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Phenotypic correlations between reproductive characteristics related to litter and reproductive cycle length in sows

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Abstract: The study estimated phenotypic correlations between reproductive traits in sows classified as maternal (Polish Large White, Polish Landrace, and Yorkshire) and paternal (Duroc, Berkshire, and Hampshire) components, kept on farms located in Poland and in the United States. Altogether, it used data on 736 litters from 196 sows to analyse traits related to litter and reproductive cycle length. The former included litter size, the numbers and the percentages of piglets born alive, stillborn, and weaned; the latter included gestation length, lactation length, and the lengths of weaning-to-conception, farrowing-to-conception, and farrowing intervals. The strongest positive correlations between the litter-related traits were those between litter size and the number of piglets born alive (0.90), the number and the percentage of piglets born alive (0.88), the numbers of piglets born alive and weaned (0.78), and litter size and the number of weaned piglets (0.68); the strongest negative correlations were between the percentage of piglets born alive and the percentage (–0.95) and the number (–0.82) of stillborn piglets. Among the traits related to reproductive cycle length, the strongest positive correlations were those between the length of weaning-to-conception interval and the lengths of farrowing-to-conception (0.96) and farrowing (0.97) intervals, and between the length of farrowing-to-conception interval and farrowing interval (0.98). Gestation length and lactation length were weakly negatively correlated (–0.25). Correlation coefficients between the traits related to litter size from one side and reproductive cycle length from the other were low and mostly statistically non-significant, suggesting that using phenotypic correlations can help improve economically important reproductive traits, but only within the two above-mentioned groups of traits.

Keywords: pigs; litter size; farrowing interval; phenotypic correlation; PCA

The breeding value of sows in terms of reproductive performance is assessed based on traits related to litter size and reproductive cycle length. These traits, in turn, strongly depend on the environmental conditions in which sows and their offspring are kept throughout the entire rearing period. Heritability coefficients reflect the influence of the genotype on reproductive traits. In sows, these coefficients for traits related to litter are low, ranging from 0.03 to 0.13 (Tyra and Rozycki 2004; Imboonta et al. 2007; Serenius et al. 2008), values that do not guarantee a quick improvement of breeding characteristics through selection using traditional methods.

However, most traits determining reproductive performance, are correlated, so selection for one of them can improve other traits (Tyra and Rozycki 2002). Thus, whether or not the simultaneous improvement of several breeding traits is likely to be effective depends on how strongly they are correlated.

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Currently, breeding researchers use mostly genetic correlation coefficients, paying much less attention to phenotypic correlations. The latter result from interactions between genetic and environmental factors. For traits of high heritability, the two types of correlations can differ a great deal; for traits of low heritability, they are close. Since current pig production is characterised by optimal – or close to optimal – nutritional and hygienic conditions, phenotypic correlations can illustrate organisational factors, providing valuable information on herd management.

A phenotypic correlation between litter size and the number of piglets born alive ranges from 0.83 (Ye et al. 2018) to 0.98 (Zhang et al. 2016b), and that between litter size and the number of stillborn piglets from 0.21 (Ye et al. 2018) to 0.26 (Popovac et al. 2012). Tyra and Rozycki (2002) observed a phenotypic correlation of 0.88 between the number of piglets born alive and weaned piglets in Polish Large White and of 0.87 in Polish Landrace sows. Lower values – 0.64 and 0.57, respectively – were reported by Dube et al. (2012) and Popovac et al. (2012), though for different breeds.

Some authors have pointed out that gestation length is correlated with litter size (Sasaki and Koketsu 2007; Chen et al. 2010), and others reported its relation with the number of weaned piglets and the length of the non-productive period (Gaustad-Aas et al. 2004; Koketsu et al. 2017). Only scarce research has focused on phenotypic correlations between these traits, however. Two examples are Imboonta et al. (2007) and Ziedina et al. (2011), but even though both studies considered phenotypic correlations between traits related to litter size and reproductive cycle length, the only trait they analysed from the second group was the length of the non-productive period.

This study aimed to estimate phenotypic correlations between traits characterising litter size and reproductive cycle length among sows classified as maternal (Polish Large White, Polish Landrace, and Yorkshire) and paternal (Duroc, Berkshire, and Hampshire) components, kept on production farms in Poland and in the United States.

