

Relationships between litter size, sex ratio and within-litter birth weight variation in a sow herd and consequences on weaning performance

Titus J. Zindove,^{†,1,*} Tonderai Mutibvu,[‡] Andrew C. Shoniwa,[§] and Erica L. Takaendesa[§]

[†]Department of Animal Science, Fiji National University, P.O Box 7222, Nasinu, Fiji [‡]Department of Animal Science, University of Zimbabwe, P.O. Box MP 167, Mount Pleasant, Harare, Zimbabwe [§]Pig Industry Board, Highlands, Harare, Zimbabwe

ABSTRACT: Routine selection for litter size has resulted in an increase in the proportion of light-weight piglets. There is a need to balance prolificacy with litter uniformity to maximize profit. A total of 3,465 piglets from 310 litter records obtained from 2016 until 2019 at the Pig Industry Board research unit, Arcturus, Zimbabwe were used to determine the relationships between litter size, sex ratio, and within-litter birth weight variation in the sow herd and consequences on performance at weaning. The regression procedure of SAS was used to determine the relationships between litter size, sex ratio, and within-litter birth weight variation. The regression procedure was also used to determine the relationships between number born alive, within-litter birth weight variation, and sex ratio, and litter performance traits at weaning. Parity of sow, year, and month of farrowing did not affect sex ratio ($P > 0.05$). The number born alive and number of piglets born

had no relationship with sex ratio ($P > 0.05$). As the sex ratio increased, percent survival of piglets at weaning also increased linearly ($P < 0.05$). As the proportion of males in litters increased, within-litter birth weight variation and within-litter weaning weight variation increased reaching maximum as the proportion of males in litters approached 0.5 and then decreased onwards. As the proportion of males in litters approached 1, within-litter birth weight variation and within-litter weaning weight variation reached their least values. In conclusion, within-litter sex ratio does not vary with parity, year, and month of farrowing. Within-litter weight variation is highest in litters with equal number of male and female piglets and lowest in unisex litters. This implies that the production of unisex litters can help to reduce the variation in the weight of pigs at birth, weaning, and marketing which is one of the biggest economic challenges faced by pork producers.

Key words: fetal sex, number born alive, piglets, uniformity

© The Author(s) 2021. Published by Oxford University Press on behalf of the American Society of Animal Science.

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact journals.permissions@oup.com

Transl. Anim. Sci. 2021.5:1-11
<https://doi.org/10.1093/tas/txab132>

INTRODUCTION

One of the most important determinants of productivity of pig enterprises is pigs weaned

per sow per year (Wolf et al., 2007). The total number of pigs weaned per sow per year is largely determined by litter size at weaning. For years, pig-breeding programs have focused mainly on improving number born alive (NBA) and, thus, litter size (Foxcroft et al., 2006). Maximizing NBA can be achieved through increasing ovulation rates coupled with minimizing embryo and fetal

¹Corresponding author: zindovetj@gmail.com

Received May 28, 2021.

Accepted August 4, 2021.

mortality. Profitability of a pig enterprise, however, primarily depends on the reproductive efficiency of sows. Reproductive efficiency of a sow is a product of traits such as NBA, litter weight at birth and within-litter birth weight variation. Large litters are associated with high within-litter birth weight variation (Milligan et al., 2002). The increased number of lightweight piglets in larger litter sizes increases the amount of weight variation among littermates at birth (Zindove et al., 2013). Schinckel et al. (2007) reported quadratic, and cubic effects of birth weight of piglets on body weight after 168 days. Light piglets are less likely to survive to weaning and have lower weights at slaughter than their heavier litter mates (Schinckel et al., 2007; Wolf et al., 2007).

There are suggestions that female fetuses are more vulnerable to the sow's nutritional stresses and tend to grow slower than their male counterparts when there is intense competition in the uterus as a result of increased litter size (Milligan et al., 2002). In their study on a commercial pig herd, Baxter et al. (2012) reported that, with an average weight of 1.5 kg, male piglets were heavier than their female counterparts which averaged 1.4 kg at birth. Lightweight male piglets in large litters have detrimental consequences on within-litter birth weight variation hence average litter weight and survivability. Low average birth weights result in slow growth rates and low survivability during pre-weaning, growing and finishing phases (Zindove et al., 2013). The current trend towards only looking at the number of piglets weaned and not accounting for the piglets' birth and weaning weights is counterproductive due to low feed conversion efficiency and high mortality rates associated with lightweight pigs (Schinckel et al., 2007; Widmar et al., 2011). The feed and medication costs associated with the lightweight pigs in large litters are uneconomical (Widmar et al., 2011). Schinckel et al. (2007) reported that greater number of lightweight piglets at weaning result in increased percentage of pigs not achieving target market weight within the expected period. The pigs which take more time to achieve specific target weights distort batching of pigs. In order to achieve optimal barn turnover, pig producers should empty the barn and refill. Considering that there are no practical methods to reduce variance in body weights of pigs in later stages, the presence of the lightweight pigs in the batches results in discount for pigs with low carcass weights at marketing and, thus, reduced profits (Alexopoulos et al., 2018).

If optimal number of piglets per year per sow is to be achieved, research in selection programs

should attempt to optimize all three; litter size, mean litter birth weight and within-litter birth weight variation (Milligan et al., 2002; Zindove et al., 2013). Considering that sex of the foetuses is likely to contribute to differences in weight at birth (Baxter et al., 2012), sex-ratio adjustment in pig litters could help produce large uniform litters at birth. Schinckel et al. (2007) reported interactions between sex and birth weight of piglets on body weight after 20 days. Production of uniform litters at birth through sex-ratio adjustment is likely to result in the production of uniform pigs at weaning and at marketing (Milligan et al., 2002; Zindove et al., 2013). This eases pig flow strategies in the modern all-in all-out systems. In addition, the production of uniform piglets at birth is also likely to reduce pre-weaning losses (Zindove et al., 2013). There is, thus, need to ascertain the relationship between sex ratio and within-litter birth weight variation, survivability and mean litter birth weight in pigs.

