumoniae.*

[b] Piglets were transferred between sows to create more homogenous litters with piglets of the same size within each litter.

piglets were moved to nurse sows. In herd 1, size standardisation of piglets within litters was performed by transferring piglets between sows from day one to four to create more homogenous litters, i.e. similar sized piglets were nursed together. No size standardisation was performed in the two other herds.

2.2. Study design and inclusion

In each herd, nine farrowing batches were included. In the morning, the investigators included sows, which had farrowed during the last night. Assignment of sows to experimental groups was done by systematic inclusion by allocating the first four sows encountered to each of the four experimental groups in a pre-defined order. Thereafter, sows were included to the experimental groups in the same order. Eight to twelve sows were included per batch. Sows fulfilling the following inclusion criteria were included: 1) multiparous sows (in herd 3, this criterion was not used), 2) healthy sows defined as: sows with no fever (rectal temperature <39.6 °C), no mastitis (no hard and warm udder), no bad smelling discharge from vulva or no shoulder ulcer (< 5 cm diameter), 3) sows with easily accessible teats for the piglets (accessed by farmers) and 4) sows with the same number or higher number of live born piglets than her number of functional teats. At inclusion, included sows' pens were marked with a colour sign identifying experimental group affiliation. Throughout the study, litters in these marked pens acted as the 'study litters', including both piglets born in the pen, piglets moved to the pen during the nursing period and cases where litters received a nurse sow.

All sows in the study fostered a number of piglets equal to their number of functional teats. Piglets in excess from both CF and non-CF litters were moved to nurse sows at inclusion and not included in the study. The smallest and the biggest piglets were removed from the litters to make the included piglets homogenously sized.

In CF litters, the usual cross-fostering strategy of the herds was applied. Hence, if the farmer assessed that cross fostering was needed, the farmer was allowed to do so. In these litters, farmers were allowed to move piglets to and from the litter and to exchange the sow with a nurse sow during the entire nursing period. Cross-fostering was performed among both CF litters and non-experimental litters. Piglets moved to CF litters were ear-tagged by the farmers if they were treated with antibiotics during the nursing period. Otherwise, they were ear-tagged by the investigators at weaning.

In non-CF litters, the piglets were nursed by their own mother and only with siblings for the entire suckling period. Hence, no movement to and from the litters during the nursing period was allowed. Non-CF litters were excluded from the experiment if the sow got ill or died as the experimental design did not allow these litters to receive a nurse sow. Ill sows were defined as sows who stopped eating or milking (evaluated by the piglets' appearance), developed a fever (>39.5 °C.), developed shoulder ulcer (> 5 cm diameter) or developed severe udder-, tail- or vulva bites inflicted by the piglets. In the non-CF litters, if piglets were emaciated, they were excluded due to ethical considerations. The following signs all needed to be present in order to exclude piglets: Visible ribs, spine and hips and a prominent tuber coxae. Farmers were trained to recognize these criteria, and after a period of training, they took the daily decisions on these exclusions.

Investigators and farmers were not blinded to interventions as nursing strategies and weaning ages are management strategies, which by nature are un-blinded.

2.3. Data collection

After inclusion of sows and allocation to experimental groups, number of live born, stillborn and sow parity were recorded for the included sows. Moreover, the included piglets were ear tagged, weighed and their gender was recorded.

During the nursing period, herd personal recorded data for the litters on: antibiotic treatments and mortality at animal level with date, cause and duration of treatment. Likewise, they recorded exclusion of piglets in non-CF litters. The herd staff was only allowed to treat piglets with antibiotics if clinical signs of disease were present and only on individual level following directions from the herd veterinarian.

Table 2
Clinical examination protocol and clinical disease measure with definitions and scales.

Measures	Definition	Scale
Face wounds	Wounds on both cheeks and nose with min. 30% of the face covered.	0/1
Carpal wounds	> 1 cm with scar tissue on proximal carpus. > 1 cm with active wound defined as either swelling, hyperaemia or laceration on proximal carpus.	0/scar/wound
Runted	Thin, long and stiff hair layer and a large head compared to the size of the body.	0/1
Umbilical hernia	Swelling at the umbilicus.	0/1
Inguinal hernia	Swelling at the inguinal region.	0/1
Diarrhoea[a]	Diarrhoea on glove after digital rectal exploration.	0/1
Joint swelling on legs	Palpable accumulation of fluid around the joint underneath the skin.	0/1
Hoof abscess	Abscess proximal to the claw.	0/1
Eye infection	Black staining below the eye and/or completely closed eyes because of discharge.	0/1
Clinical disease	Presence of one or several of the above clinical diseases, except for face and carpal wounds.	0/1

[a] Faeces was classified as diarrhoea if loose or watery in consistency as defined by Pedersen and Toft (2011).