MATERIAL AND METHODS

The study included data on 736 litters from 196 sows of six breeds: Polish Large White (45 sows), Polish Landrace (37), Yorkshire (40), Duroc (33), Berkshire (26), and Hampshire (15). The animals were kept on two farms located in Poland (Polish Large White, Polish Landrace, and Duroc) and on one farm in Texas, United States (Yorkshire, Duroc, Berkshire, and Hampshire).

The following litter-related traits were analysed: litter size, the number and the percentage of piglets born alive, the number and the percentage of stillborn piglets, and the number and the percentage of weaned piglets. The percentage traits were determined as the ratio of the respective number to litter size. The traits related to reproductive cycle length included the lengths of gestation and lactation, the weaning-to-conception interval (the number of days from weaning to successful conception), the farrowing-to-conception interval (the number of days from farrowing to the next gestation), and the farrowing interval (the number of days from one farrowing to the next one) (Table 1).

Statistical analysis was conducted using R 3.4.4 (R Core Team 2018). Summary statistics for the traits analysed were estimated using the *pastecs*

Table 1. Summary statistics for the analysed reproductive traits of sows (across the breeds studied)

Trait	Mean	Median	SD	Min	Max	CV (%)
TNB	12.2	12.0	3.56	2	23	29.2
NBA	11.0	11.0	3.39	0	20	30.8
%NBA	90.0	92.9	13.5	0	100	15.0
STB	1.23	1.00	1.63	0	13	132.5
%STB	9.96	7.14	13.3	0	100	133.5
NW	9.12	10.00	2.92	0	16	32.0
%NW	76.2	78.6	18.5	18	100	24.3
GL	115.2	115.0	2.01	104	125	1.7
LL	27.2	27.0	3.28	0	45	12.1
WCI	9.9	5.0	12.65	2	118	127.8
FCI	37.1	37.0	13.20	2	145	35.6
FI	152.0	148.0	13.01	117	261	8.7

%NBA = the percentage of piglets born alive; %NW = the percentage of weaned piglets; %STB = the percentage of stillborn piglets; CV = coefficient of variation; FCI = the length of farrowing-to-conception interval; FI = the length of farrowing interval; GL = gestation length; LL = lactation length; NBA = the number of piglets born alive; NW = the number of weaned piglets; SD = standard deviation; STB = the number of stillborn piglets; TNB = litter size (total number of born piglets); WCI = the length of weaning-to-conception interval

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package (Grosjean and Ibanez 2018), and phenotypic correlations using the *psych* package (Revelle 2018). Principal component analysis (PCA) was applied using *adegenet* (Jombart and Ahmed 2011), *ade4* (Bougeard and Dray 2018) and *factoextra* (Kassambara and Mundt 2017) packages.

RESULTS

Phenotypic correlations

The strongest positive correlation between the studied traits was 0.98 between the lengths of the farrowing and farrowing-to-conception interval (Table 2); other very strong correlations were those between the length of weaning-to-conception interval and the lengths of other two intervals: the farrowing-to-conception (0.97) and farrowing (0.96) ones. The strongest negative correlations were observed between the percentage of piglets born alive and the number (−0.95) and the percentage (−0.82) of stillborn piglets.

Positive, very strong and statistically significant correlations were detected between litter size and the number of piglets born alive (0.90), and between the number and the percentage of stillborn piglets (0.88). Positive, either strong or moderate, statistically significant correlations, ranging from 0.37 to 0.78, were found between litter size and the number of weaned piglets as well as between the number and the percentage of piglets born alive. The number of weaned piglets negatively correlated with the number of stillborn piglets and gestation length.

The number of piglets born alive was rather weakly, although statistically significantly, correlated with the percentage of piglets born alive (0.40), and so it was – but negatively – correlated with the percentage of stillborn piglets (−0.36).