Once the phenotypic relationship between sex ratio, litter size and within-litter birth weight variation and their impact on subsequent performance is ascertained, sex ratio in sows producing large litters can be adjusted through techniques such as sperm sexing. It is also possible to modify sex ratio through genetic selection since genetic variance for sex ratio of litters in pigs has been reported (Toro et al., 2006). Reduction of weight variation of pigs through adjustment of sex ratio in large litters will reduce losses at marketing by pig producers since there will be less variation in carcass weight. In addition to reducing variation in weight of pigs, for maternal lines and pig multiplication systems, production of litters comprised of more female piglets would be of advantage since less multiplier herds would be needed. In genetic analysis of traits, estimates for fixed factors are required for adjusting the random genetic influences that are inherited across generations. To improve the understating of sex ratio and within-litter birth weight variation in pig litters, the relative importance of these factors, thus, also needs to be explored. The objective of this study was, therefore, to determine the relationships between litter size, sex ratio, and within-litter weight variation at birth and their impact on subsequent litter traits of sows.

MATERIALS AND METHODS

Study Site

Data were collected from a pig herd at the Pig Industry Board research unit located in

Arcturus, approximately 30 km Northeast of Harare, Zimbabwe. The research unit is located at 17°46'60" S and 31°19'0" E and lies 1,500 m above sea level. An approximate mean annual rainfall of 800 mm is received with mean annual temperature of 18.5°C.

Herd Management

The study was conducted on a mixed pig herd consisting of a Landrace dam line and Large White sire line. The herd was kept on an all-in all-out system in the farrowing, weaner and grower houses. Sows and gilts were given 2 kg a day of commercial sow meal (12MJ digestible energy and 160 g/kg crude protein/kg as fed). In preparation for farrowing, sows were moved to illuminated farrowing houses on day 109 of gestation. Potable tap water was provided *ad libitum*. Piglets were kept in a creep area heated using an infra-red lamp from day 110.

Data Handling

Data used in the study included records on 3,465 piglets from 310 litters obtained from 2016 until 2019. The records consisted of identity of piglets, identity of sows, breed of sows, breed of boars, parity, farrowing date, number of piglets born (NPB), NBA, number born dead (NBD), individual piglet birth weight, litter size at weaning (five weeks) and individual piglet weight at weaning. From these records, mean birth weight (MBWT), Total litter weight at farrowing (BWT), within-litter birth weight coefficient of variation (CVBWT) and within-litter sex ratio were calculated. Within-litter sex ratio was calculated as the proportion of males in a litter including stillbirths. The minimum birth weight (MinBWT) and maximum birth weight (MaxBWT) for each litter were also determined. At 5 weeks of age (weaning), litter weight (WWT), mean litter weight (MWWT) and within-litter weight coefficient of variation (CVWWT) were computed. Percent survival of piglets at weaning (SVW) was calculated as the proportion of litter size at weaning to NBA. The minimum weaning weight (MinWWT) and maximum weaning weight (MaxWWT) for each litter were also determined. Records of litters with piglets fostered in or out were excluded in the analyses. Litters less than three piglets were assumed to have piglets fostered out and were excluded from the analyses. Parities greater than six were categorized as more than or equal to seven. Data from 73 litters were deleted, leaving a total of 310 litters available for analysis.

Statistical Analyses

The effects of parity of sow, season of farrowing, year of farrowing and the relevant covariates on sex ratio, NPB, NBA, MBWT, BWT, MinBWT, MaxBWT, CVBWT, CVWWT, MWWT, WWT, MinWWT, MaxWWT, and SVW were analyzed using the PROC MIXED procedure of SAS v. 9.4 (SAS, 2013). The effects of parity were tested after removing the effect of individual sows as a blocking term. Initial analyses assumed fixed models with all possible first-order interactions. All tested interactions were not statistically significant ($P > 0.05$) and, thus, were eliminated from models for final analyses. Before analyses, the variables NPB, NBA, MBWT, BWT, WWT, and MWWT were transformed using the square root transformation to normalize them. The least square means and their respective standard errors were back transformed in the presentation of results.

The PROC REG procedure of SAS v. 9.4 (SAS, 2013) was used to determine the relationship between sex ratio and NPB. The PROC REG procedure of SAS v. 9.4 (SAS, 2013) was also used to determine whether the relationships between NBA and litter performance parameters (CVBWT, MBWT, BWT, MinBWT, MaxBWT, CVWWT, MWWT, WWT, SVW, MinWWT, and MaxWWT) and the relationship between sex ratio and the litter performance parameters (MBWT, BWT, MinBWT, MaxBWT, MWWT, WWT, MinWWT, MaxWWT, and SVW) were linear or quadratic. The NPB, NBA, and sex ratio were fitted as independent variables in the regression models. Pearson's correlation coefficients among sow performance traits at farrowing and at weaning were determined using correlation analysis (SAS, 2013).

Binomial logistic regression was used to estimate the probability of a piglet having MinBWT, MaxBWT, MinWWT, or MaxWWT (SAS, 2013). The logit model fitted gender (male; female) as the predictor. The logit model used was:

$$\ln [P/1 - P] = \beta_0 + \beta_1 X_1 + \epsilon$$

Where:

P = probability of a piglet having (MinBWT, MaxBWT, MinWWT, MaxWWT);

$[P/1 - P]$ = odds ratio (the odds of a piglet having MinBWT, MaxBWT, MinWWT, MaxWWT);

β_0 = intercept;

$\beta_1 X_1$ = regression coefficients for gender;

ϵ = random residual error.

When computed for each predictor ($\beta_1 \dots \beta_t$), the odds ratio was interpreted as the proportion of

piglets with the least birth weight in a litter versus those that did not weigh the least, the proportion of piglets with the highest birth weight in a litter versus those that did not weigh the most, the proportion of piglets with the least weaning weight in a litter versus those that did not weigh the least, the proportion of piglets with the highest weaning weight in a litter versus those that did not weigh the most.

