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Factors influencing within-litter variation of birth weight and the incidence of runt piglets

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Abstract

The present study was conducted to investigate factors affecting within-litter variation of piglet birth weight and the incidence of runt piglets. In total, 8433 piglets were included in the study. They had been born from 624 Landrace x Yorkshire sows raised on ten farms in the north of Vietnam. A linear mixed effect model (LMEM) and a generalized linear mixed model (GLMM) were used to determine the associations between the risk factors and within-litter variation in birth weight and number of runt piglets, respectively. The within-litter standard deviation (SD) of birth weight and its coefficient of variation were 0.27 ± 0.10 kg and 19.8 ± 8.0%, respectively. Litter size was positively associated with within-litter variation in birth weight, whereas the mean birth weight was negatively associated with litter size. The incidence of runt piglets (birth weight <1.11 kg) was 21.3%. Increases in litter size and decreases in litter weight were associated with the incidence of runt piglets. Mean and SD of birth weight within litter were the most significant risk factors for runt piglets. The GLMM, which contained the mean and SD of birth weight, explained 36% variation of the incidence of runt piglets. The results of the present study suggested that increased mean birth weight and litter weight would be beneficial approaches for reducing within-litter variation in piglet birth weight and incidence of runt piglets, which may subsequently increase perinatal and preweaning survival.

Keywords: gestation length, litter size, litter weight, parity
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Introduction

The breeding of highly prolific sows has resulted in a drastic increase in litter size (LS) (Koketsu *et al*., 2017). However, a large litter is accompanied by a decrease in birth weight (BW), an increase in the number of runt piglets (Yuan *et al*., 2015), and increased within-litter variation in BW (Wolf *et al*., 2008; Charneca *et al*., 2021; Peltoniemi *et al*., 2021). Runt piglets are susceptible to perinatal death (Nam & Sukon, 2020), have a lower preweaning survival rate (Baxter *et al*., 2009; Wientjes *et al*., 2012), and a lower growth rate (Beaulieu *et al*., 2010; Fix *et al*., 2010a). The carcass value of these small piglets is also reduced in comparison with their larger littermates (Fix *et al*., 2010b). Heterogeneous litters increase the incidence of cross-fostering with subsequent extra cost for labour and management (Zindove *et al*., 2014), reduce colostrum intake, and increase mortality (Charneca *et al*., 2021). Piglets from highly variable litters with low BW need more time to reach the market (Wolter *et al*., 2002) and have lower meat quality (Gondret *et al*., 2006).

In the last two decades, the literature has contained an increasing number of reports about factors that affect within-litter variation in the BW of piglets (Quiniou et *al*., 2002; Quesnel *et al*., 2008; Zindove *et al*., 2014; Zhang *et al*., 2016). However, recent reviews suggested that causal mechanisms for the variability in BW were unclear (Yuan *et al*., 2015; Moreira *et al*., 2020).). Risk factors associated with the incidence of runt piglets needed to be clarified. Thus, factors affecting within-litter variation of piglet BW and the incidence of runt piglets were investigated.

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Materials and Methods

Review of this study by the Animal Care and Use Committee of Vietnam National University of Agriculture was waived because it was conducted on commercial pig farms outside the university and all procedures were components of routine management. The study was conducted on ten farms in five provinces in the north of Vietnam from February 2019 to February 2021. In total, 8433 piglets born from 624 Landrace x Yorkshire sows were included. Sows were inseminated twice with Duroc boar semen. Pregnant and farrowing sows were held in individual crates. Pregnant sows were fed 1.8 - 3.5 kg of industrialized food, and had ad libitum access to water through a bite nipple. About seven days before the anticipated farrowing date, sows were moved from gestation to farrowing rooms. All sows were vaccinated against foot and mouth disease, pseudorabies, reproductive and respiratory syndrome, and parvovirus. Sows were dewormed twice every year. Depending on ambient temperature, sows were bathed once or twice daily.

