Universiteit
Antwerpen

This item is the archived peer-reviewed author-version of:

Piglet performance and colostrum intake in litters either or not split-suckled during the first day or during the first three days of life

Reference:
Vandaele M., Van Kerschaver C., Degroote J., van Ginneken Christa, Michiels J..- Piglet performance and colostrum intake in litters either or not split-suckled during the first day or during the first three days of life
Livestock science - ISSN 1871-1413 - 241(2020), 104265
Full text (Publisher's DOI): https://doi.org/10.1016/J.LIVSCI.2020.104265
To cite this reference: https://hdl.handle.net/10067/1746760151162165141

uantwerpen.be
Institutional repository IRUA

Piglet performance and colostrum intake in litters either or not split-suckled during the first day or during the first three days of life

M. Vandaele [a,*], C. Van Kerschaver [a], J. Degroote [a], C. Van Ginneken [b], J. Michiels [a],

[a] Laboratory for Animal Production and Animal Product Quality (LANUPRO), Department of Animal Sciences and Aquatic Ecology, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

[b] Laboratory of Applied Veterinary Morphology, Department of Veterinary Sciences, Faculty of Biomedical, Pharmaceutical and Veterinary Sciences, University of Antwerp, Wilrijk, Belgium

'Declarations of interest: none'

Abstract

The objective was to investigate the effect of split-suckling on the performance of piglets during the first three days of life. Split-suckling implies that not all piglets have access to the udder at all times; i.e. the litter is split-in two or more groups being nursed in alternating order, or only the heaviest piglets are enclosed temporarily; in order to benefit colostrum consumption and survival of disadvantaged neonates. The experiment included three treatments: no split-suckling (CON) (n=111), split-suckling was applied only in the first day of life (SS1d) (n=174), and split-suckling was applied during the first three days of life (SS3d) (n=184). Split-suckling involved alternated nursing of two groups every three hours in order to privilege nursing of the third group for 12 hours per day. The two groups which were removed from the sow included

* Corresponding author.

E-mail addresses: mario.vandaele@ugent.be (M. Vandaele), celine.vankerschaver@ugent.be (C. Van Kerschaver), jerdgroo.degroote@ugent.be (J. Degroote), joris.michiels@ugent.be (J. Michiels), chris.vanginneken@uantwerpen.be (C. Van Ginneken).

the heavier piglets either born in first part or second part of parturition. Group sizes of these two groups were equal and depended on the litter size and the criterion that at least 10 piglets remained with the sow during split-suckling. Split-suckling started after farrowing was completed. In total, 469 piglets from 28 litters were followed for colostrum intake, growth and mortality. Colostrum intake did not differ between treatments. However, colostrum intake of heavy piglets in SS1d and SS3d were lower when compared to CON ($P < 0.05$). Growth at 24h post-farrowing was lower in SS3d (51 ± 5 g) as compared to CON (82 ± 7 g) ($P = 0.001$), and intermediate in SS1d (65 ± 6 g). Further, growth at 72h post-farrowing was lower in SS3d (82 ± 4 g/d) as compared to CON (110 ± 6 g/d) and SS1d (101 ± 4 g/d) ($P < 0.001$). Thus, heavier piglets in SS1d were able to catch up growth loss, contracted during first day of life, by the third day of life. When piglets were split-suckled for three days, growth continued to be impaired. Furthermore, mortality at 72 h post-farrowing did not differ between treatments but was higher amongst the non-isolated piglets within SS3d compared to those within SS1d ($P = 0.007$). In conclusion, piglet performances were not improved nor impaired when split-suckling was applied during the first day of life. However and on the contrary, growth was impaired when litters were intensively split-suckled during first three days of life.

Keywords

Split-suckling, piglet, colostrum, mortality, growth

1. Introduction

Continued selection for hyper-prolificacy in sows has resulted in a tremendous increase in the number of live-born piglets (Kemp et al., 2018; Hansen, 2019). However, concomitantly the proportion of low birth weight piglets accrued. Thus, the farmer is facing challenges in rearing these light and disadvantaged piglets (Quiniou et al., 2002, Wolf et al., 2008), as well as supernumerary piglets (Baxter et al; 2013). Various management techniques are applied to cope with these difficulties. One particular technique is split-suckling (Michiels et al., 2013). Split-suckling implicates that not all piglets have access to the udder at all times; i.e. the litter is split in two or more groups being nursed in alternating order. Sometimes the litter is split into a group containing only the heaviest piglets which are enclosed temporarily leaving the – most often disadvantaged piglets - at the udder (Kyriazakis & Edwards, 1986; Donovan & Dritz, 2000; Alonso et al., 2012). Split-suckling is particularly recommended to safeguard sufficient colostrum intake in the first day of life, especially for small piglets and for surplus piglets when the number of live-born largely exceeds the number of functional teats (Baxter et al., 2013). In a survey among Flemish pig breeders in years 2013 (Michiels et al., 2013), 2015 and 2018 by our group (both unpublished data), it was found that only 19, 26, and 36% of farms applied split-suckling, respectively. Most of them focused on the first day of life in order to reduce competition amongst newborns whilst colostrum is freely available. However, there is no consensus on how to apply split-suckling, e.g. in terms of duration, which piglets to isolate, how many groups to make, which group sizes and when to start. It looks like every farmer applies split-suckling slightly different and that the work load is limiting the use of split-suckling. Studies often failed to reveal any convincing beneficial and cost-efficient outcomes of split-suckling (Kyriazakis & Edwards, 1986; Thorup, 2006; Dewey et al., 2008; Huser et al., 2015a; Muns et al., 2015) or described no distinct effect (Holyoake et al., 1995; Rosvold et al., 2017). Some researchers suggested that split-suckling may only be useful in large litters (Kyriazakis & Edwards, 1986). Nonetheless, a decreased variation in growth until weaning was suggested by Donovan & Dritz (2000) in litters of 9 piglets or more. Furthermore, higher serum IgG-concentrations were observed by Vallet et al. (2013) in low birth weight piglets and by Alonso et al. (2012) in piglets of primiparous sows compared to those of multiparous sows within the split-suckling treatment. Very promising results were reported in two recent studies:

increased neonatal growth (Morton et al., 2017) and reduced mortality (Huser et al., 2015b) of small piglets when applying split-suckling by isolating heavier piglets. The latter observation is interesting since the major proportion of piglet mortality during the nursery period occurs in the first days of life and is highest among the smaller piglets within the litter (Quiniou et al., 2002). Moreover, some other authors (Holyoake et al., 1995; Galiot et al., 2018) identified the first three days of life as most critical. Safeguarding colostrum intake of vulnerable piglets in their first day of life, and even milk later on, can reinforce their likelihood of survival since energy supply is life-determining in first days of life, in particular for low birth weight piglets, rather than the transfer of passive immunity which is determinant on the longer term (Theil et al., 2014b). However, these studies did use different modes of split-suckling making it difficult to compare or to conclude on the best technique. Thus, more studies are necessary in which different set-ups for split-suckling are compared.