RESULTS

Summary Statistics and Levels of Significance

Summary statistics for the traits analyzed are shown in Table 1. The NBA ranged from 3 to 18, averaging 10 piglets. The CVBWT and CVWWT had wide ranges of 2.66–54.16 % and 0.87–70.71 %, respectively. The MinBWT ranged from 0.2 to 2 kg whilst MaxBWT ranged from 0.9 to 2.8 kg. The mean sex ratio was 0.44. Significant levels for all effects included in the final general linear models and relevant covariates are shown in Table 2. The parity of sow had significant effects on NPB, NBA, BWT, CVBWT, and MinBWT ($P < 0.05$). The year of farrowing had

Table 1. Summary statistics for sex ratio, Number of piglets born (NPB), number born alive (NBA), within-litter birth weight coefficient of variation (CVBWT), mean birth weight (MBWT), total litter weight at birth (BWT), total litter weight at weaning (WWT), within-litter weaning weight coefficient of variation (CVWWT), Mean weaning weight (MWWT), Percent survival of piglets at weaning (SVW), within-litter minimum birth weight (MinBWT), within-litter maximum birth weight (MaxBWT), within-litter minimum weaning weight (MinWWT) and within-litter maximum weaning weight (MaxWWT) ($N = 310$)

Trait	Mean	Standard deviation	Minimum	Maximum
Sex ratio	0.44	0.29	0.09	0.94
NPB	10.80	2.31	5.00	18.00
NBA	10.13	3.02	3.00	18.00
MBWT, kg	1.43	0.29	0.54	2.21
BWT, kg	15.40	4.87	2.70	33.20
CVBWT	17.92	6.78	2.66	54.16
MinBWT, kg	1.00	0.36	0.20	2.00
MaxBWT, kg	1.77	0.34	0.90	2.80
WWT, kg	74.60	26.88	15.50	178.50
MWWT, kg	8.04	1.93	3.26	15.16
CVWWT	20.81	10.19	0.87	70.71
MinWWT, kg	5.68	2.12	2.40	12.30
MaxWWT, kg	9.97	2.41	3.80	20.50
SVW, %	83.11	16.88	22.22	100.00

Table 2. Significance levels for fixed effects and covariates tested to estimate the impact of sex ratio on litter performance.

	Sex ratio	NPB	NBA	MBWT	BWT	CVBWT	MinBWT	MaxBWT	WWT	MWWT	CVW	MinWWT	MaxWWT	SVW
Sex ratio	-	-	-	NS	NS	*	*	NS	NS	NS	**	NS	NS	*
NPB	NS	-	*	*	*	*	*	NS	-	-	-	-	-	-
NBA	NS	-	-	**	*	**	*	NS	*	*	*	*	NS	*
MBWT	-	-	-	-	-	-	-	-	*	*	-	-	-	**
BWT	-	-	-	-	-	-	-	-	*	NS	-	-	-	-
CVBWT	-	-	-	NS	NS	-	-	-	-	-	**	-	-	*
MinBWT	-	-	-	-	-	-	-	-	-	-	-	**	NS	-
MaxBWT	-	-	-	-	-	-	-	-	-	-	-	-	*	-
Parity	NS	*	**	NS	*	*	**	NS	NS	NS	NS	NS	NS	NS
Year of farrowing	NS	*	**	NS	**	*	NS	NS	NS	**	**	NS	NS	NS
Month of farrowing	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS, not significant ($P > 0.05$); NPB, number of piglets born; NBA, number born alive; MBWT, mean birth weight; BWT, total litter weight at farrowing; CVBWT, within-litter birth weight coefficient of variation; MinBWT, minimum birth weight for each litter; MaxBWT, maximum birth weight for each litter; WWT, litter weight at weaning; MWWT, mean litter weight at weaning; CVWWT, within-litter weight coefficient of variation; SVW, percent survival of piglets at weaning; MinWWT, minimum weaning weight for each litter; MaxWWT, maximum weaning weight for each litter; * $P < 0.05$; ** $P < 0.01$

significant effects on NPB, NBA, BWT, CVBWT, WWT, and CVWWT ($P < 0.05$). Month of farrowing affected MBWT ($P < 0.05$). Parity of sows, year and month of farrowing did not affect sex ratio ($P > 0.05$).

Effects of Parity of Sow on Litter Performance at Birth

Least square means for the effects of parity of sows on NPB, NBA, BWT, CVBWT, and MinBWT are shown in Table 3. The NPB and NBA increased with parity with the maximum values being observed in Parity 6. The NPB and NBA then decreased significantly for litters from sows beyond parity 6. The NBA for gilts was significantly lower than multiparous sows, except those in parity 2 and greater than Parity 6. The BWT also increased with parity up to Parity 4 and decreased beyond the fifth parity. The heaviest litters were born to sows in mid-parities (parity 3, 4, 5, and 6) ($P < 0.05$). Litters born to sows in mid-parities (parity 3, 4, 5, and 6) had the highest CVBWT ($P < 0.05$). The MinBWT was the same ($P > 0.05$) for litters from sows in all parities except for those in parity 6 where it was the lower ($P < 0.05$).

Effects of Season of Farrowing and Year of Farrowing on Litter Performance at Birth and Weaning

Least square means for the effects of year of farrowing on NPB, NBA, BWT, CVBWT, WWT,

and CVWWT are shown in Table 4. The NPB and NBA were highest in 2016 and 2018 ($P < 0.05$). The BWT and CVBWT were highest in 2018 ($P < 0.05$). The MBWT was high during the hot-wet season (November to March) and the dry-hot season (August to October) ($P < 0.05$; Figure 1). Low MBWTs were observed during the cold-dry season (May to July) reaching the lowest value in July ($P < 0.05$). The MWWT and CVWWT were highest in 2016 ($P < 0.05$).

Relationships Between Litter Size and Litter Performance at Birth and Weaning

The NPB had no relationship with sex ratio ($P > 0.05$). Relationships of NBA to sex ratio and litter performance at farrowing and weaning are shown in Table 5. The NBA had no relationship with sex ratio, MaxBWT and MaxWWT ($P > 0.05$). The CVBWT increased quadratically as NBA increased ($P < 0.01$). As NBA increased, MBWT and SVW decreased linearly ($P < 0.01$). The NBA had negative linear and quadratic relationships with MinBWT, MWWT and MinWWT ($P < 0.01$). The NBA had positive linear and quadratic relationships with WWT and CVWWT ($P < 0.01$). The CVBWT had positive and negative correlations with CVWWT and SVW, respectively ($P < 0.01$; Table 6). The MBWT was positively correlated to WWT, MWWT, and SVW ($P < 0.01$; Table 6).

Table 3. Least square means (\pm SE) for the effects of sow parity on number of piglets born (NPB), number born alive (NBA), litter weight at birth (BWT) and minimum birth weight within a litter (MinBWT).