Data were collected by trained veterinarians. Parity number (PN) (1 - 15), gestation length (GL), litter size (LS) (number born), stillborn piglets, and piglet gender (GD) were recorded. Birth weight (BW) of each piglet was weighed with a digital scale, and crown-rump length (CRL) was measured with a tape measure. The measurement of BW and CRL was conducted before nursing and required about 35 - 40 seconds for each piglet. Body mass index (BMI) was calculated as:

$$BMI = BW/CRL^2$$

and the ponderal index (PI) was calculated as:

$$PI = BW/CRL^3.$$

Litter weight (LW) was the sum of the birth weight of all of the piglets that were born in that litter. Mean birth weight of a given litter (MBW) was calculated as the average of BW of all piglets that were born in that litter. The within-litter SD of birth weight (SDBW) was calculated from the BWs of all piglets in that litter. The within-litter coefficient of variation of birth weight (CVBW) was:

$$CVBW = 100*SDBW/MBW.$$

An LMEM was used to determine the risk factors affecting CVBW. In the LMEM, farms were fitted as a random factor and the continuous independent variables, including PN, GL, LS, LW, and MBW, were fitted as fixed. Piglets with BW <1.1 kg were defined as runts, and piglets with a BW ≥1.1 kg were defined as normal. This definition was adopted because Feldpausch *et al*. (2019) found 1.11 kg was a threshold for preweaning survival and Magnabosco *et al*. (2015) reported that piglets weighing <1.1 kg at birth had significantly lower survival and growth rates in comparison with their heavier littermates. The PN, GL, LS, BW, CRL, BMI, PI, MBW, LW, SDBW, and CVBW of normal and runt piglets were compared in t-tests (SPSS, version 26).

A GLMM was used to examine the effect of various factors on the incidence of runt piglets. To take into account potential differences in litters and farms, sows nested in farms were fitted as a random factor. The continuous variables GD, PN, GL, LS, LW, SDBW, and CVBW were fitted as fixed effects. The GLMM was conducted in two steps. At first, a univariate GLMM was used to determine the preliminary associations between runt piglets and various potential risk factors. Then all factors significantly associated with the incidence of runt piglets at P <0.1 were retained for further analysis in a multivariate GLMM. In the third step, combinations of potential risk factors were analysed simultaneously to establish the final GLMM that best explained the variation of incidence of runt piglets. The LMEM and GLMM analyses were conducted in Rstudio. The variance inflation factor (VIF) was calculated to determine the degree of multi-collinearity that existed in the GLMM.

Results and Discussion

The average BW of piglets in this study was 1.40 ± 0.36 kg, decreasing with an increase in LS from 1.60 kg for litters <11 piglets to 1.42 kg for litters with 11 to 15 piglets and 1.35 kg for litters >15 piglets. Average SDBW and CVBW were 0.27 ± 0.10 kg and 19.8 ± 8.0 %. Both SDBW and CVBW increased with increase in LS. The SDBW was 0.23, 0.27 and 0.29 kg when LS was <11, 11-15, and >15 piglets, respectively. Likewise, the CVBW was 14.8, 19.4 and 22.6% when LS was <11, 11-15, and >15 piglets, respectively. The positive associations between SDBW, CVBW and LS may be the result of the increased incidence of runt piglets from 7.4 to 19.4 to 26% with LSs of <11, 11-15, and >15 piglets, respectively. The MBW did not change with the change of parity, but sows with more parities had smaller SDBW and CVBW with the SDBW equal to 0.28 at parity 1–6 and 0.25 when the number of parities was greater than 6. Likewise, CVBW was 20.3% for parities 1 to 6 and 18.3% for parities greater than 6.

Associations between PN, GL, LS, MBW, LW, SDBW, and CVBW were measured withy Pearson's correlations (Table 1). Pearson's correlations showed that PN was associated with GL and SBBW, GL was related to LW, and LS correlated with MBW, LW, SDBW, and CVBM.