The day before weaning (from here this will be referred to as 'at weaning'), piglets were clinically examined and weighed by the investigators. The clinical examination protocol is presented in Table 2. In CF litters, the 'study litter' was examined at weaning. For each piglet, it was recorded whether it was nursed by its own mother or a nurse sow. At weaning, the investigators looked for piglets missing in the 'study litter', i.e. piglets that were not in the 'study litter' at weaning and not registered as dead, in non-experimental pens in the stable. If they were not found at weaning, they were classified as missing.

For the analysis, the clinical recordings runted, umbilical hernia, inguinal hernia, diarrhoea, joint swelling on legs, hoof abscess and eye infection (Table 2) were joined into a single dichotomized measure of clinical disease as either healthy (no clinical disease present) or diseased (one or several clinical diseases present).

2.4. Analytical statistics

All variables were aggregated to litter level to get a single measure for each litter. The following outcome variables were analysed: average daily gain (ADG), mortality, antibiotic treatment, clinical disease, face wounds and carpal wounds. Definitions of outcomes, are specified in Table 3. The effect of nursing strategy (CF vs. non-CF) on ADG was analysed using a mixed linear regression model. The effect of nursing strategy (CF vs. non-CF) on mortality, antibiotic treatment, clinical disease, face wounds and carpal wounds was analysed using mixed logistic analysis.

Herd was included as a random effect to account for the multi-site nature of the data. In addition, alternative models with herd as fixed effect were examined. Secondary explanatory variables were: sow parity, number of live born piglets, number of stillborn piglets, number of nursed piglets, mean birth weight (per 100 g) of nursed piglets, female: male ratio of nursed piglets and weaning age (defined by the experimental group: 4 vs. 5 wk.). To account for the 2x2 factorial study design a two-way interaction between nursing strategy and weaning age was included. In the final models, explanatory variables were only kept if significant except for nursing strategy, which was kept in the models even if not significant because of the study design. The full model was

Table 3
Definitions of outcome variables. All variables were measured on individual level and summarised at litter level for the data analysis.

Outcome	Definition
Average daily gain (ADG)	$\frac{\text{Weaning } weight(\text{g}) - \text{Birth } weight(\text{g})}{\text{Days between birth and } weaning}$
Mortality	$\frac{\text{Number of dead piglets in the litter during the suckling } period}{\text{Number of piglets included in the litter at farrowing}}$
Antibiotic treatment	$\frac{\text{Number of piglets treated with antibiotics in the litter during the suckling } period}{\text{Number of piglets included in the litter at } farrowing}$
Clinical disease	$\frac{\text{Number of piglets with clinical disease in the litter at } weaning}{\text{Number of piglets in the litter at } weaning}$
Face wounds	$\frac{\text{Number of piglets with face wounds in the litter at } weaning}{\text{Number of piglets in the litter at } weaning}$
Carpal wounds	$\frac{\text{Number of piglets with carpal wounds in the litter at } weaning}{\text{Number of piglets in the litter at } weaning}$

reduced using backward elimination with a 5% significance level. Model control was performed with residuals vs. fitted, normal Q-Q, scale-location and residuals vs. leverage plots for the linear model of ADG. For the logistic models, Hosmer-Lemeshow and chi-square goodness of fit tests were performed. Data analysis was performed in R version 3.6.1. (RCoreTeam, 2019).

2.5. Ethical permission

The study did not require ethical review according to University policy, since the experimental setup only used common production strategies approved in Denmark and did not include invasive procedures.

3. Results

3.1. Descriptive statistics

Table 4 shows the number of litters, prevalence of litters cross-fostered and mean of selected measures at birth and weaning at litter level grouped for the four experimental groups. In total, 268 litters were included in the trial with 66–68 litters in each experimental group. Due to the differences in herd sizes, a lower number of litters were included in herd 3 with only 53 litters included compared to 107 and 108 in herd 1 and 2, respectively. Fourteen litters were excluded during the nursing period because the sow was ill (n = 5), cross-fostering was performed by mistake (n = 7), the sow died during the nursing period (n = 1) or the litter was missing at weaning because it had been weaned by the farmer by mistake (n = 1). A higher number of litters were excluded during the nursing period from non-CF litters (n = 12) compared to CF litters (n = 2). Six litters were excluded from the analysis because of missing values for either parity, live born or stillborn. Furthermore, seven litters were excluded from the analysis because the herd staff by mistake treated the entire litter with antibiotics shortly after inclusion (n = 1) or at castration (n = 6). For comparative purposes, the analysis was also conducted on a dataset including the six litters treated routinely with antibiotics at castration.