Parity	n	NPB	NBA	BWT, kg	CVBWT	MinBWT, kg
1	89	9.1 \pm 0.77 ^a	8.9 \pm 0.29 ^a	14.0 \pm 0.46 ^a	15.4 \pm 0.65 ^a	1.1 \pm 0.04 ^a
2	66	9.9 \pm 0.36 ^a	9.3 \pm 0.35 ^a	14.3 \pm 0.57 ^a	16.2 \pm 0.79 ^{ab}	1.0 \pm 0.04 ^a
3	50	12.0 \pm 0.20 ^c	10.6 \pm 0.40 ^b	16.9 \pm 0.65 ^b	18.6 \pm 0.89 ^{bc}	1.0 \pm 0.05 ^a
4	44	11.7 \pm 0.59 ^{bc}	11.4 \pm 0.43 ^b	17.5 \pm 0.70 ^b	20.3 \pm 0.99 ^c	0.9 \pm 0.05 ^a
5	27	11.0 \pm 0.14 ^b	11.0 \pm 0.55 ^b	17.5 \pm 0.89 ^b	20.6 \pm 1.22 ^c	0.9 \pm 0.07 ^a
6	17	13.6 \pm 0.66 ^d	12.1 \pm 0.79 ^b	15.9 \pm 1.28 ^{ab}	19.5 \pm 1.64 ^{bc}	0.7 \pm 0.10 ^b
7 \leq	17	8.3 \pm 0.29 ^a	7.6 \pm 1.28 ^a	12.28 \pm 2.06 ^a	16.8 \pm 2.94 ^{abc}	1.1 \pm 0.16 ^a

Values in the same column with different superscripts differ ($P < 0.05$).

Table 4. Least square means (\pm SE) for the effects of year of farrowing on number of piglets born (NPB), number born alive (NBA), litter weight at birth (BWT), within-litter birth weight coefficient of variation (CVBWT), mean weaning weight and within-litter weaning weight coefficient of variation (CVWWT).

Year	n	NPB	NBA	BWT, kg	CVBWT	MWWT, kg	CVWWT
2016	76	11.9 \pm 0.11 ^b	11.7 \pm 0.31 ^c	17.4 \pm 0.52 ^c	16.9 \pm 1.18 ^b	8.9 \pm 0.21 ^c	27.3 \pm 2.29 ^b
2017	70	10.2 \pm 0.64 ^a	9.4 \pm 0.34 ^a	12.7 \pm 0.54 ^a	16.3 \pm 1.23 ^{ab}	6.9 \pm 0.21 ^a	17.6 \pm 2.38 ^a
2018	97	12.2 \pm 0.33 ^b	11.8 \pm 0.29 ^c	16.6 \pm 0.46 ^c	23.12 \pm 1.04 ^c	8.6 \pm 0.18 ^{bc}	20.4 \pm 2.02 ^a
2019	67	11.8 \pm 0.81 ^b	10.4 \pm 0.35 ^b	14.3 \pm 0.55 ^b	13.0 \pm 1.25 ^a	7.5 \pm 0.22 ^b	17.4 \pm 2.44 ^a

Values in the same column with different superscripts differ ($P < 0.05$).

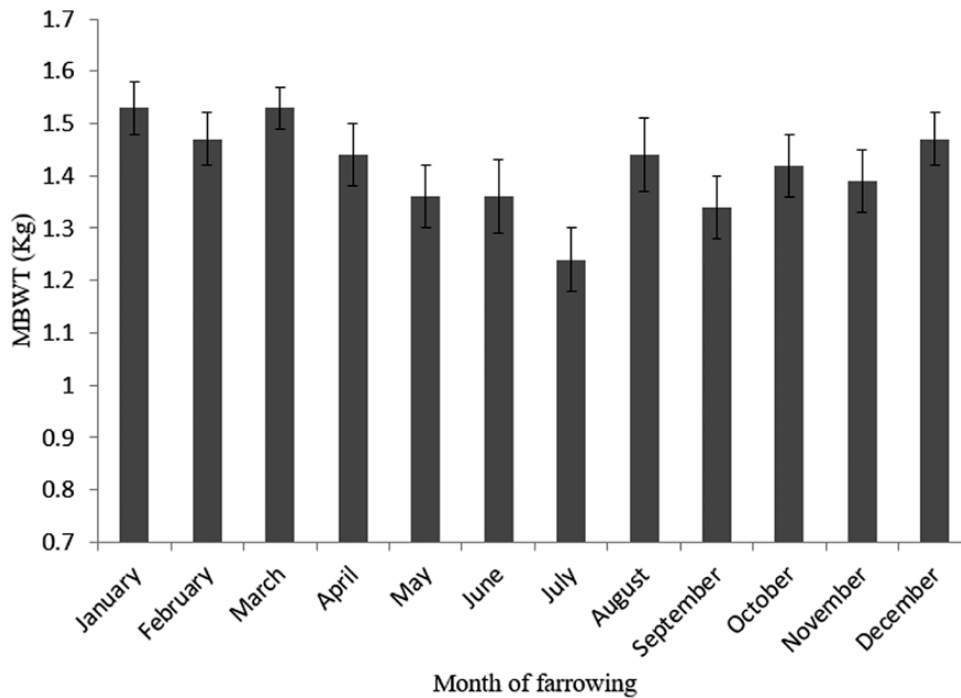


Figure 1. Mean birth weight (MBWT) for litters farrowed in different months.

Table 5. Relationship coefficients (\pm s.e.) of number born alive (NBA) on sex ratio, within-litter birth weight coefficient of variation (CVBWT), mean birth weight (MBWT), total litter weight at birth (BWT), total litter weight at weaning (WWT), within-litter weaning weight coefficient of variation (CVWWT), Mean weaning weight (MWWT), within-litter minimum birth weight (MinBWT), within-litter maximum birth weight (MaxBWT), within-litter minimum weaning weight (MinWWT), within-litter maximum weaning weight (MaxWWT) and percent survival at weaning ($N = 310$).