The percentage of weaned piglets positively though moderately correlated with the number of piglets born alive (0.56) and the percentage of weaned piglets (0.49). It was also negatively correlated with the number (−0.58) and percentage (−0.53) of stillborn piglets and litter size (−0.26). Weak but statistically significant correlations were also detected between the percentage of weaned piglets and the lengths of the weaning-to-conception, farrowing-to-conception, and farrowing intervals, with the coefficients being about 0.11–0.12.

Lactation length was negatively correlated with gestation length (−0.25) and positively with the length of the farrowing-to-conception interval (0.25), the length of the farrowing interval (0.29), the number of weaned piglets (0.13), and the number of piglets born alive (0.14). Gestation length positively, though weakly, correlated with the length of the farrowing-to-conception interval.

Table 2. Phenotypic correlations between the traits analysed

Trait	TNB	NBA	%NBA	STB	%STB	NW	%NW	LL	WCI	FI	FCI
GL	−0.22*	−0.22*	−0.06	−0.03	0.05	−0.20*	−0.02	−0.25*	0.06	0.01	0.16
TNB	1.00	0.90*	0.00	0.33*	0.04	0.68*	−0.26*	0.12*	0.00	0.02	−0.01
NBA	–	1.00	0.40*	−0.10	−0.36*	0.78*	−0.01	0.15*	0.02	0.05	0.02
%NBA	–	–	1.00	−0.82*	−0.95*	0.36*	0.56*	0.06	0.04	0.06	0.06
STB	–	–	–	1.00	0.88*	−0.12	−0.53*	−0.03	−0.04	−0.05	−0.06
%STB	–	–	–	–	1.00	−0.34*	−0.58*	−0.05	−0.04	−0.06	−0.06
NW	–	–	–	–	–	1.00	0.49*	0.13*	0.10	0.13	0.10
%NW	–	–	–	–	–	–	1.00	0.01	0.12*	0.11*	0.12*
LL	–	–	–	–	–	–	–	1.00	0.06	0.29*	0.25*
WCI	–	–	–	–	–	–	–	–	1.00	0.97*	0.96*
FI	–	–	–	–	–	–	–	–	–	1.00	0.98*

%NBA = the percentage of piglets born alive; %NW = the percentage of weaned piglets; %STB = the percentage of stillborn piglets; FCI = the length of farrowing-to-conception interval; FI = the length of farrowing interval; GL = gestation length; LL = lactation length; NBA = the number of piglets born alive; NW = the number of weaned piglets; STB = the number of stillborn piglets; TNB = litter size (total number of born piglets); WCI = the length of weaning-to-conception interval
*Phenotypic correlation significant at $P \leq 0.05$

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Principal component analysis

The first six principal components accounted for over 99% of variation in the data. Further analysis used the first three principal components, which accounted for over 75% of the variation. Table 3 shows their correlations with the traits studied.

The first principal component was associated with the number and percentage of piglets born alive (negative correlations), the number of weaned piglets (negative correlation), and the percentage of stillborn piglets (positive correlation). The second principal component was related to the lengths of the farrowing and farrowing-to-conception intervals (negative correlations); the third principal component, to litter size (positive correlation).

Figures 1–3 show how the individual traits affect the three principal components, with the direction and length of the vectors representing the influence of the respective traits on the principal components. Traits located close to each other in the graph are positively correlated; traits located on the opposite sides of the graph are negatively correlated. The longer the vector, the stronger the correlation it represents.

Table 3. Correlation coefficients between the original traits and the first three principal components

Trait	Principal component		
	PC1	PC2	PC3
TNB	–0.55	–0.35	0.72
NBA	–0.78	–0.08	0.55
%NBA	–0.74	0.60	–0.18
STB	0.56	–0.66	0.41
%STB	0.74	–0.60	0.18
NW	–0.79	–0.11	0.47
%NW	–0.61	0.40	–0.18
GL	0.27	0.07	–0.35
LL	–0.21	–0.30	0.11
WCI	–0.50	–0.68	–0.47
FI	–0.49	–0.71	–0.49
FCI	–0.54	–0.72	–0.41

%NBA = the percentage of piglets born alive; %NW = the percentage of weaned piglets; %STB = the percentage of stillborn piglets; FCI = the length of farrowing-to-conception interval; FI = the length of farrowing interval; GL = gestation length; LL = lactation length; NBA = the number of piglets born alive; NW = the number of weaned piglets; STB = the number of stillborn piglets; TNB = litter size (total number of born piglets); WCI = the length of weaning-to-conception interval