Therefore, the objective of the current study was to investigate the time span in which split-suckling needs to be applied in order to reduce piglet mortality. The study was conducted on a commercial Flemish sow farm with the preconceived hypothesis that the growth performances and likelihood of survival in piglets is enhanced through split-suckling of the litter either in the first day of life or during the first three days of life.

2. Materials & Methods

2.1. Animals and handling

The study was conducted in one farrowing group at a Flemish commercial farm (Zele, Belgium). The sows were managed by a four-week-batch-system and housed in conventional farrowing crates accommodated with floor heating and infrared lamps for newborn piglets. In the study, 30 sows were randomly selected from a larger population based on the date of partus, in order to limit the differences in partus dates to three days. No parturition induction was applied. Piglets were cross-bred of Topigs-20 sows and Piétrain boars. Parturitions were continuously supervised and manual birth assistance was carried out to maximize number of live-born piglets. If necessary, 1 ml of oxytocin (Carbetocin and Chlorobutanol hemihydrate, LongActon 0.07 mg/ml, Vetoquinol SA, France) was administered intramuscularly, but only after checking for an obstruction-free birth canal (Cowart, 2007), to sows with contraction weakness.

Immediately after birth the umbilical cord was shortened to maximally 15 cm (Decaluwé et al., 2014) and disinfected. Subsequently, the newborn was ear tagged and birth weight was determined. Thereafter, the newborn was placed back in farrowing pen on the heated floor scattered with lime powder under an infrared lamp (Pederson et al., 2016). Post-parturient management routines were limited to the administration of 1 ml iron intramuscularly (Fe^{3+} hydroxide dextran; Uniferon 200 mg/ml, MSD Animal Health BVBA, Belgium) and 0.4 ml/kg body weight of an oral antiparasitic (toltrazuril; Dozuril 50 mg/ml, Dopharma, Belgium).

Sow health was monitored and abnormalities were noted as well as medication use.

2.2. Experimental design and treatments

The experiment included three treatments: a control (CON), as well as two split-suckling treatments, whereby split-suckling was applied either during the first day of life only (SS1d) or during the first three days of life (SS3d). Litters were split into three groups: a group composed of heavier birth weight piglets born in the first part of parturition (SSG1), a second group of heavier birth weight piglets, but born in the second part of parturition (SSG2) and a group of the remaining piglets (which have lower birth weights) (SSG3) (Fig. 1). Only piglets without abnormalities such as splay leg and difficulties to breath were eligible for isolation (Devillers et al., 2007). Further, udder occupancy during split-suckling was at all times a minimum of 10 littermates in order to maintain galactopoiesis (Farmer et al., 2006) and to preserve lactogenesis

(Theil et al., 2006). Considering this and combined with litter size, the number of piglets in SSG1 and SSG2 was determined and kept equal. In this way udder occupancy was fixed during the 12 hours of split-suckling. Split-suckling was initiated by isolating SSG1 when parturition was completed. The end of parturition was defined as birth moment of last-born piglet. Piglets were separated by placing a bottomless box in the farrowing pen on the heated floor and under infrared lamp to avoid hypothermia (Kirkden et al., 2014; Pederson et al., 2016). After three hours, these piglets were reunited with the sow and at the same time SSG2 was isolated for three hours. In this way, it was aimed to ensure passive immunity through colostrum intake of piglets with high birth rank number (Le Dividich et al., 2005b). This procedure was repeated resulting in a total of 12 hours of split-suckling to privilege colostrum intake of low birth weight piglets (SSG3). Thus, piglets in SSG3 had at all times access to the dam whilst piglets in SSG1 and SSG2 were isolated for a total duration of 6 hours per day (Fig. 2). This split-suckling mode was repeated in the second and third day of life for litters in treatment SS3d. Cross-fostering was not allowed during the first three days of life. Treatments were allocated to sows to balance for parity and the number of live-born piglets.

2.3. Measurements and calculations

At farrowing, ear tag number, time of birth, birth rank number, gender and birth weight were recorded for all piglets (dead and live-born). Furthermore, sow parity and number of functional teats were listed. Gestation length was determined as the number of days from artificial insemination until parturition. Litter heterogeneity, expressed in percentages, was defined the variation coefficient of piglet birth weights within a litter. Udder occupancy, also expressed in percentages, was calculated as the number of live-born piglets divided by the number of functional teats. Udder occupancy during split-suckling was defined as the number of live-born piglets that had access to their mother compared to the number of functional teats. Colostrum intake of piglets alive 24 hours after the first-born piglet (T_{24}) (Theil et al., 2014a; Declerck et al., 2017) was estimated by the model of Theil et al. (2014a):

$$CI = -106 + 2.26\,WG + 200\,BW_b + 0.111\,D - 1{,}414\,WG/D + 0.0182\,WG/BW_b.$$

Hereby colostrum intake (CI) and weight gain (WG) were expressed in grams, birth weight (BW_b) in kilograms whilst duration of colostrum intake (D) in minutes. The accuracy of the weight scale was 0.001 kg. A negative CI was assumed to be 0 (Devillers et al., 2007). Colostrum production of the sow was calculated as the sum of the individual colostrum intakes of each piglet within the litter (Theil et al., 2014a).

To determine growth performances, piglets were weighed 72 hours after the first-born piglet (T_{72}). Daily gain was calculated based on the differences with birth weight. In addition, piglet mortality was monitored until T_{72}. Stillborn piglets were defined as a piglet with no signs of decay and found dead behind the sow (Declerck et al. 2015). Mortality percentage in first three days of life was determined as the number of deceased piglets versus the number of live-born piglets.