Parameter	Regression coefficient		Significance
	Linear	Quadratic	
Sex ratio	0.002 \pm 0.0086	0.001 \pm 0.0004	NS
CVBWT	–	0.042 \pm 0.0051	**
MBWT	–0.023 \pm 0.0048	–	**
BWT	1.213 \pm 0.0588	0.055 \pm 0.0029	**
MinBWT	–0.034 \pm 0.0064	–0.002 \pm 0.0003	**
MaxBWT	0.001 \pm 0.0062	–0.003 \pm 0.0003	NS
CVW	0.892 \pm 0.1427	0.041 \pm 0.0068	**
MWWT	–0.131 \pm 0.0325	–0.006 \pm 0.0016	**
WWT	4.612 \pm 0.4095	0.206 \pm 0.0200	**
SVW	–0.884 \pm 0.2582	–	**
MinWWT	–0.288 \pm 0.0337	–0.013 \pm 0.0016	**
MaxWWT	0.006 \pm 0.0424	0.001 \pm 0.0020	NS

Relationships Between Sex Ratio and Litter Performance at Birth and Weaning

The odds ratios of the gender of piglets with MinBWT, MaxBWT, MaxWWT, MinWWT

within a litter are shown in Table 7. As indicated by the significant odds ratios, male piglets were six times more likely to be the heaviest in a litter whilst female piglets were four times more likely to be the lightest at birth. Female piglets were 33 times (multiplicative inverse of 0.03) more likely to be the heaviest and lightest within their litters at weaning ($P < 0.05$).

Sex ratio had no relationship with MBWT, BWT, MWWT, MaxBWT, MinWWT, and MaxWWT ($P > 0.05$). Figures 2–4 illustrate the relationship of sex ratio with CVBWT, CVWWT, and SVW, respectively. The CVBWT and CVWWT had quadratic relationships with sex ratio ($P < 0.05$). As the proportion of males in litters increased, CVBWT and CVWWT generally increased reaching maximum as the proportion of males in litters approached 0.5 and then increased from there onwards. As the proportion of males in litters approached 1, CVBWT and CVWWT reached their least values. As the proportion of males in litters increased, SVW increased linearly ($P < 0.05$).

DISCUSSION

The observed NBA mean and range tallies with Umesiobi (2009) and Zindove et al. (2013) who reported that, to date, sows from most breeds exhibit NBA of over 10. Mungate et al. (1999) and Marandu et al. (2015) also reported similar NBA values for pig litters. This shows that there has been a remarkable progress in improving

Table 6. Pearson's correlation coefficients among sow performance traits at farrowing and at weaning.

Variable	BWT	CVBWT	MinBWT	MaxBWT	WWT	MWWT	CVWWT	MinWWT	MaxWWT	SVW
MBWT	0.05 ^{ns}	0.04 ^{ns}	0.04 ^{ns}	0.09 ^{ns}	0.41**	0.17**	-0.004 ^{ns}	0.10 ^{ns}	0.02 ^{ns}	0.22**
BWT		0.05 ^{ns}	0.07 ^{ns}	0.07 ^{ns}	0.60**	0.19 ^{ns}	0.02 ^{ns}	0.02 ^{ns}	0.03 ^{ns}	0.02 ^{ns}
CVBWT			0.09 ^{ns}	0.06 ^{ns}	0.02 ^{ns}	0.01 ^{ns}	0.23**	-0.02 ^{ns}	-0.09 ^{ns}	-0.46*
MinBWT				0.38**	0.01 ^{ns}	0.13*	0.04 ^{ns}	0.12*	0.12**	0.07 ^{ns}
MaxBWT					0.09 ^{ns}	0.19**	-0.03 ^{ns}	0.12*	0.23**	0.02 ^{ns}
WWT						0.53**	-0.03 ^{ns}	0.01 ^{ns}	0.04 ^{ns}	0.32**
MWWT							-0.07 ^{ns}	0.75**	0.89**	0.10 ^{ns}
CVWWT								-0.05 ^{ns}	-0.06 ^{ns}	-0.04 ^{ns}
MinWWT									0.47**	0.08 ^{ns}
MaxWWT										0.04 ^{ns}

NS, not significant ($P > 0.05$); MBWT, mean birth weight; BWT, Total litter weight at farrowing, CVBWT, within-litter birth weight coefficient of variation; MinBWT, minimum birth weight for each litter; MaxBWT, maximum birth weight for each litter; WWT, litter weight at weaning; MWWT, mean litter weight at weaning; CVWWT, within-litter weight coefficient of variation; SVW, percent survival of piglets at weaning; MinWWT, minimum weaning weight for each litter; MaxWWT, maximum weaning weight for each litter; * $P < 0.05$; ** $P < 0.01$.

Table 7. Odds ratio estimates, lower (LCI) and upper confidence (UCI) interval of a piglet with minimum birth weight for each litter (MinBWT), maximum birth weight for each litter (MaxBWT), maximum weaning weight for each litter (MaxWWT), (minimum weaning weight for each litter) MinWWT to be male ($N = 310$).

Parameter	Odds ratio	Lower CI	Upper CI
MinBWT	0.26*	2.90	5.03
MaxBWT	6.12*	4.59	8.15
MinWWT	0.03*	0.02	0.05
MaxWWT	0.03*	0.02	0.04

* $P .00.05$.

NBA over the past decade. Progress in improving NBA over time is also evident herein, with NBA increasing from 2017 to 2019. There are, however, some studies which have recorded NBA ranging from 14 to 18 piglets for hybrid sows (Schild et al., 2020). The differences in NBA could be due to differences in breeds and structure of the pig herds under study. Although suggestive, our present analysis can, therefore, not be used to make conclusions on other breeds commonly found in commercial herds such as Landrace-Yorkshire crossbred sows. Differences in litter sizes might result in conflicting results. The observed MBWT and its standard deviation were similar to Zindove et al. (2013) and Marandu et al. (2015) who reported a MWBT of 1.55 kg and an SD of 0.33 and 1.5 kg and SD of 0.26, respectively. Wide range and high standard deviation values for sex ratio, CVBWT, and CVWWT indicate that these are highly variable traits. The mean sex ratio observed

in this study is lower than that reported by Baxter et al. (2012).

In agreement with the current study, Soede et al. (2000), Gorecki (2003) and Alfonso (2002) reported that sex ratio is not influenced by parity of sow, month of farrowing, year of farrowing and litter size. These findings suggest that variation in sex ratio is not caused by environmental factors. Toro et al. (2006) suggested that genetic variance for sex ratio in litters does exist in pigs and some genotypes have a genetic tendency to produce more progeny of the one sex than the other. Genetic selection for sex ratio is, therefore, a possibility. The pig herd used for the study was comprised of the same genotype from 2016 to 2019 and this could explain the finding that sex ratio did not vary over the years.