In approximately 30% of the CF litters, cross-fostering was performed. Sixty-two percent of CF litters in herd 1, 17% of CF litters in herd 2 and 4% of CF litters in herd 3 either were mingled with non-siblings, received a nurse sow or both. Across herds, 67% of the actual cross-fostered litters were mingled with non-siblings and 15% received a nurse sow. Eighteen percent of the litters both received a nurse sow and were mingled with non-siblings.

The number of live born piglets and the number of nursed piglets were comparable for the four experimental groups with approximately 19 live born piglets per litter and approximately 14 nursed piglets per litter. Hence, an average of five piglets were moved to other, non-experimental sows shortly after birth and not followed in the study.

Table 5 shows the mean ADG and mean of proportions of different health measures at weaning at litter level grouped for the four experimental groups. Details on herd level measures are provided in Supplementary Table 1. The ADG of piglets from birth to weaning was 219–236 g for each of the four experimental groups. Across experimental groups in herd 1, the ADG was 201 g, compared to 240 g and 250 g in herd 2 and 3, respectively. At weaning, approximately 3% of

Table 4
Characteristics of litters in the study. The results were grouped by weaning age (4 vs. 5 weeks) and nursing strategy (cross-fostering allowed (CF) vs. cross-fostering not allowed (non-CF)).

Weaning age (weeks)	4		5	
Nursing strategy	CF	non-CF	CF	non-CF
Litters at weaning (n[a])	62	60	62	57
Litters cross-fostered (%)[b]	33.9	–	29.0	–
Sow parity (mean)	3.3	3.3	3.1	2.8
Live born (n, mean)	19.8	19.3	19.8	19.0
Stillborn (n, mean)	1.6	2.2	1.6	1.7
Nursed piglets[c] (n, mean)	13.9	13.9	13.8	13.9
Birth weight of nursed piglets (mean) [Std[d]]	1385 [213]	1438 [192]	1473 [231]	1440 [211]
Female:male ratio of nursed piglets (mean)	1.0	1.3	1.1	1.2
Weaned piglets (n, mean)	12.6	12.4	12.5	12.5

[a] n: number
[b] Prevalence of litters where cross-fostering was performed. Cross-fostering could either be that non-siblings piglets were moved to the litter or that the litter got a nurse sow or both during the nursing period.
[c] Number of piglets nursed by the sow at the day of birth. Equal to number of functional teats.
[d] Std: standard deviation

Table 5
Mean of selected measures at litter-level the day before weaning. The results were grouped by weaning age (4 vs. 5 weeks) and nursing strategy (cross-fostering allowed (CF) vs. cross-fostering not allowed (non-CF)).

Weaning age (weeks)	4		5	
Nursing strategy	CF	non-CF	CF	non-CF
ADG[a] (g, mean) [Std.[b]]	219 [39.6]	223 [35.7]	236 [42.7]	229 [36.2]
Dead (%, mean)	5.3	6.0	6.3	5.8
Moved (%, mean)	6.3	4.1	1.9	3.3
Missing[c] (%, mean)	3.0	0.8	2.6	1.0
Diseased (%, mean)	15.5	11.8	9.9	9.4
Face wounds (%, mean)	6.8	5.3	6.7	5.8
Carpal wounds (%, mean)	11.5	7.7	12.7	10.5
Antibiotic treatment (%, mean)	10.5	6.4	11.9	8.1

[a] ADG: average daily gain
[b] Std.: standard deviation
[c] Piglets missing in the 'study litters' at weaning and not found by the investigators in the farrowing stable in non-experimental litters.

piglets in CF litters were missing compared to 1% in non-CF litters. We assume that missing piglets represent a mixture of piglets that were overlooked in the pens, moved to other stables and deceased. More piglets were missing at weaning in herd 1 compared to herd 2 and 3. Thus, in herd 1, 3.6% were missing at weaning compared to below 1% in herd 2 and 3. However, the mortality was higher in herd 2 and 3 compared to herd 1.

At weaning, the majority of piglets in all three herds had carpal wounds. Thus, approximately 95% had either wounds or scars on the proximal carpus. As seen from Table 5, the mean prevalence of diseased piglets, piglets with face wounds, piglets with carpal wounds and piglets treated with antibiotics was numerically higher in CF litters compared to non-CF litters. For piglets treated with antibiotics, there was a large variation between herds with an average prevalence of 13%, 8% and 5% across experimental groups in herd 1, 2 and 3, respectively. Overall, approximately half of the litters were treated with antibiotics (one or several piglets in the litter were treated) during the study period.