Table 1 Pearson's correlations between parity number, litter size, mean birth weight, standard deviation of birth weight and coefficient of variation of birth weight (624 litters)

	Parity number	Gestation length, days	Litter size	Mean birth weight, kg	Litter weight, kg	SD birth weight, kg
GL	0.127					
LS	-0.025	-0.075				
MBW	-0.023	-0.022	-0.359			
LW	-0.061	-0.084	0.647	0.247		
SDBW	-0.086	0.031	0.208	-0.167	0.117	
CVBW	-0.063	0.050	0.301	-0.531	-0.033	0.897

GL: gestation length; LS: litter size; MBW: mean birth weight; SDBW: standard deviation of birth weight; CVBW: coefficient of variation of birth weight; $|r| > 0.1$ $P < 0.01$, $|r| > 0.08$ $P < 0.05$

Univariate analysis showed that LS and MBW were significantly associated with CVBW, whereas LW, PN, and GL were not associated with CVBW (Table 2).

Table 2 Results of univariate analysis of risk factors for within-litter variation of birth weight defined as coefficient of variation of bodyweight (624 litters)

Covariates	Coefficient	Constant	mR^2	cR^2	*P*-value
Litter size	0.496	12.71	0.04	0.32	<0.01
Parity number	0.041	19.46	0.00	0.31	>0.05
Gestation length, days	-0.040	24.28	0.00	0.31	>0.05
Mean birth weight, kg	-16.95	43.55	0.22	0.43	<0.01
Litter weight, kg	-0.389	20.42	0.00	0.31	>0.05

mR^2: marginal R^2, cR^2: conditional R^2

A combination of MBW and LS in a multivariate LMEM showed that neither marginal R^2 nor conditional R^2 was increased in comparison with a model consisting solely of MBW. Therefore, MBW was the single most important risk factor for CVBW of piglets, explaining 21.7 % of the variation.

The incidence of runt piglets was 21.3% (1795/8433). The LS, LW, SDBW, CVBW, CRL, BW, BMI, and PI for piglets with normal BW (N = 6638) piglets and runt piglets (N = 1795) are shown in Table 3. The incidence of stillbirth was 6.7% (569/8433). About 34.1% (194/569) stillborn and 20.4% (1601/7864) born alive piglets were runts ($P < 0.001$). The BMI and PI of normal piglets were 19.49 ± 0.04 and 70.22 ± 0.22, respectively; whereas the corresponding values for runt piglets were 15.32 ± 0.10 and 64.79 ± 0.56.

Univariate GLMM analyses demonstrated that LS, GD, LW, CVBW, SDBW, and MBW influenced the incidence of runt piglets, but that PN and GL did not (Table 4). Male piglets were at lower odds of being born as a runt compared with females (OR =0.75, $P < 0.001$). The multivariate GLMM analysis THAT best explained variation in the incidence of runt piglets included MBW and SDBW.

Table 3 Comparison of normal (6638) and runt piglets (1795) for various measures related to their body size

	PN	GL, days	LS	LW, kg	MBW, kg	SDBW, kg	CVBW	CRL, cm	BW, kg
Normal	4.49 ± 0.03	115.6 ± 0.02	14.72 ± 0.04	21.21 ± 0.06	1.45 ± 0.003	0.27 ± 0.001	19.03 ± 0.10	28.22 ± 0.03	1.54 ± 0.003
Runt	4.39 ± 0.06	115.6 ± 0.04	15.85 ± 0.07	19.25 ± 0.10	1.22 ± 0.004	0.31 ± 0.002	26.02 ± 0.22	24.31 ± 0.06	0.90 ± 0.005
P-value	0.16	0.81	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

PN: parity number, GL: gestation length, LS: litter size, LW: litter weight, MBW: mean birth weight, SDBW: standard deviation of birth weight within litter, CVBW: coefficient of variation of birth weight, CRL: crown rump length, BW:; birth weight

Table 4 Univariate general linear mixed model analysis for potential risk factors for runt piglets (8433 piglets)