2.4. Statistical analysis

Measurements and calculations were gathered into two datasets, i.e. on piglet level and on sow level, to process statistically using IBM SPSS Statistics 25. From these datasets one litter was excluded since the sow endured severe mastitis. A second litter was excluded in order to uniform the distribution of sow parity and number of live-born piglets between treatments. In total 469 live-born piglets from 28 litters were included in this study: 111 piglets in CON, 174 piglets in SS1d and 184 piglets in SS3d. To check for normality and homoscedasticity the Kolmogorov-Smirnov and Levene's test were applied, respectively. On piglet level, continuous variables comprised birth weight, weight gain (growth) at T_{24}, colostrum intake and daily growth at T_{72}. When normality and homoscedasticity were confirmed, these variables were subjected to GLM-analysis and means were separated by the Bonferroni post-hoc test, if appropriate. GLM-analysis included treatment as fixed factor and sow as random factor nested within treatment. If only normality was met, a Welch-test was performed and subsequently a Dunnett's C post-hoc test to distinguish means, if appropriate. Otherwise the non-parametric Kruskal-Wallis test was employed. The nominal variable mortality at T_{72} was subjected to a Kaplan-Meier survival analysis with Log-rank Chi-square test. Means of piglet variables are given either for all piglets, or separated into quartiles, based on their birth weight. Quartile 1 was characterized by 25% of the piglets with lowest birth weights within each litter, whereas quartile 4 was characterized by 25% of the piglets with highest birth weights within each litter. Accordingly, intermediary birth weights were classified in quartile 2 and 3. Similarly, data of SSG1, SSG2 and SSG3 were analysed between the split-suckling treatments. On sow level, parametric data were analysed through a GLM-procedure with only treatment as fixed factor and means were separated by the Bonferroni post-hoc test, if appropriate. If non-parametric, similarly, a Welch test was carried out when homoscedasticity was not confirmed, otherwise a Kruskal-Wallis test was chosen.

3. Results

3.1. Sow and litter characteristics

Average parity did not differ between treatments (Table 1). However, gestation length was shorter in SS1d (113.1 ± 0.3 days) than SS3d (115.1 ± 0.4 days) ($P = 0.001$), and intermediate for CON (114.3 ± 0.4 days). Litter size at birth was higher in SS3d (18.4 ± 0.7) as compared to SS1d (15.8 ± 0.7) ($P = 0.018$) and tended to be higher than CON (15.9 ± 0.9) ($0.05 < P < 0.10$). Sows had on average 15.0 ± 0.4, 14.7 ± 0.3 and 14.4 ± 0.5 functional teats in treatments CON, SS1d and SS3d ($P = 0.642$), respectively. In addition, at the end of parturition and prior to split-suckling, udder occupancy was 107.1 ± 10.4 % in CON, 107.4 ± 3.8 % in SS1d and 129.8 ± 7.4

% in SS3d (P = 0.062). Litter birth weight in SS3d was 36.4% and 21.1% higher than CON and SS1d, respectively (P < 0.001).

3.2. Split-suckling characteristics

During split-suckling on average 4.0 piglets were isolated in SS1d (i.e. group size of SSG1 and SSG2 in SS1d), whilst this number mounted to 5.8-5.9 in SS3d (i.e. group size of SSG1 and SSG2 in SS3d) (SEM = 0.3; P = 0.002) (Table 1). Piglets from SSG1 and SSG2 were isolated consecutively. Consequently, 7.8 and 6.7 piglets were allowed to suckle continuously (i.e. group size of SSG3) in treatment SS1d and SS3d, respectively (SEM = 0.4; P = 0.172). In this way the number of piglets with access to the udder during split-suckling was at least 10: either the number of piglets in SSG3 added with those of SSG2 or the number of piglets in SSG3 added with those of SSG1. Udder occupancy rate during split-suckling established in SS1d (80.3 ± 2.8 %) and SS3d (88.3 ± 5.1 %) tended to be lower as compared to CON (107.1 ± 10.4 %) (0.05 < P < 0.10).

3.3. Colostrum intake

Colostrum intake was 384 ± 12, 383 ± 10 and 377 ± 9 g per piglet in CON, SS1d and SS3d, respectively (P = 0.857) (Table 2). Estimations for colostrum intake of piglets in quartile 1 were not different between treatments: 236 ± 17 (CON), 266 ± 15 (SS1d) and 274 ± 13 (SS3d) g (P = 0.200). When considering piglets in quartile 3, colostrum intake was lower in SS1d (398 ± 11 g) and SS3d (393 ± 11 g) as compared to CON (445 ± 14 g) (P = 0.008). Colostrum intake in quartile 4 of SS1d (497 ± 12 g) was higher than SS3d (456 ± 12 g) (P = 0.046), but not different from CON (490 ± 15 g).

3.4. Piglet birth weight, growth and mortality

In general, piglets were born lighter in CON (1.038 ± 0.023 kg) than in SS1d (1.162 ± 0.022 kg) and SS3d (1.220 ± 0.023 kg) ($P < 0.001$) (Table 3) (Fig. 1). Evidently, this observation was also noticed when considering the different quartile classes for birth weight. During the first day of life, weight gain was significantly lower in treatment SS3d (51 ± 5 g) when comparing to CON (82 ± 7 g) ($P = 0.001$). SS1d had an intermediate gain of 65 ± 6 g. Weight gain in the first day of life was smaller for quartile 3 in both split-suckling treatments ($P < 0.001$) and for quartile 4 in SS3d ($P < 0.001$) compared to CON. Furthermore, daily weight gain until T_{72} was lower for piglets in SS3d (82 ± 4 g/d) than SS1d (101 ± 4 g/d) and CON (110 ± 6 g/d) ($P < 0.001$). On the other hand, growth rates at T_{72} for piglets classified in quartile 1 were 62 ± 7 g/d and 67 ± 8 g/d in SS1d and SS3d, respectively, but only 56 ± 10 g/d in CON ($P = 0.667$). Mortality rates did not differ between treatments ($P = 0.189$). However, mortality at T_{72} seemed to be substantially lower in SS1d (11.5 ± 2.4 %) compared to CON (14.4 ± 3.3 %) and SS3d (18.5 ± 2.9 %) ($P = 0.189$).

Daily growth at T_{72} of non-isolated piglets, thus piglets allocated to group SSG3, did not differ ($P = 0.568$) from split-suckled litters of SS1d and SS3d being 78 ± 6 g and 72 ± 9 g, respectively (Table 3). However, isolated piglets allocated to SSG1 and SSG2 grew slower in litters split-suckled during three consecutive days (86 ± 6 and 84 ± 7 g, respectively) compared to litters split-suckled only the first day of life (123 ± 7 and 113 ± 8 g, respectively) ($P < 0.001$ and $P = 0.004$, respectively). In addition, mortality was higher ($P = 0.007$) for SSG3 in SS3d (41.8 ± 6.0 %) compared to SS1d (20.9 ± 4.4%). In accordance, 28 out of 67 piglets died in SSG3 within SS3d whereas 18 out of 86 piglets died in SSG3 within SS1d during the first three days of life. From these deaths in SSG3, 11 piglets died in each split-suckling treatment within their first day of life.