Table 6 shows the distribution of causes of antibiotic treatment at individual level grouped for nursing strategy and weaning age. In total, 469 antibiotic treatments were administered during the nursing period for the included piglets (n = 3350) in the litters used for the data analysis. Some piglets were treated several times during the nursing period. In herd 1, 21% of the treated piglets were treated several times whereas this was only the case for 2% and 3% of the piglets in herd 2 and 3, respectively. The treatments were administered for one to three days depending on treatment strategy and cause. The most frequent cause for antibiotic treatment was for leg problems e.g. arthritis and hoof abscesses. Piglets raised in CF litters were treated more for diarrhoea with 21% of the treatments for piglets weaned at 4 weeks of age compared to no treatments for diarrhoea in piglets raised in non-CF litters.

3.2. Analytical statistics

Table 7 shows the parameter estimates, standard errors (SE), odds ratios (OR) and p-values (P) for the six different outcomes analysed.

The odds of being treated with antibiotics during the suckling period were higher for piglets raised in CF litters compared to non-CF litters. The odds for antibiotic treatment in CF litters were 1.58 times larger than for non-CF litters. Odds for antibiotic treatment were lower in herd 2 (OR = 0.61) and 3 (OR = 0.32) compared to herd 1 (see Supplementary Table 2). We also saw a gender effect and an effect of parity on antibiotic treatment. Hence, in litters with a higher proportion of females and an increased sow parity the odds for antibiotic treatment were

Table 6
Absolute number of antibiotic treatments[a], number of included piglets[b] and prevalence of causes of antibiotic treatment grouped by weaning age (4 vs. 5 weeks) and nursing strategy (cross-fostering allowed (CF) vs. cross-fostering not allowed (non-CF)).

Weaning age	4		5		Total
Nursing strategy	CF	non-CF	CF	non-CF	
Total	136	93	140	100	469
Leg (% of treated)	68 (50)	58 (62.4)	93 (66.4)	66 (66)	285 (60.8)
Diarrhoea (% of treated)	29 (21.3)	0 (0)	22 (15.7)	1 (1)	52 (11.1)
Other/*NA*[c] (% of treated)	39 (28.7)	35 (37.6)	25 (17.9)	33 (33)	132 (28.1)
Piglets included (n[d])	863	836	856	795	3350

[a] Absolute number of antibiotic treatments. Some piglets were treated several times during the nursing period.
[b] Number of included piglets in litters not excluded from the experiment i.e. litters used for the data analysis.
[c] *NA*: Cause not available
[d] n: number

Table 7
Parameter estimates (Est.), standard errors (SE), odds ratios (OR) and p-values (P) for fixed effects and variance for random herd effect from the six final models. The outcomes in the six models were: mean average daily gain (ADG) at litter level and litter prevalence of dead piglets, diseased piglets, piglets treated with antibiotics, piglets with face wounds and piglets with carpal wounds. ADG was analysed by mixed linear regression and the other outcomes were analysed by mixed logistic analysis. All models were on litter level and included 241 litters from three pig herds.

		ADG			%dead				%diseased				%antibiotic treatment				%face wounds				%carpal wounds			
Fixed effects	Levels	Est.	SE	P	Est.	SE	OR	P	Est.	SE	OR	P	Est.	SE	OR	P	Est.	SE	OR	P	Est.	SE	OR	P
Intercept		336.86	38.30		2.72	1.32			-1.01	0.44			-1.84	0.32			-4.28	1.18			-1.83	0.74		
Nursing strategy	CF[1]	-0.20	4.14	0.961	0.04	0.15	1.04	0.796	0.22	0.12	1.25	0.057	0.46	0.12	1.58	< 0.001	0.26	0.15	1.30	0.095	0.34	0.12	1.40	0.005
Weaning age	5			*not incl.*[3]				*not incl.*	-0.40	0.12	0.67	< 0.001				*not incl.*				*not incl.*				*not incl.*
Nursing strategy*weaning age				*not incl.*				*not incl.*				*not incl.*				*not incl.*				*not incl.*				*not incl.*
Parity				*not incl.*				*not incl.*				*not incl.*	-0.18	0.05	0.83	< 0.001	-0.24	0.07	0.78	< 0.001				*not incl.*
Live born				*not incl.*	-0.06	0.03	0.94	0.034	-0.05	0.02	0.95	0.030				*not incl.*				*not incl.*	-0.09	0.02	0.91	< 0.001
Stillborn				*not incl.*	0.11	0.05	1.12	0.019				*not incl.*				*not incl.*				*not incl.*				*not incl.*
Nursed piglets[2]		-9.86	2.38	< 0.001	-0.18	0.08	0.84	0.034				*not incl.*				*not incl.*				*not incl.*				*not incl.*
Mean birth weight (per 100 g)		2.13	0.98	0.030	-0.15	0.04	0.86	< 0.001				*not incl.*				*not incl.*	0.08	0.04	1.08	0.031	0.08	0.03	1.09	0.005
Female:male ratio[4]				*not incl.*				*not incl.*				*not incl.*	-0.28	0.10	0.76	0.003				*not incl.*				*not incl.*
Random effect																								
Herd variance		621.70			0.14				0.01				0.19				3.01				0.11			
Residual variance		1025.00			–				–				–				–				–			