Litters from primiparous sows and sows in their late parities had smaller litters, this being attributable to reports that gilts and young sows have low ovulation rates compared to mature sows (Mungate et al., 1999). Reduction in NBA in sows in parities greater than six can be attributed to high incidences of farrowing problems which lead to higher piglet mortalities that reduce NBA. The effect of parity on CVBWT, BWT and MinBWT can be attributed to parity effects on NBA. The same can also be said about the effect of year on BWT, CVBWT, MWWT, and CVWWT. During the years when NPB and NBA were high, BWT, CVBWT, MWWT, and CVWWT were also high.

The observation that an increase in NBA resulted in adverse changes in litter performance traits such as CVBWT, MBWT and SVW is in agreement with previous findings (Milligan et al., 2002), Wolf et al., 2007; Zindove et al., 2013). Although, NBA is an important contributor

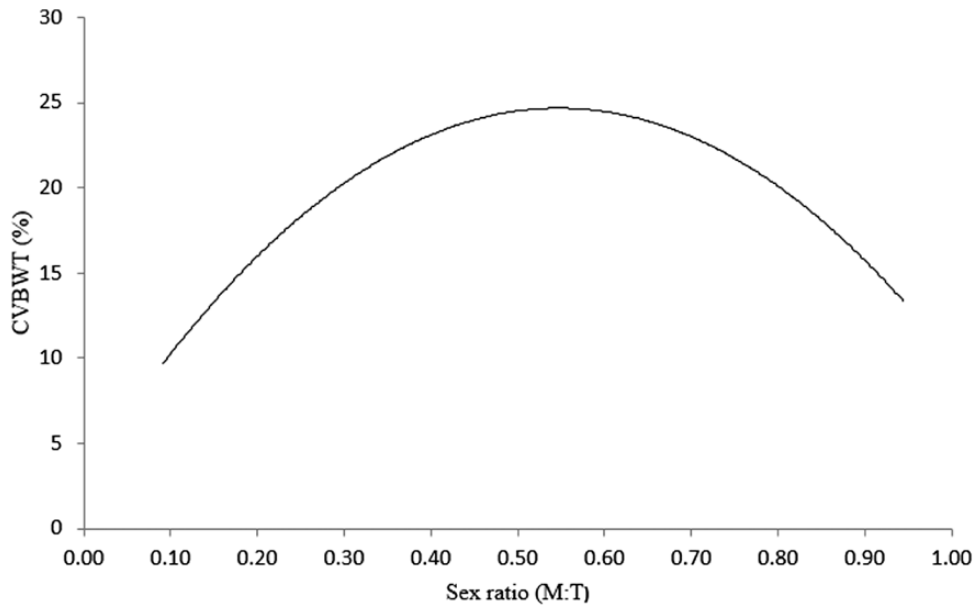


Figure 2. Relationship between sex ratio and within-litter birth weight variation (CVBWT). $Y = -71.88x^2 + 78.71x + 3.13$ ($P < 0.05$). M: T = Male piglets in a litter: Total number of piglets in the litter.

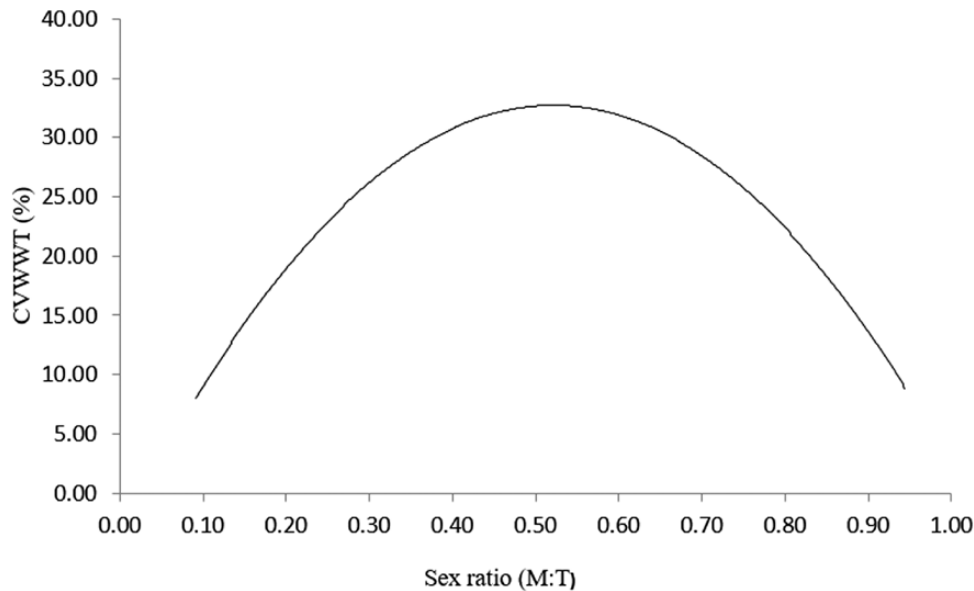


Figure 3. Relationship between sex ratio and within-litter weaning weight variation (CVWWT). $Y = -133.39x^2 + 139.12x - 3.56$ ($P < 0.05$). M: T = Male piglets in a litter: Total number of piglets in the litter.

to maximizing number of piglets weaned per sow per year, large litters comprised of light weighing piglets can have negative effects on the profitability of the enterprise. Light litters at birth have been found to be associated with slow growth (Zindove et al., 2013). Large litters at farrowing also do not guarantee large litters at weaning since they are associated with a high level of losses due to pre-weaning mortality (Zindove et al., 2013).