5. Discussion

In general, results show that piglet weight gain in first day of life was impaired in split-suckled litters. Moreover, and in contrast to the perceived major advantage of split-suckling, small piglets were unable to increase their colostrum intake despite having more access to the udder during split-suckling. In consequence, the weight gain at T_{24} and at T_{72} of these piglets did not improve nor did their mortality rates drop. Importantly, weight gain of piglets isolated during split-suckling was negatively affected. When split-suckling only lasted one day, heavy piglets suffering from a growth check caught up in second and third day of life. Whether the piglets isolated for three days were able to catch up the loss in growth after the period of split-suckling is not known. Altogether, these findings reject the hypothesis that split-suckling improves the performances of – especially small - piglets. Reasons for this lack of benefits of split-suckling in this study might be various and are discussed hereafter.

5.1. Sow and litter characteristics

Sows were allocated to treatments with the objective to balance treatments for parity and number of live-born piglets. Unfortunately, we failed to balance the number of live-born piglets and hence some descriptive parameters were found different across treatments. It is likely that this affected the outcome of the study. For example, the combination of a heavier birth weight and higher number live-born piglets explained the higher litter birth weight of SS3d. Probably, these two factors influenced individual colostrum intake and hitherto sow colostrum yield, which was higher in SS3d. After all, birth weight contributes greatly to the calculation of colostrum intake (Theil et al., 2014a; Devillers et al., 2004), since it is positively correlated to colostrum consumption (Devillers et al., 2007). Additionally, lighter newborn piglets (<1 kg) have a lower likelihood to survive the first day of life (Quiniou et al., 2002), which makes it not so obvious to estimate their colostrum intake (Devillers et al., 2004, Devillers et al., 2007; Quesnel et al., 2011; Theil et al., 2014a; Declerck et al., 2015; Declerck et al., 2017). Not surprisingly, sows with high colostrum yield are those with a heavy litter at birth (Devillers et al., 2005; Vadmand et al., 2015), a higher litter birth weight when considering only piglets alive at the end of their first day of life (Declerck et al., 2015), or a high number of piglets born alive, or a large litter size at 24 h postpartum (Vadmand et al., 2015). Therefore, colostrum yield not only depends on the ability of the sow to produce colostrum for the whole litter, but also on the vitality of the litter (Devillers et al., 2007).

5.2. The effect of split-suckling on colostrum intake and growth performance during the first day of life

When considering all piglets, irrespective of quartile and isolation group, no differences between treatments for colostrum intake were observed. In contrast, differences in colostrum intake were present when piglets within a litter were classified in quartiles. Colostrum intake for quartile 3 in SS3d and SS1d was lower compared to CON whereas colostrum intake for quartile 4 did not differ between SS1d and CON, but was higher in SS1d compared to SS3d. The lower colostrum intake in these quartiles can be explained by the isolation of heavy birth weight piglets during split-suckling in first day of life. These heavy piglets were prevented to suckle twice for three hours which equals to 25% of their first day of life. The principal reason for split-suckling is to enhance colostrum intake by small piglets (Kyriazakis and Edwards, 1986), yet, this was not shown in this study. In quartile 1 and 2, colostrum intake did not differ between the treatments. However, the use of colostrum intake to determine the success of split-suckling is not straightforward. Differences in birth weight between treatments could have biased the effect of treatment on colostrum intake since birth weight is a determining factor in equations to estimate colostrum intake (Theil et al., 2014a). It is more appropriate to rely on direct measurements of colostrum intake or alternatively to use piglet weight measurements as a proxy for pig performances. Piglets in split-suckling treatments gained less weight in first day of life compared to CON. This can be explained by a combination of different factors. Firstly, the isolation of piglets during split-suckling. This is confirmed when considering the different quartile classes for weight gain in first day of life. Piglets with a heavy birth weight (quartile 3 and 4) were isolated and thus prevented to suckle causing a lower weight gain. Moreover, piglets in quartile 3 did not seem to benefit from a lower occupied udder during two times three hours within this split-suckling mode. Possibly, birth weight compared to birth weight of littermates (birth weight variation within the litter) might be more decisive to suckle successfully than a lower udder occupancy. In this respect, piglets in quartile 3 within CON had access to the udder at all times resulting in higher colostrum intakes. The latter also applies for the heaviest piglets – classified in quartile 4 – in CON. Yet, colostrum intake of these piglets was not different with those of SS1d. Maybe the heaviest piglets in SS1d – and supported by their higher birth weight compared to CON – were able to catch up their colostrum intake despite their isolation. If so, then the lower colostrum intake for quartile 4 within SS3d compared to SS1d could be influenced by the effect of litter size on colostrum intake as discussed hereafter. Secondly, the number of live-born piglets also impacted on growth performances. More piglets were isolated when litter size was larger. On average, one out of two piglets were isolated within each litter of SS1d whilst almost two out of three piglets were isolated within each litter of SS3d. Thus, the more piglets isolated within a litter, the bigger the detrimental effects of isolation on average weight gain. Moreover, weight gain at T_{24} is reduced in larger litters (Vasdal et al., 2011). Some researchers advocate that there is less colostrum available for each piglet when litter size increases (Le Dividich et al., 2005a; Devillers et al., 2007; Quesnel et al., 2011; Decaluwé et al., 2014). Thirdly, when focusing on the 25% smallest piglets (quartile 1) they did not gain more weight. Thus, the loss in weight gain of the isolated heavier piglets was not compensated by an increased growth of the non-isolated piglets, resulting in an overall (litter) reduced weight gain in the first day. Nevertheless, the result of even a small increase in weight gain for small piglets in split-suckling treatments should not be underrated. Piglets with a lower or negative percentage weight change in first day of life are more likely to die (Baxter et al., 2008). When piglets cannot meet their energy requirements, they may suffer from hypothermia (Herpin et al., 2002; Theil et al., 2014b), become less vigorous, and end up dying either because of starvation or because they are crushed by the sow (Theil et al., 2014b). Typically, small piglets are more predisposed due to the smaller energy reserves at birth (Herpin et al., 2002; Theil et al., 2011) and the greater heat loss due to the greater surface to body mass ratio (Herpin et al., 2002). To maintain homeothermic balance in the first day of life early colostrum intake is of utmost importance (Noblet et al., 1997; Herpin et al., 2002, Theil et al., 2014b). Small piglets experience more difficulties to reach and compete for a teat, to withdraw colostrum (De Pasille and Rushen, 1989; Le Dividich et al., 2005a; Declerck et al., 2017) and thus to cover their energy requirements. Increasing the suckling chances of these small piglets through split-suckling could thus improve their survival. Unfortunately, in this trial, colostrum intake nor weight gain in first day of life and in consequence survival was increased in small piglets.