[1]CF: cross-fostering [2]Number of piglets nursed by the sow. Equal to number of functional teats. [3]*Not included*. Removed from the final model. [4]Calculated as: number of females in litter/number of males in litter.

reduced. There was a tendency (P = 0.059) to more diseased piglets (OR = 1.25) at weaning in CF litters compared to non-CF litters. If the six litters routinely treated with antibiotics at castration were included in the analysis, the effect of nursing strategy on disease occurrence at weaning was significant (P = 0.03) with comparable parameter estimates (model results are not shown). In addition, there was a significant effect of weaning age with weaning at five weeks of age being protective for disease at weaning (OR = 0.67).

The odds for carpal wounds was higher for CF litters compared to non-CF litters, with 1.40 times higher odds for carpal wounds. Moreover, there was a tendency (P = 0.095) to more piglets with face wounds (OR = 1.30) at weaning in CF litters compared to non-CF litters. In the comparative model including the six litters routinely treated with antibiotics, there was a significant effect (P = 0.04) of nursing strategy. There were fewer piglets with face wounds and carpal wounds in herd 2 and 3 compared to herd 1 (see Supplementary Table 2), and an increased occurrence of face wounds and carpal wounds with increasing birth weight. Increased parity was protective for the occurrence of face wounds.

There was no significant difference in ADG and mortality for piglets raised in non-CF litters compared to CF litters. However, there was a herd effect on ADG with an increased ADG of 39.1 g in herd 2 and 47.0 g in herd 3, compared to herd 1. In contrast, we saw increased mortalities in herd 2 and 3 compared to herd 1 (see Supplementary Table 2). We saw an increasing ADG and decreasing mortality with increasing mean birth weight, whereas a higher number of nursed piglets was associated with a decreased ADG and lower mortality. Generally, fewer pigs were missing at weaning in herd 2 and 3 with a significant effect of raising in CF litters on being missing with an OR of 3.0 compared to non-CF litters (model results are not shown).

4. Discussion

The effect of keeping piglets with their own mother and siblings vs. allowing the management intervention of cross-fostering during the nursing period after initial litter equalisation was investigated in this field trial.

The level of cross-fostering was approximately 30% in CF litters. For comparison, a minimum of 50% of the piglets were cross-fostered during the nursing period in two recent Danish studies in four commercial herds (Eriksen et al., 2021; Hovmand-Hansen et al., 2021). Thus, the level of cross-fostering in our study seems to be low and the level is probably low compared to the general Danish situation.

In our study, non-CF litters were treated less with antibiotics compared to CF litters. A recent study, aiming at identify risk factors for antibiotic treatment, did not find this association (Lynegaard et al., 2021). The study by Lynegaard et al. (2021) was carried out in two Danish RWA (raising without antibiotics) herds having a specific focus on avoiding antibiotic treatment. The very low use of antibiotics and very few non-fostered piglets in one of the herds may partly explain the discrepancy between the two studies. Aligning with our findings, Thomsson (2008) found a lower antibiotic usage after weaning in pigs weaned in their farrowing pen with their littermates compared to pigs moved to a nursery unit and mixed with unfamiliar pigs.

Most antibiotics in both non-CF and CF litters were applied for leg infections in the current study. In a Danish observational study including 3 herds and 12,493 number of piglets, 6% and 5% of the included piglets were treated with antibiotics against arthritis and diarrhoea, respectively, whereas only 1% was treated for other infections during the suckling period (Johansen et al., 2004). Interestingly, we saw a different pattern in the usage of antibiotics in CF and non-CF litters, with CF litters having a higher proportion of antibiotics administered to treat diarrhoea. Thus, the result might suggests that non-CF litters experience reduced pathogen transmission. However, other factors like reduced stress and undisturbed feed intake may also have an impact.

As is the case for antibiotic usage during the suckling period, the tendency towards less disease at weaning in non-CF litters may be explained by less stress and reduced pathogen transmission. This association was even significant in the comparative model including the litters routinely treated with antibiotics indicating lack of power in the study as explanation for this association to be non-significant. A recent study shows that pigs weaned from their birth pen have lower odds for developing umbilical outpouchings (Norval, 2021). Development of umbilical outpouchings is to some extent associated with umbilical infections and can be prevented by antibiotic treatment (Searcybernal et al., 1994; Yun et al., 2017). Therefore, reduced pathogen transmission may contribute to the tendency to decreased disease occurrence in non-CF litters. In addition, stress caused by social instability e.g. a disturbed teat order may be associated with a higher disease risk (Proudfoot and Habing, 2015).