The finding that CVBWT increased as NBA increased could be the reason why large litters are associated with low mean litter weights

and increased pre-weaning losses. It is pointless having large numbers of piglets born if they result in unacceptable levels of pre-weaning mortality, slow growths and undesirable carcass traits. Reducing CVBWT could help reduce losses and increase litter weight at birth and weaning and, thus, maximizing profit. The negative relationship between CVBWT and MinBWT confirms suggestions by Zindove et al. (2013) that, in large litters, high CVBWT results in fetal growth retardation. Retarded piglets at birth usually suffer from stunted growth and are more likely to die before weaning (Foxcroft, 2008). This could explain the

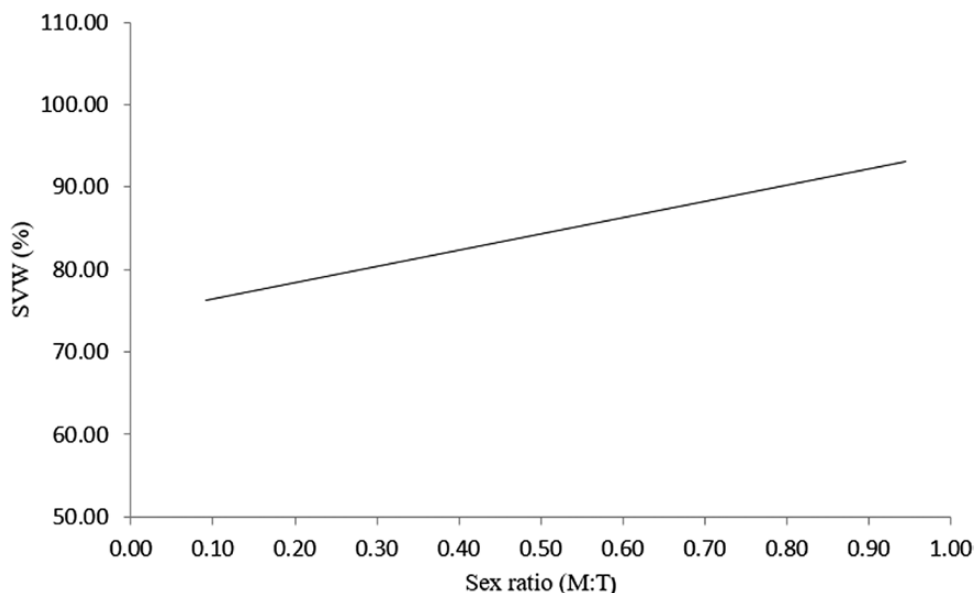


Figure 4. Relationship between sex ratio and percent survival of piglets at weaning (SVW). $Y = 19.81x + 74.44$ ($P < 0.05$). M: T = Male piglets in a litter: Total number of piglets in the litter.

finding herein that as CVBWT increased; MWWT, MinWWT, and SVW decreased. Similar observations were reported previously (Milligan et al., 2002; Zindove et al., 2013).

Confirming reports by Milligan et al. (2001) and Canario et al. (2010), CVWWT increased as NBA increased. The observed relationship between NBA and CVWWT can be attributed to effects of NBA on CVBWT. Variation in litters at birth is maintained up to weaning through to marketing (Zindove et al., 2013). Increased NBA, thus, results in large weight variation at birth which is maintained up to weaning (Marandu et al. 2015) and marketing. Pigs can, thus, can be placed in the barn at once, but selected for marketing over an extended period of time because they reach market weight at different times. This makes revenue prediction difficult and results in “tail-end pigs,” thus unfavorable throughput and increased extra feed costs.

The observation that male piglets were more likely to be the heaviest at birth in a litter whilst female piglets were more likely to be the lightest is in agreement with Alfonso (2002) and Baxter et al. (2012) who reported that males are born on average heavier than their female littermates. This suggests that litter heterogeneity is influenced by gender proportion of the piglets in a litter. The sex of the piglet plays an important role in the growth rate of the developing fetus. The difference can be attributed to hormonal differences between the two sexes and their resultant effects on fetal growth. At weaning, females were more likely to be the lightest, indicating that piglets with prenatal stunting fail to catch up with their heavier

littermates. Heavy weighing by male piglets at birth is not sustained up to weaning as evidenced by females being more likely to be the heaviest at weaning. This might be attributed to greater susceptibility of the male piglets to causal environmental stressors such as heat. Male piglets have poorer thermoregulatory capacity compared to females (Baxter et al., 2012).

The decrease in CVBWT and CVWWT as the proportion of males in litters increased can imply that manipulating sex ratio can be used as a strategy to reduce CVBWT in litters. Reducing CVBWT and CVWWT through manipulating sex ratio of litters can help to optimize both NBA and within-litter weight variation. As evident in our findings, CVBWT and CVWWT can be optimized by sex standardization to produce single sex litters. Production of single sex litters will result in small variation in weight between littermates at birth and weaning. The weight of the litters will not be compromised by production of unisex litters since sex ratio does not have a significant relationship with MBWT, BWT and MWWT. Large litters with small CVBWT and CVWWT can, thus, be produced. This could help produce large litters with low levels pre-weaning mortality and variation at weaning and marketing and, therefore, optimal numbers of piglets weaned per year per sow will be achieved. It will be more beneficial to produce unisex female litters due to the finding that female piglets are more likely to be the heaviest at weaning. Production of unisex litters can be achieved through genetic selection for sex ratio (Toro et al., 2006) and use of sexed semen.

The finding that SVW increases as the proportion of males in litters increased concurs with findings herein that as the proportion of males increase, the CVBWT decreased. A decrease in CVBWT due to an increase in proportion of male piglets is expected to result in an increase in SVW since CVBW has a negative relationship with SVW. An increase in SVW as the proportion of males in a litter increased also agrees with the finding that MinBWT increases as the sex ratio increases. As MinBWT increases, SVW is expected to increase since heavy piglets are more likely to survive to weaning than light piglets (Quiniou et al., 2002; English and Bilkei, 2004). Litters with low CVBWT, as a result of a high proportion of male piglets, have more heavy piglets (Milligan et al., 2002). Heavy piglets are thought to be at a lesser possibility of death because they consume large amounts colostrum due to their vigor and are less susceptible to crushing by the sow (Cutler et al., 2006). Consumption of large amounts of colostrum is associated with good acquisition of passive immunity hence increases the piglets' chances for surviving to weaning (Quiniou et al., 2002).

CONCLUSIONS

Within-litter sex ratio does not vary with parity of sows, year and month of farrowing. Within-litter weight variation is largest in litters with equal numbers of male and female piglets and lowest in unisex litters. Manipulating sex ratio in litters could help reduce within-litter weight variation in large litters, hence reduce pre-weaning mortality, and improve uniformity at marketing and weaning. There is a need for further studies on the relationships between litter size, sex ratio, and within-litter weight variation at birth and their impact on subsequent litter traits of hybrid sows with larger litter sizes.