5.3. The effect of split-suckling on growth and mortality during the first three days of life

In contrast to SS3d, the isolated piglets in SS1d caught up for the growth loss of first day of life in the second and third day of life. Apparently, these piglets experience little harm of a restricted colostrum intake and are able to claim and withdraw sufficient milk in the second and third day of life. This probably also explains why no negative effect on their survival in the first three days of life is observed. Similar, Thorup (2006) observed no increased mortality in the heaviest piglets when isolating or cross-fostering them for four hours starting approximately six hours after farrowing was completed. These findings are in line with the fact that heavy birth weight piglets have better chances for survival until weaning (Quiniou et al., 2002). Moreover, it contributes to the observation that heavy birth weight piglets are less dependent on colostrum to ensure good survival chances (Ferrari et al., 2014). In addition, this study indicated that safeguarding colostrum intake is crucial for low birth weight piglets. In our set-up, no effect on colostrum intake, no effect on growth and on mortality rates in piglets with lower birth weights were observed. However, when comparing the split-suckling treatments, mortality rates in non-isolated piglets were higher in SS3d than in SS1d. In contrast, Huser et al. (2014 & 2015b) reported an increased survival of 13% for small piglets (<0.85 kg) at weaning (24 ± 6 days) when heavy birth weight piglets were isolated during two hours split-suckling in the first day of life. Holyoake et al. (1995) reported also a decrease in mortality (of low viability piglets) at an average weaning age of 21 days. Yet, a distinct effect of split-suckling, in this study of Holyoka et al., is absent since supervised litters were subjected to several interventions. Moreover, split-suckling was only applied as alternative for cross-fostering to rear litters of 12 piglets or more during the supervised period. Overall, one should be cautious since other, than split-suckling, factors could have had an influence on mortality. In particular, birth weight is a determining factor for growth and mortality (Quiniou et al., 2002, Galiot et al., 2018), especially in large litters where small piglets endure more competitiveness for a teat (Vasdal et al., 2011). As mentioned before, birth weight and litter size were not in balance between treatments. Therefore it remains uncertain if split-suckling improved survival of small piglets in the current study.

5.4. Added value of split-suckling until three days of life on performance and mortality

At the end of the third day of life we saw a negative effect on daily weight gain in the litters which were split-suckled during three consecutive days. As observed in the case of split-suckling for one day, growth of the heavier piglets in SS3d was impaired due to restricted suckling. This reduced growth in the isolated piglets, is only justified if those piglets can catch up their growth loss or if the performance of the non-isolated, underprivileged littermates is enhanced. This better performance includes a reduced pre-weaning mortality and thus split-suckling could have an ethical benefit (Rutherford et al., 2011). Unfortunately, and in contrast to the perceived advantage of split-suckling, no increase in the performance (growth and survival) of small piglets was observed during the first three days. Mortality was even more pronounced in the non-isolated piglets (smaller piglets, SSG3) of SS3d compared to SSG3 in SS1d. Clearly, mortality was situated among the small piglets despite efforts to stimulate their suckling chances through split-suckling during 12 hours each day. It is hard to interpret and clarify this. According to Rutherford et al. (2013) and Hales et al. (2013) litter size is a main determinant for postnatal survivability. In addition, Vasdal et al. (2011) reported an overall higher postnatal mortality in larger litters regardless of colostrum and milk intake. Deen and Bilkei (2004) concluded that low birth weight piglets have the highest chances to survive in small litters irrespective of birthweight of their littermates. Thus, presumably the high mortality in SS3d is then caused by the higher number of live-born piglets, in combination with the prohibition of cross-fostering in the three first days of life. Further, udder occupancy and thus teat competition is bigger in large litters (Milligan et al., 2001). Competition still occurred during the periods that split-suckling was not in place, or eventually additional stress at moments when isolated piglets are reintroduced in the litter may have taken place. At moments all piglets are in the litter (12 h per day), low birth weight piglets may dedicate more time in teat disputes and miss more nursing episodes (Deen & Bilkei, 2004). In an attempt to increase their milk intake, piglets then spent more time in close proximity to the sow which increases the probability of being crushed (Weary et al., 1996). Moreover, isolated piglets seemed to show the same riskful behaviour when they were prevented to nurse during several nursing bouts (Weary et al., 1996). This observation could explain the somewhat lowered survival of isolated piglets, i.e. SSG2, in SS3d. Notwithstanding no beneficial effect was observed, split-suckling of large litters in first day of life might still be recommended. Afterwards, and if possible, it is suggested to cross-foster at the end of the first day of life, especially when surplus piglets are present (Baxter et al., 2013; Kirkden et al., 2014). However in case no sows to cross-foster are available, prolonged split-suckling until third day of life might still be worthwhile. Because of the potential detrimental effects on growth when piglets are isolated for a longer period – and since milk replacer is mainly consumed by the heavier piglets within the litter (Kobek-Kjeldager et al., 2020) – offering milk replacer to isolated piglets could be recommended. Results from the current study point out that split-suckling for one day is not having a negative effect. In order to increase the benefit of split-suckling (for a day), other aspects should be considered and need further optimization: for example how long to apply split-suckling, when to start with, how many piglets to isolate or how many groups to form in a litter.

Conclusion

In conclusion the labour-intensive split-suckling approach did not result in beneficial effects in terms of improved growth and reduced mortality of piglets when applied for one day, rather it decreased growth when applied for three consecutive days. This urges for a less intensive approach of split-suckling. However, cautious interpretation of the study results is needed, since other factors than treatment could have confounded the outcome. Therefore, more emphasis should be on litter size and birth weight when allocating the experimental units to treatment in future research.

Acknowledgment

The authors wish to thank the sow farmer sincerely for granting access to the farrowing facilities to complete this study. The authors acknowledge the Flanders Innovation & Entrepreneurship Agency (VLAIO) [HBC.2016.0786], Flanders, Belgium, for their support.