Almost all piglets in the study had carpal wounds. Carpal wounds emerge during nursing when piglets press their legs against the hard surface (Norring et al., 2006). The fact that carpal wounds in our study were more prevalent in CF litters corresponds well with a previous study which concluded that carpal wounds were more prevalent in cross-fostered litters and related this association to increased teat fighting (Sorensen et al., 2016). CF litters tended to have more face wounds than non-CF litters. Robert and Martineau (2001) observed piglet behavior immediately after cross-fostering and found increased fighting in cross-fostered litters caused by a disturbed teat order which resulted in more face and body lesions. It seems reasonable to assume that CF-litters that were cross-fostered would have a more unstable teat order compared to litters that were not cross-fostered. An unstable teat order has been associated with poor growth (Prunier et al., 2010) which was not the case in the CF litters in our study. This may be explained by the fact that only 30% of CF litters in our study was cross-fostered. Other studies show that repeated cross-fostering or cross-fostering at 1 week of age reduces the weight gain during the suckling period (Giroux et al., 2000; Robert and Martineau, 2001; King et al., 2020). In our study, we did not request the farmer to register at which time point cross-fostering was performed. This was done to limit the workload for registrations for the farmer and thereby ensure compliance with the experimental setup. However, this setup prevents us from drawing conclusions on the effect of timing of cross-fostering.

In herd 2 and 3, piglets were provided milk replacer in addition to suckling the sow's udder, which may explain the higher ADG in these herds compared to herd 1. It was previously show that provision of milk replacer as a supplement to sow-rearing increases the weaning weight with 10% (Dunshea et al., 1999). In herd 1, more cross-fostering was performed compared to the two other herds. This is likely explained by the strategy on litter standardisation in this herd, which was not performed in the other herds. Herd 1 had more antibiotic treatments, more carpal wounds and more face wounds than seen in the other two herds. These differences may be linked to the more extensive use of cross fostering in herd 1. In herd 1, cleaning and disinfection was only performed one time per year and operation was performed continuously compared to sectioned operation with cleaning and disinfection in the two other herds. It is well know that a reduced internal biosecurity is a risk factor for an increased antibiotic usage (Postma et al., 2017). Differences in level of cross-fostering, thresholds for antibiotic treatment and other management practices may also explain some differences between herds. Those differences may influence the effect of cross-fostering on health measures during the suckling period.

We had to contact a large amount of herds in order to obtain the three herds for the study. Thus, it is worth considering whether the identified herd differences are likely to be due to expected farm variation. Production parameters in the study herds were comparable to the general Danish situation in 2019 with an average of 17.5 live born piglets per sow and 33.6 piglets weaned per sow per year (Hansen, 2020). Also, housing and management practices (e.g. crating of sows, tail-docking, castration and prophylaxis against coccidiosis) were comparable to the general situation in Denmark. Due to our herd selection criterion, herd 1 and 2 were larger than the Danish average herd. The many refusals to participate in the study may be explained by the complex experimental setup. Many herds were not able to practice weaning at five weeks of age because of lack of space in the farrowing pens. Others were not interested in reducing the number of weaned piglets per sow per year, which would follow by half of the experimental pigs staying a week longer with the sow. Moreover, a high number of herds were unwilling to leave out medical zinc oxide in the experimental groups.

At weaning, we saw less disease in piglets weaned at five weeks of age compared to piglets weaned at four weeks of age with an equal level of antibiotic treatments during the suckling period. The lower level of disease is probably explained by the fact that piglets weaned later have a longer period to recover from disease happening early in the suckling period. The result implicates that piglets weaned later are less affected by disease at the point of weaning and therefore likely to be more robust towards the stressors of weaning.

Our study had some limitations inflicted by the design. Piglets moved away from the CF litters were not followed in the study, and therefore we do not know about the eventual effect of being moved away on their condition. Furthermore, during inclusion of litters, on average, five piglets were removed from the litters shortly after birth. Those piglets were not followed in the study. Therefore, our study does not provide knowledge on the effect of the investigated nursing strategies for very small or very large piglets. Another limitation relates to the possibilities for providing a nurse sows in the CF litters. In the study, 12 non-CF litters were excluded compared to two CF litters. Ill sows can be expected to have a reduced milk production, which may affect the piglets' growth and well-being (Kaiser et al., 2018). There might be a systematic difference between CF and non-CF litters as because of CF litters being affected by illness in sows which is not an option in non-CF litters.