Covariates	Odds ratio	95% Confidence interval	*P*-value	mR^2	cR^2
CVBW, %	1.10	1.09 - 1.11	<0.001;	0.155	0.354
LW, kg	0.92	0.90 - 0.94	<0.001	0.030	0.379
LS	1.13	1.10 - 1.17	<0.001	0.032	0.398
GL, day	0.93	0.88 - 0.99	0.026	0.003	0.397
Sex	0.75	0.67 - 0.84	<0.001	0.004	0.397
PN	1.00	0.96 - 1.05	0.895	0.000	0.395
SDBW, 10 g	1.04	1.03 - 1.05	<0.001	0.034	0.374
MBW, 100 g	0.57	0.55 - 0.59	<0.001	0.318	0.367

OR: odds ratio, CI: confidence interval, P: probability level, mR^2: marginal R^2; cR^2: conditional R^2, CVBW: coefficient of variation of birth weight, LW: litter weight, LS: litter size, GL: gestation length, PN: parity number, SDBW: standard deviation of birth weight within litter, MBW: mean birth weight

The final GLMM that best explained variation in the incidence of runt piglets included MBW and SDBW. Mean birth weight of the litter negatively influenced (OR = 0.56, *P* <0.001) the incidence of runt piglets and SWBW had a positive effect (OR = 1.03, *P* <0.001). These effects collectively explained 36% variation in the incidence of runt piglets. The VIF for both MBW and SDBW was 1.001, signifying there was no issue with collinearity in this model.

Within-litter variation of BW can be expressed as SDBW or CVBW and has been shown to vary between 0.25 and 0.3 kg, and 16.9 and 24.0 %, respectively, depending on LS (Beaulieu *et al*., 2010). Magnabosco *et al*. (2015) reported that the CVBW of 1495 female piglets born from Landrace x Large White sows was 24.4%, whereas Zindove *et al*. (2014) reported a CVBW of 17.7% in the 1768 piglets born from a similar sow line. In a recent systematic review, the pooled SDBW and CVBW of piglets born from hyper-prolific sows were 280 g and 22.92%, respectively (Moreira *et al*., 2020). Therefore, the within-litter variation in BW in this study was in a range that is consistent with earlier published results.

The lack of an effect of parity on CVBW in this study disagreed with results in previous studies (Quiniou *et al*., 2002; Zindove *et al*., 2014; Zhang *et al*., 2016). Zhang *et al*. (2016) explained that the positive association between parity and CVBW was attributable to an increase in LS as the sows produce more litters. In these studies, CVBW increased with parity. However, in this study CVBW was stable when the first through sixth parities were grouped, and decreased in more advanced parities. This non-significant effect can be explained partly by the finding that parity did not influence LS, MBW, and LW in this study.

Previous studies showed that LS was negatively associated with within-litter variation of BW (Quiniou *et al*., 2002; Quesnel *et al*., 2008; Zindove *et al*., 2014). This association was partly attributable to the negative relationship between LS and BW and the positive correlation between LS and incidence of runt piglets. Interestingly, despite a highly positive correlation between LS and LW, LW did not have any significant effect on CVBW. In other words, increased LW had partly relieved the effect of increased LS on CVBW via an increase in MBW. In another study, CVBW was positively associated with both LS and LW (Zindove *et al*., 2014). The discrepancies in results may be attributable to the differences in the strength of associations between CVBW and LS and MBW in the two studies. In the study of Zindove *et al*. (2014), the correlations of CVBW with LS and MBW were of similar magnitude (0.30 and -0.31, respectively) to those in the present study, whereas the correlation between CVBW and MBW found here was much stronger than that between CVBW and LS. Moreover, the variety of definitions of within-litter variation of piglet BW may be another reason for the differences in results among studies. In this study, the authors quantified within-litter variation in BW as CVBW. In a previous study (Quiniou *et al*., 2002), within-litter variation of BW was quantified as SDBW, which would result in a positive relationship between LW and SDBW in this study. However, MBW explained 5.5 times more variation in CVBW than LS. Therefore, selection for increased MBW might beneficial in order to reduce CVBW, given that use of prolific sow lines in modern swine farming is inevitable. This idea is supported by the finding that the heritability value of MBW was widely reported to be moderate ranging from 0.16 to 0.51 (Varona *et al*., 2007; Wolf *et al*., 2008; Canario *et al*., 2010; Banville *et al*., 2015; Carmago *et al*., 2020). It has also been suggested that selection for increased MBW be considered in combination with increased LS to reduce the mortality of piglets (Hermesch *et al*., 2001; Wolf *et al*., 2008). Carmago *et al*. (2020) postulated that there was a point at which optimal LS met maximum MBW, and it might a goal of breeding programmes.