References

Alonso, V., Rocco, V.V.B., Galdeano, J.V.B., Santana, R.S., Molero, A.H.T., Oliveira, M.C.d., 2012. Split-suckling in relation to the parturition order of sows. Rev. Bras. Zootec. 41, 221-224. http://dx.doi.org/10.1590/S1516-35982012000100031

Baxter, E., Jarvis, S., D'Eath, R., Ross, D., Robson, S., Farish, M., Nevison, I., Lawrence, A., Edwards, S., 2008. Investigating the behavioural and physiological indicators of neonatal survival in pigs. Theriogenology 69, 773-783. https://doi.org/10.1016/j.theriogenology.2007.12.007

Baxter, E., Rutherford, K., D'Eath, R., Arnott, G., Turner, S., Sandøe, P., Moustsen, V., Thorup, F., Edwards, S., Lawrence, A., 2013. The welfare implications of large litter size in the domestic pig II: management factors. Anim. Welfare 22, 219-238. https://doi.org/10.7120/09627286.22.2.219

Cowart, R.P., 2007. Parturition and dystocia in swine, in: Youngquist, R.S., Threlfall, W.R. (Eds), Current Therapy in Large Animal Theriogenology (Second Edition). Elsevier Inc., St. Louis, pp. 778-784. https://doi.org/10.1016/B978-072169323-1.50106-9

Decaluwé, R., Maes, D., Wuyts, B., Cools, A., Piepers, S., Janssens, G.P.J., 2014. Piglets′ colostrum intake associates with daily weight gain and survival until weaning. Livest. Sci. 162, 185-192. https://doi.org/10.1016/j.livsci.2014.01.024

Declerck, I., Dewulf, J., Piepers, S., Decaluwé, R., Maes, D., 2015. Sow and litter factors influencing colostrum yield and nutritional composition. J. Anim. Sci. 93, 1309-1317. https://doi.org/10.2527/jas.2014-8282

Declerck, I., Sarrazin, S., Dewulf, J., Maes, D., 2017. Sow and piglet factors determining variation of colostrum intake between and within litters. Animal 11, 1336-1343. https://doi.org/10.1017/S1751731117000131

Deen, M.G.H., Bilkei, G., 2004. Cross fostering of low-birthweight piglets. Livest. Prod. Sci. 90, 279-284. https://doi.org/10.1016/j.livprodsci.2004.02.012

De Passille, A.M.B., Rushen, J., 1989. Suckling and teat disputes by neonatal piglets. Appl. Anim. Behav. Sci. 22, 23-38. https://doi.org/10.1016/0168-1591(89)90077-4

Devillers, N., Farmer, C., Le Dividich, J., Prunier, A., 2007. Variability of colostrum yield and colostrum intake in pigs. Animal 1, 1033-1041. https://doi.org/10.1017/S175173110700016X

Devillers, N., Le Dividich, J., Farmer, C., Mounier, A., Lefèbvre, M., Prunier, A., 2005. Origine et conséquences de la variabilité de la production de colostrum par la truie et de la consommation de colostrum par les porcelets. Journées de la Recherche Porcine en France 37, 435.

Devillers, N., Van Milgen, J., Prunier, A., Le Dividich, J., 2004. Estimation of colostrum intake in the neonatal pig. Anim. Sci. 78, 305-313. https://doi.org/10.1017/S1357729800054096

Dewey, C.E., Gomes, T., Richardson, K., 2008. Field trial to determine the impact of providing additional care to litters on weaning weight of pigs. Can. J. Vet. Res. 72, 390-395.

Donovan, T.S., Dritz, S.S., 2000. Effect of split-nursing on variation in pig growth from birth to weaning. J. Am. Vet. Med. Assoc. 217, 79-81. https://doi.org/10.2460/javma.2000.217.79

Farmer, C., Devillers, N., Rooke, J.A., Dividich, J.L., 2006. Colostrum production in swine: from the mammary glands to the piglets. CAB Reviews. doi: 10.1079/PAVSNNR20061003

Ferrari, C.V., Sbardella, P.E., Bernardi, M.L., Coutinho, M.L., Vaz Jr, I.S., Wentz, I., Bortolozzo, F.P., 2014. Effect of birth weight and colostrum intake on mortality and performance of piglets after cross-fostering in sows of different parities. Prev. Vet. Med. 114, 259-266. https://doi.org/10.1016/j.prevetmed.2014.02.013

Galiot, L., Lachance, I., Laforest, J.-P., Guay, F., 2018. Modelling piglet growth and mortality on commercial hog farms using variables describing individual animals, litters, sows and management factors. Anim. Reprod. Sci. 188, 57-65. https://doi.org/10.1016/j.anireprosci.2017.11.009

Hales, J., Moustsen, V.A., Nielsen, M.B.F., Hansen, C.F., 2013. Individual physical characteristics of neonatal piglets affect preweaning survival of piglets born in a noncrated system. J. Anim. Sci. 91, 4991-5003. 4991-5003. https://doi.org/10.2527/jas.2012-5740

Hansen, C., 2019. National Average for Pig Production in 2018 [In Danish: Landsgennemsnit for Producktionen af grise i 2018]. Report no. 1920. SEGES Danish Pig Research Centre, Axelborg, Copenhagen, Denmark.

Herpin, P., Damon, M., Le Dividich, J., 2002. Development of thermoregulation and neonatal survival in pigs. Livest. Prod. Sci. 78, 25-45. https://doi.org/10.1016/S0301-6226(02)00183-5

Holyoake, P.K., Dial, G.D., Trigg, T., King, V.L., 1995. Reducing pig mortality through supervision during the perinatal period. J. Anim. Sci. 73, 3543-3551. https://doi.org/10.2527/1995.73123543x

Huser, J. S., 2014. Improving neonatal piglet survival by alternative management techniques Dissertation, The University of Adelaide.

Huser, J.S., Plush, K.J., Pitchford, W.S., Kennett, T.E., Lines, D.S., 2015a. Neonatal split-suckling has no impact on pre-and post-weaning piglet growth. Anim. Prod. Sci. 55, 1482-1482. https://doi.org/10.1071/ANv55n12Ab080

Huser, J.S., Plush, K.J., Pitchford, W.S., Kennett, T.E., Lines, D.S., 2015b. Neonatal split-suckling improves survival of small piglets. Anim. Prod. Sci. 55, 1477-1477. https://doi.org/10.1071/ANv55n12Ab079

Kemp, B., Da Silva, C.L.A., Soede, N.M., 2018. Recent advances in pig reproduction: Focus on impact of genetic selection for female fertility. Reprod Dom. Anim. 53, 28-36. https://doi.org//10.1111/rda.13264

Kirkden, R.D., Broom, D.M., Andersen, I.L., 2014. Invited review: piglet mortality: management solutions. J. Anim. Sci. 91, 3361-3389. https://doi.org/10.2527/jas.2012-5637

Kobek-Kjeldager, C., Moustsen, V.A., Theil, P.K., Pedersen, L.J., 2020. Effect of large litter size and within-litter differences in piglet weight on the use of milk replacer in litters from hyper-prolific sows under two housing conditions. Appl. Anim. Behav. Sci. 230, 105046. https://doi.org/10.1016/j.applanim.2020.105046

Kyriazakis, I., Edwards, S.A., 1986. The effect of "split-suckling" on behaviour and performance of piglets. Appl. Anim. Behav. Sci. 16, 92. https://doi.org/10.1016/0168-1591(86)90045-6

Le Dividich, J., Rooke, J.A. , Herpin, P., 2005a. Nutritional and immunological importance of colostrum for the new-born pig. J. Agr. Sci. 143, 469-485. https://doi.org/10.1017/S0021859605005642

Le Dividich, J., Thomas, F., Renoult, H., Oswald, I., 2005b. Acquisition de l'immunité passive chez le porcelet: rôle de la quantité d'immunoglobulines ingérées et de la perméabilité intestinale, in: Proceedings des 37èmes Journées de la Recherche Porcine, (pp. 443-448).