5. Conclusions

In this study, we saw a higher usage of antibiotics during the suckling period when applying a management strategy allowing mingling of piglets between litters and application of nurse sows after initial litter equalisation. Especially, antibiotic treatments against diarrhoea were more common when this strategy was used. The effects were seen even though the level of cross-fostering was only moderate in the study. Therefore, we hypothesize that in herds with extensive cross-fostering the effects of a change in management strategy may be even more pronounced. Our results indicate that nursing of piglets by their own mother during the entire suckling period has a positive effect on disease resilience in piglets. Therefore, the results of the study call for an increased focus on reducing the mingling of suckling piglets in order to reduce the development of disease and thus reduce the need for antibiotics. However, this strategy is not possible to apply to all piglets in present productions with hyper-prolific sows as the number of live born piglets exceeds the rearing abilities of the sows. Therefore, piglets in excess have to be moved to nurse sows. Thereafter, the litters should stay as undisturbed as possible.

Funding

This work was funded by the Danish Veterinary and Food Administration as part of The Veterinary III Agreement.

Acknowledgements

The authors acknowledge the three herd owners and staff for their cooperation and help with the study. In addition, we acknowledge the help from technician Stine Lindgren and student helpers involved in data collection.

Declaration of competing interest

The authors report no declarations of interest.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2022.105678.

References

Albers, G.A.A., Gray, G.D., Piper, L.R., Barker, J.S.F., Lejambre, L.F., Barger, I.A., 1987. The genetics of resistance and resilience to haemonchus-contortus infection in young merino sheep. Int. J. Parasitol. 17, 1355–1363.

Alexopoulos, J.G., Lines, D.S., Hallett, S., Plush, K.J., 2018. A review of success factors for piglet fostering in lactation. Animals 8.

Baxter, E.M., Rutherford, K.M.D., D'Eath, R.B., Arnott, G., Turner, S.P., Sandoe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig II: management factors. Anim. Welf. 22, 219–238.

Calderon Diaz, J.A., Boyle, L.A., Diana, A., Leonard, F.C., Moriarty, J.P., McElroy, M.C., McGettrick, S., Kelliher, D., Garcia Manzanilla, E., 2017. Early life indicators predict mortality, illness, reduced welfare and carcass characteristics in finisher pigs. Prev Vet Med 146, 94–102. https://doi.org/10.1016/j.prevetmed.2017.07.018.

Calderon Diaz, J.A., Garcia Manzanilla, E., Diana, A., Boyle, L.A., 2018. Cross-fostering implications for pig mortality, welfare and performance. Front. Vet. Sci. 5, 123.

Dunshea, F.R., Kerton, D.J., Eason, P.J., King, R.H., 1999. Supplemental skim milk before and after weaning improves growth performance of pigs. Aust. J. Agric. Res. 50, 1165–1170.

Eriksen, E.O., Kudirkiene, E., Christensen, A.E., Agerlin, M.V., Weber, N.R., Nodtvedt, A., Nielsen, J.P., Hartmann, K.T., Skade, L., Larsen, L.E., Pankoke, K., Olsen, J.E., Jensen, H.E., Pedersen, K.S., 2021. Post-weaning diarrhea in pigs weaned without medicinal zinc: risk factors, pathogen dynamics, and association to growth rate. Porc. Health Manag. 7, 54.

Giroux, S., Robert, S., Martineau, G.P., 2000. The effects of cross-fostering on growth rate and post-weaning behavior of segregated early-weaned piglets. Can. J. Anim. Sci. 80, 533–538.

Hansen, C., 2020. LANDSGENNEMSNIT FOR PRODUKTIVITET I PRODUKTIONEN AF GRISE I 2019. Notat nr. 2014. SEGES Svineproduktion.

Heim, G., Mellagi, A.P.G., Bierhals, T., de Souza, L.P., de Fries, H.C.C., Piuco, P., Seidel, E., Bernardi, M.L., Wentz, I., Bortolozzo, F.P., 2012. Effects of cross-fostering within 24h after birth on pre-weaning behaviour, growth performance and survival rate of biological and adopted piglets. Livest. Sci. 150, 121–127.

Heo, J.M., Opapeju, F.O., Pluske, J.R., Kim, J.C., Hampson, D.J., Nyachoti, C.M., 2013. Gastrointestinal health and function in weaned pigs: a review of feeding strategies to control post-weaning diarrhoea without using in-feed antimicrobial compounds. J. Anim. Physiol. Anim. Nutr. 97, 207–237.

Horrell, I., Bennett, J., 1981. Disruption of teat preferences and retardation of growth following cross-fostering of 1-week-old pigs. Anim. Sci. 33, 99–106.

Hovmand-Hansen, T., Jensen, T.B., Vestergaard, K., Nielsen, M.B.F., Leifsson, P.S., Jensen, H.E., 2021. Early risk factors, development, disappearance and contents of umbilical outpouching in Danish pigs. Livest. Sci. 251.

Johansen, M., Alban, L., Kjaersgard, H.D., Baekbo, P., 2004. Factors associated with suckling piglet average daily gain. Prev. Vet. Med. 63, 91–102.