Low individual BW of piglets is an important factor associated with increased rate of stillbirth (Nam & Sukon, 2020), reduced survival from birth to weaning (Feldpausch *et al*., 2019), reduced growth rate (Paredes *et al*., 2014; Magnabosco *et al*., 2015), reduced weight at the slaughterhouse (Beaulieu *et al*., 2010), and reduced longevity and productive performance of female pigs (Magnabosco *et al*., 2016). This study defined runt piglets based on previous publications (Magnabosco *et al*., 2015; Feldpausch *et al*., 2019) and found an incidence of runt piglets of more than one fifth of total born. This incidence is higher than that in the study by Feldpausch *et al*. (2019), who reported an incidence of 15.2% of piglets with BW lower than 1.11 kg. Quiniou *et al*. (2002) also reported that the incidence of <1.0 kg piglets was 13.1% (1583/12042), which was in agreement with the incidence of 14.7% (1236/8433) piglets born with a BW lower than 1.0 kg in the present study. In this study, postnatal mortality was not monitored. However, previous results showed that about 28% of piglets with a BW of less than 1.2 kg died before weaning in comparison with 7% of piglets with a BW above 1.2 kg (Quiniou *et al*., 2002). Similarly, Magnabosco *et al*. (2015) showed that only 79% of piglets with a BW less than 1.16 kg survived until weaning, whereas 95% of heavier piglets survived. Therefore, the high incidence of runt piglets in this study suggested that many piglets might not have survived until weaning, which would result in a substantial economic loss to the farms.

Many studies investigated the effect of LS on the VIF of piglets. Quiniou *et al*. (2002) reported that an increase of one piglet in LS resulted in a 35 g reduction in mean BW. Similarly, a reduction of 43 g in mean BW was found to result from an increase of one piglet in LS (Beaulieu *et al*., 2010). The present study showed that for each additional piglet born the risk for a litter to have a runt piglet increased 1.13 times. Increased LS resulted in increased LW but decreased MBW, and in turn, LW and MBW were negatively associated with the incidence of runt piglets. In comparison to LW, MBW explained a greater amount of incidence of runt piglets, Therefore, selection for increased MBW, in comparison with LW, will more effectively reduce the negative effect of LS on incidence of runt piglets. It was also found that minimal BW had a negative correlation with within-litter variability, and suggested that selection on minimal BW would reduce litter heterogeneity (Wolf *et al*., 2008) which subsequently results in a reduction of the incidence of runt piglets.

Gender of piglets and GL were significantly associated with incidence of runt piglets, and these factors explained 0.3 to 0.4% variation of its incidence. These associations can be explained via the increased MBW of the male in comparison with the female (1425 *vs* 1377 g), and the negative relationship between GL and LS, respectively.

Conclusions

Approaches aimed at reducing the incidence of runt piglets should focus on increasing MBW and LW while making the piglets more uniform in weight. It is suggested that the optimum combination of LS and MBW should be identified in breeding programmes.

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Authors' Contributions

NHN (ORCID: 0000-0002-2110-0006) collected data, NHN and PS (ORCID: 0000-0002-0899-2572) designed the study, analysed the data, interpreted the results and wrote the manuscript.

Conflict of Interest Declaration

The authors declare that they have no conflict of interest.

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