Presented at 37. Journées de la Recherche Porcine, Paris, FRA (2005-02-01 – 2005-02-03). Paris, FRA : ITP. https://prodinra.inra.fr/record/16870

Michiels, J., Vandenberghe, H., Vangansbeke, S., Degroote, J., Fremaut, D., Ampe, B., 2013. Handling of supernumerary piglets in Flanders, a survey among pig breeders, in: Book of abstracts of the 64th annual meeting of the European Federation of Animal Science (Vol. 19, pp. 399-399) Wageningen, The Netherlands: Wageningen Academic Publishers. http://hdl.handle.net/1854/LU-8610032

Milligan, B.N., Fraser, D., Kramer, D.L., 2001. Birth weight variation in the domestic pig: effects on offspring survival, weight gain and suckling behaviour. Appl. Anim. Behav. Sci. 73, 179-191. https://doi.org/10.1016/S0168-1591(01)00136-8

Morton, J., Langemeier, A., Rathbun, T., Davis, D., 2017. Split-Suckling, Birth Order, and Birth Weight Affects Colostrum Intake and Pre-Weaning Weight Gain. Kansas Agricultural Experiment Station Research Reports 3, 7. https://doi.org/10.4148/2378-5977.7460

Muns, R., Manteca, X., Gasa, J., 2015. Effect of different management techniques to enhance colostrum intake on piglets' growth and mortality. Anim. Welfare 24, 185-192. https://doi.org/10.7120/09627286.24.2.185

Noblet, J., Dourmad, J.Y., Etienne, M., Le Dividich, J., 1997. Energy metabolism in pregnant sows and newborn pigs. J. Anim. Sci. 75, 2708-2714. https://doi.org/10.2527/1997.75102708x

Pedersen, L.J., Larsen, M.L.V., Malmkvist, J., 2016. The ability of different thermal aids to reduce hypothermia in neonatal piglets. J. Anim. Sci. 94, 2151-2159. https://doi.org/10.2527/jas.2015-0219

Quesnel, H., 2011. Colostrum production by sows: variability of colostrum yield and immunoglobulin G concentrations. Animal 5, 1546-1553. https://doi.org/10.1017/S175173111100070X

Quiniou, N., Dagorn, J., Gaudré, D., 2002. Variation of piglets' birth weight and consequences on subsequent performance. Livest. Prod. Sci. 78, 63-70. https://doi.org/10.1016/S0301-6226(02)00181-1

Rosvold, E.M., Kielland, C., Ocepek, M., Framstad, T., Fredriksen, B., Andersen-Ranberg, I., Næss, G., Andersen, I.L., 2017. Management routines influencing piglet survival in loose-housed sow herds. Livest. Sci. 196, 1-6. https://doi.org/10.1016/j.livsci.2016.12.001

Rutherford, K.M.D., Baxter, E.M., D'Eath, R.B., Turner, S.P., Arnott, G., Roehe, R., Ask, B., Sandøe, 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. Welfare 22, 199-218. https://doi.org/10.7120/09627286.22.2.199

Rutherford, K.M.D., Baxter, E.M., Ask, B., Berg, P., D'Eath, R.B., Jarvis, S., Jensen, K.K., Lawrence, A.B., Moustsen, V.A., Robson, S.K., Thorup, F., Turner, S.P., Sandøe, P., 2011. The ethical and welfare implications of large litter size in the domestic pig: challenges and solutions. Danish Centre for Bioethics and Risk Assessment (CeBRA). Project report, No. 17

Theil, P.K., Cordero, G., Henckel, P., Puggaard, L., Oksbjerg, N., Sørensen, M.T., 2011. Effects of gestation and transition diets, piglet birth weight, and fasting time on depletion of glycogen pools in liver and 3 muscles of newborn piglets. J. Anim. Sci. 89, 1805-1816. https://doi.org/10.2527/jas.2010-2856

Theil, P.K., Flummer, C., Hurley, W.L., Kristensen, N.B., Labouriau, R.L., Sørensen, M.T., 2014a. Mechanistic model to predict colostrum intake based on deuterium oxide dilution technique data and impact of gestation and prefarrowing diets on piglet intake and sow yield of colostrum. J. Anim. Sci. 92, 5507-5519. https://doi.org/10.2527/jas.2014-7841

Theil, P.K., Lauridsen, C., Quesnel, H., 2014b. Neonatal piglet survival: impact of sow nutrition around parturition on fetal glycogen deposition and production and composition of colostrum and transient milk. Animal 8, 1021-1030. https://doi.org/10.1017/S1751731114000950

Theil, P.K., Sejrsen, K., Hurley, W.L., Labouriau, R., Thomsen, B., Sørensen, M.T., 2006. Role of suckling in regulating cell turnover and onset and maintenance of lactation in individual mammary glands of sows. J. Anim. Sci. 84, 1691-1698. https://doi.org/10.2527/jas.2005-518

Thorup, F., 2006. Ensuring colostrum to the smallest piglets. The National Committee for Pig Production, Danish Bacon & Meat Council. February, 14. Report no. 736.

Vadmand, C.N., Krogh, U., Hansen, C.F., Theil, P.K., 2015. Impact of sow and litter characteristics on colostrum yield, time for onset of lactation, and milk yield of sows. J. Anim. Sci. 93, 2488-2500. https://doi.org/10.2527/jas.2014-8659

Vallet, J.L., Miles, J.R., Rempel, L.A., 2013. A simple novel measure of passive transfer of maternal immunoglobulin is predictive of preweaning mortality in piglets. Vet. J. 195, 91-97. https://dx.doi.org/10.1016/j.tvjl.2012.06.009

Vasdal, G., Østensen, I., Melišová, M., Bozděchová, B., Illmann, G., Andersen, I.L., 2011. Management routines at the time of farrowing—effects on teat success and postnatal piglet mortality from loose housed sows. Livest. Sci. 136, 225-231. https://doi.org/10.1016/j.livsci.2010.09.012

Weary, D.M., Pajor, E.A., Thompson, B.K., Fraser, D., 1996. Risky behaviour by piglets: a trade off between feeding and risk of mortality by maternal crushing? Anim. Behav. 51, 619-624. https://doi.org/10.1006/anbe.1996.0066

Wolf, J., Žáková, E., Groeneveld, E., 2008. Within-litter variation of birth weight in hyperprolific Czech Large White sows and its relation to litter size traits, stillborn piglets and losses until weaning. Livest. Sci. 115, 195-205. https://doi.org/10.1016/j.livsci.2007.07.009

Fig. 1: Graph A: cumulative birth weight distribution for CON (no split-suckling), SS1d (split-suckling in first day of life) and SS3d (split-suckling in first three days of life). Graph B: cumulative birth weight of SSG1 (heavier piglets born in first part of parturition and isolated during split-suckling), SSG2 (heavier piglets born in second part of parturition and isolated during split-suckling) and SSG3 (non-isolated piglets) within SS1d and SS3d.