ACKNOWLEDGMENTS

The authors are grateful to the Pig Industry Board directorate for their support in the collection of data.

Conflict of interest statement. None declared.

LITERATURE CITED

- Alexopoulos, J.G., D.S. Lines, S. Hallett, K.J. Plush. 2018. A review of success factors for piglet fostering in lactation. *Animals*. 8:38. doi:10.3390/ani8030038.
- Alfonso, L. 2002. Sex ratio of offspring in pigs: farm variability and relationship with litter size and piglet birth weight. *Span J. Agric. Res.* 3:287–295. doi:10.5424/sjar/2005033-151.
- Baxter, E. M., S. Jarvis, J. Palarea-Albaladejo, and S. A. Edwards. 2012. The weaker sex? The propensity for male-biased piglet mortality. *Plos One* 7:e30318. doi:10.1371/journal.pone.0030318.
- Canario, L., H. Lundgren, M. Haandlykken, and L. Rydhmer. 2010. Genetics of growth in piglets and the association with homogeneity of body weight within litters. *J. Anim. Sci.* 88:1240–1247. doi:10.2527/jas.2009-2056.
- Cutler, R.S., V.A. Fahy, G.M. Cronin, and E.M. Spicer. 2006. Preweaning mortality. In: Straw, B.E., J.J. Zimmerman, S.D. D'Allaire, D.J. Taylor, editors. *Diseases of Swine*. Ames, Iowa, USA: Blackwell Publishing Ltd; p. 993–1010.
- English, J.G.H., and G. Bilkei. 2004. The effect of litter size and littermate weight on pre-weaning performance of low-birth-weight piglets that have been cross fostered. *Anim. Sci.* 79:439–443. doi:10.1017/S1357729800090305.
- Foxcroft, G. 2008. Hyper prolificacy and acceptable post-natal development- a possible contradiction. *Adv. Pork Prod.* 19:205–211.
- Foxcroft, G. R., W. T. Dixon, S. Novak, C. T. Putman, S. C. Town, and M. D. Vinsky. 2006. The biological basis for prenatal programming of postnatal performance in pigs. *J. Anim. Sci.* 84 Suppl:E105–E112. doi:10.2527/2006.8413_supple105x.
- Gorecki, M.T. 2003. Sex ratio in litters of domestic pigs (*Sus scrofa* f. *domestica* Linnaeus, 1758). *Biol. Lett.* 40:111–118.
- Marandu, N., T.E. Halimani, M. Chimonyo, A. Shoniwa, and T. Mutibvu. 2015. The effect of within litter variation on piglet survival and pre-weaning weight gain in a commercial herd. *J. Agr. Rural Dev. Trop.* 116:123–129.
- Milligan, B. N., D. Fraser, and D. L. Kramer. 2001. Birth weight variation in the domestic pig: effects on offspring survival, weight gain and suckling behaviour. *Appl. Anim. Behav. Sci.* 73:179–191. doi:10.1016/s0168-1591(01)00136-8.
- Milligan, B.N., D. Fraser, and D.L. Kramer. 2002. Within-litter birth weight variation in the domestic pig and its relation to pre-weaning survival, weight gain, and variation in weaning weights. *Livest. Prod. Sci.* 76:181–191. doi:10.1016/S0301-6226(02)00012-X.
- Mungate, F., K. Dzama, K. Mandisonza, and A. Shoniwa. 1999. Some non-genetic factors affecting commercial pig production in Zimbabwe. *S. Afr. J. Anim. Sci.* 29:164–173. doi:10.4314/sajas.v29i3.44202.
- Quiniou, N., J. Dagorn, and D. Gaudre. 2002. Variation of piglets' birth weight and consequences on subsequent performance. *Livest. Prod. Sci.* 78:63–70. doi:10.1016/S0301-6226(02)00181-1.
- Schild, S.A., L. Foldager, L. Rangstrup-Christensen, and L. J. Pedersen. 2020. Characteristics of Piglets Born by Two Highly Prolific Sow Hybrids. *Front. Vet. Sci.* 7:355. doi:10.3389/fvets.2020.00355.
- Schinckel, A.P., R. Cabrera, R.D. Boyd, S. Jungst, C. Booher, M. Johnston, P.V. Preckel, and M.E. Einstein. 2007. Modeling the impact of birth and twenty-day body weight on the postweaning growth of pigs. *Prof. Anim. Sci.* 23:211–223. Doi:10.15232/S1080-7446(15)30966-9.
- Soede, N. M., A. K. Nissen, and B. Kemp. 2000. Timing of insemination relative to ovulation in pigs: effects on sex ratio of offspring. *Theriogenology* 53:1003–1011. doi:10.1016/S0093-691X(00)00246-6.
- Statistical Analysis System. 2013. SAS/STAT user's guide, release 9.4. Cary (NC): SAS Institute Inc.
- Toro, M. A., A. Fernández, L. A. García-Cortés, J. Rodríguez, and L. Silió. 2006. Sex ratio variation in Iberian pigs. *Genetics* 173:911–917. doi:10.1534/genetics.106.055939.
- Umlesiobi, D.O. 2009. Vitamin E supplementation to sows and effects on fertility rate and subsequent body development of their weanling piglets. *J. Agr. Rural Dev. Trop.* 110:155–168.

- Widmar, D.A., N.J. Olynk, B.T. Richert, A.P. Schinckel, K.A. Foster. 2011. In Integrated on-farm decision making: economic implications of increased variation in litter size. In: Proceedings of the 2011 Annual Meeting, Corpus Christi, TX, USA, 5–8 February 2011. Southern Agricultural Economics Association, USA.
- Wolf, J., E. Zakova, and E. Groeneveld. 2007. Within-litter variation of birth weight in hyper prolific Czech Large White sows and its relation to litter size traits, stillborn piglets and losses until weaning. *Livest. Sci.* 115:195–205. doi:[10.1016/j.livsci.2007.07.009](https://doi.org/10.1016/j.livsci.2007.07.009).
- Zindove, T.J., E.F. Dzomba, M. Chimonyo. 2013. Effects of within-litter birth weight variation on performance at three weeks of age and at weaning in a Large White × Landrace sow herd. *Livest. Sci.* 155:348–354. doi:[10.1016/j.livsci.2013.04.013](https://doi.org/10.1016/j.livsci.2013.04.013).