Kaiser, M., Jacobsen, S., Andersen, P.H., Baekbo, P., Ceron, J.J., Dahl, J., Escribano, D., Theil, P.K., Jacobson, M., 2018. Hormonal and metabolic indicators before and after farrowing in sows affected with postpartum dysgalactia syndrome. BMC Vet. Res. 14.

King, R.L., Matheson, S.M., Baxter, E.M., Edwards, S.A., 2020. Sow behaviour and piglet weight gain after late cross-fostering in farrowing crates and pens. Animal 14, 1923–1933.

Lynegaard, J.C., Larsen, I., Hansen, C.F., Nielsen, J.P., Amdi, C., 2021. Performance and risk factors associated with first antibiotic treatment in two herds raising pigs without antibiotics. Porc. Health Manag. 7.

McBride, G., 1963. The "teat order" and communication in yound pigs. Anim. Behav.

McCaw, M.B., 2000. Effect of reducing crossfostering at birth on piglet mortality and performance during an acute outbreak of porcine reproductive and respiratory syndrome. J. Swine Health Prod. 8.

Norring, M., Valros, A., Munksgaard, L., Puumala, M., Kaustell, K.O., Saloniemi, H., 2006. The development of skin, claw and teat lesions in sows and piglets in farrowing crates with two concrete flooring materials. Acta Agric. Scand. Sect. A 56, 148–154.

Norval, A., 2021. The management of newborn piglets for the prevention of umbilical outpouching development. Faculty of Health and Medical Sciences. University of Copenhagen.

Pedersen, K.S., Toft, N., 2011. Intra- and inter-observer agreement when using a descriptive classification scale for clinical assessment of faecal consistency in growing pigs. Prev. Vet. Med. 98, 288–291.

Pluske, J.R., Hampson, D.J., Williams, I.H., 1997. Factors influencing the structure and function of the small intestine in the weaned pig: a review. Livest. Prod. Sci. 51, 215–236.

Postma, M., Vanderhaeghen, W., Sarrazin, S., Maes, D., Dewulf, J., 2017. Reducing antimicrobial usage in pig production without jeopardizing production parameters. Zoonoses Public Health 64, 63–74.

Proudfoot, K., Habing, G., 2015. Social stress as a cause of diseases in farm animals: Current knowledge and future directions. Vet. J. 206, 15–21.

Prunier, A., Heinonen, M., Quesnel, H., 2010. High physiological demands in intensively raised pigs: impact on health and welfare. Animal 4, 886–898.

RCoreTeam, 2019. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Robert, S., Martineau, G.P., 2001. Effects of repeated cross-fosterings on preweaning behavior and growth performance of piglets and on maternal behavior of sows. J. Anim. Sci. 78, 88–93.

Rutherford, K.M.D., Baxter, E.M., D'Eath, R.B., Turner, S.P., Arnott, G., Roehe, R., Ask, B., Sandoe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Berg, P., Lawrence, A. B., 2013. The welfare implications of large litter size in the domestic pig I: biological factors. Anim. Welf. 22, 199–218.

Schmitt, O., Baxter, E.M., Boyle, L.A., O'Driscoll, K., 2018. Nurse sow strategies in the domestic pig: II. Consequences for piglet growth, suckling behaviour and sow nursing behaviour. Animal 13, 590–599.

Searcybernal, R., Gardner, I.A., Hird, D.W., 1994. Effects of and factors associated with umbilical hernias in a swine herd. J. Am. Vet. Med. Assoc. 204, 1660–1664.

Sorensen, J.T., Rousing, T., Kudahl, A.B., Hansted, H.J., Pedersen, L.J., 2016. Do nurse sows and foster litters have impaired animal welfare? Results from a cross-sectional study in sow herds. Animal 10, 681–686.

Stege, H., Bager, F., Jacobsen, E., Thougaard, A., 2003. VETSTAT - the Danish system for surveillance of the veterinary use of drugs for production animals. Prev. Vet. Med. 57, 105–155.

Straw, B.E., Dewey, C.E., Biirgi, E.J., 1998. Patterns of crossfostering and piglet mortality on commercial U.S. and Canadian swine farms. Prev. Vet. Med. 33, 83–89.

Thomsson, A., 2008. Weaning of pigs. Effects of lectin exposure and weaning strategies on feeding behaviour, performance and health. Faculty of Landscape Planning, Horticulture and Agricultural Science Department of Rural Buildings and Animal Husbandry. Swedish University of Agricultural Sciences.

Yun, J., Olkkola, S., Hanninen, M.L., Oliviero, C., Heinonen, M., 2017. The effects of amoxicillin treatment of newborn piglets on the prevalence of hernias and abscesses, growth and ampicillin resistance of intestinal coliform bacteria in weaned pigs. PLoS One 12.