Fig. 2: Split-suckling started after the end of parturition by isolating SSG1 (= the heavier piglets born in first half of parturition, marked green – thin black line) in a bottomless box on heated floor and under infrared lamp. After 3 hours SSG1 was reunited with the sow and SSG2 (= the heavier piglets born in second half of parturition, marked blue) were isolated. This isolation cycle was repeated, resulting in less competitive suckling for SSG3 piglets (= non-isolated piglets, not marked) during 12 hours.

Table 1: Sow and litter characteristics for the different treatments: control (CON), split-suckling in first day of life (SS1d) and split-suckling during three first days of life (SS3)

	Treatment			SEM	P-value
	CON	SS1d	SS3d		
Parity	4.14	4.45	4.20	0.27	0.962
Gestation length (days)	114.3[ab]	113.1[a]	115.1[b]	0.3	0.001
Number of live-born piglets	15.9[ab]	15.8[a]	18.4[b]	0.4	0.018
Number of stillborn piglets	1.1	2.1	0.7	0.3	0.112
Litter birth weight (kg)	16.5[a]	18.4[a]	22.4[b]	0.6	<0.001
Litter heterogeneity (%) *	21.2	20.8	20.2	0.9	0.884
Number of functional teats	15.0	14.7	14.4	0.2	0.642
Udder occupancy (%) **	107.1	107.4	129.8	4.4	0.062
Udder occupancy during split-suckling (%) ***	107.1	80.3	88.3	3.8	0.066
Number of isolated piglets in SSG1		4.0	5.9	0.3	0.002
Number of isolated piglets in SSG2		4.0	5.8	0.3	0.002
Number of non-isolated piglets in SSG3		7.8	6.7	0.4	0.172
Colostrum production (kg)	5.795[ab]	5.622[a]	6.378[b]	0.139	0.047

Means with a different superscript are significantly different ($P < 0.05$),

* defined as coefficient of variation (= standard deviation / average) for birth weights within a litter,

** calculated as number of live-born piglets divided by number of functional teats,

*** calculated as number of piglets with access to the dam divided by number of functional teats.

Table 2: Piglet colostrum intake per treatment: CON (no split-suckling), SS1d (split-suckling in first days of life) and SS3d (split-suckling during first three days of life); per quartile within treatment (quartile 1 = 25% piglets with lowest birth weights within each litter < > quartile 4 = 25% piglets with heaviest birth weights within each litter); per group within split-suckling treatment (SSG1 = heavier piglets born in first part parturition and isolated during split-suckling, SSG2 = heavier piglets born in second part parturition and isolated during split-suckling, SSG3 = non-isolated piglets).

	Treatment			SEM	P-value
	CON	SS1d	SS3d		
Overall	384	383	377	6	0.857
Quartile 1	236	266	274	9	0.200
Quartile 2	369	349	371	7	0.288
Quartile 3	445^{a}	398^{b}	393^{b}	7	0.008
Quartile 4	490^{ab}	497^{a}	456^{b}	7	0.038
SSG1		475^{a}	412^{b}	9	0.001
SSG2		406	425	8	0.221
SSG3		320	286	9	0.066

Means with a different superscript are significantly different ($P < 0.05$),

Table 3: Piglet birth weight and postnatal performances: CON (no split-suckling), SS1d (split-suckling in first day of life) and SS3d (split-suckling during first three days of life); per quartile within treatment (quartile 1 = 25% piglets with lowest birth weights within each litter < > quartile 4 = 25% piglets with lowest birth weights within each litter); per group within split-suckling treatment (SSG1 = heavier piglets born in first part parturition and isolated during split-suckling, SSG2 = heavier piglets born in second part parturition and isolated during split-suckling, SSG3 = non-isolated piglets).

	Treatment			SEM	P-value
	CON	SS1d	SS3d		
Birth weight (kg)					
Overall	1.038^{a}	1.162^{b}	1.220^{b}	0.014	<0.001
Quartile 1	0.767^{a}	0.869^{b}	0.921^{c}	0.009	<0.001
Quartile 2	0.984^{a}	1.113^{b}	1.175^{b}	0.019	<0.001
Quartile 3	1.156^{a}	1.256^{b}	1.307^{b}	0.019	0.002
Quartile 4	1.281^{a}	1.444^{b}	1.500^{b}	0.021	<0.001
SSG1		1.331	1.388	0.015	0.054
SSG2		1.320	1.358	0.023	0.387
SSG3		0.999	0.962	0.020	0.548
Daily weight gain until T_{24} (g)					
Overall	82^{a}	65^{ab}	51^{b}	3	0.002
Quartile 1	10	23	22	6	0.656
Quartile 2	79	50	57	5	0.060
Quartile 3	110^{a}	66^{b}	50^{b}	5	<0.001
Quartile 4	129^{a}	111^{a}	70^{b}	5	<0.001
SSG1		103^{a}	50^{b}	6	<0.001
SSG2		64	73	7	0.567

SSG3		44	25	8	0.159
<u>Daily weight gain until T_{72} (g)</u>					
Overall	110^{a}	101^{a}	82^{b}	3	< 0.001
Quartile 1	56	62	67	5	0.667
Quartile 2	105	96	80	4	0.072
Quartile 3	111	106	88	4	0.046
Quartile 4	139^{a}	128^{a}	87^{b}	7	0.001
SSG1		123^{a}	86^{b}	5	<0.001
SSG2		113^{a}	84^{b}	5	0.004
SSG3		78	72	5	0.568
<u>Mortality until T_{72} (%)</u>					
Overall	14.4	11.5	18.5	1.7	0.189
Quartile 1	36. 7	29. 8	40.0	4.4	0.683
Quartile 2	14.8	9.5	18.2	3.4	0.496
Quartile 3	3.8	4.9	9.8	2.4	0.546
Quartile 4	0.0	0.0	4.1	0.1	0.227
SSG1		4.5	5.1	2.1	0.899
SSG2		0.0	5.2	1.8	0.128
SSG3		20.9^{a}	41.8^{b}	3.8	0.007

Means with a different superscript are significantly different ($P < 0.05$)