The graph showing the first principal component against the second (Figure 1) documents strong positive correlations between (1) the percentages of piglets born alive and weaned, (2) the numbers of piglets born alive and weaned, (3) the number and the percentage of stillborn piglets, and (4) the lengths of the weaning-to-conception, farrowing-to-conception, and farrowing intervals. The strongest negative correlations were detected between the number of stillborn piglets and the percentages of piglets born alive and weaned; similar correlations were obtained between the last two traits and the percentage of stillborn piglets.

Figure 2, visualising the first principal component against the third, shows the strongest correlations between (1) litter size and the numbers of piglets born alive and weaned, and (2) between the traits related to reproductive cycle length (the lengths of the weaning-to-conception, farrowing-to-conception, and farrowing intervals). The strongest negative correlations were between (1) the number of stillborn piglets and the lengths of the weaning-to-conception, farrowing-to-conception, and farrowing intervals; (2) the percentage of stillborn piglets and the lengths of these three intervals; and (3) gesta-

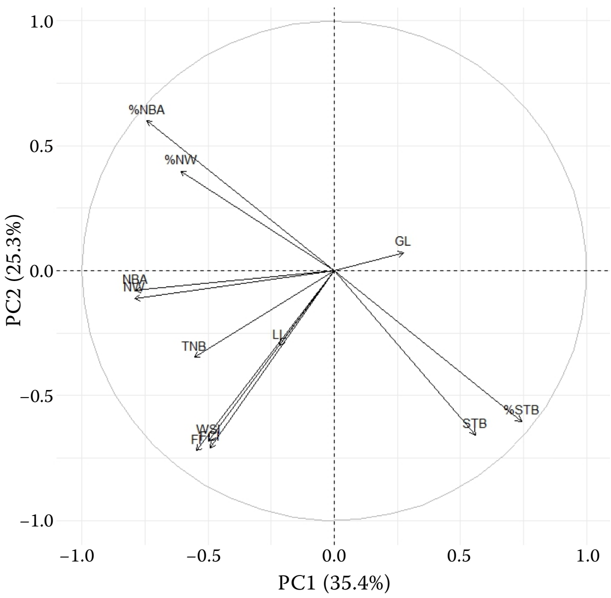

Figure 1. The scatterplot of loadings of PC1 against PC2. Direction and length of the vectors representing the influence of the respective traits on the principal components, with pairs of traits located close to each other in the graph being positively correlated and those on the opposite sides being negatively correlated

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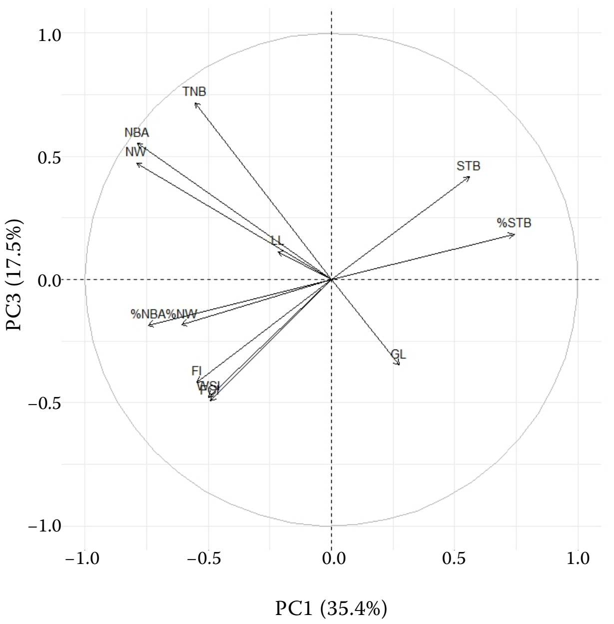

Figure 2. The scatterplot of loadings of PC1 against PC3. Direction and length of the vectors representing the influence of the respective traits on the principal components, with pairs of traits located close to each other in the graph being positively correlated and those on the opposite sides being negatively correlated

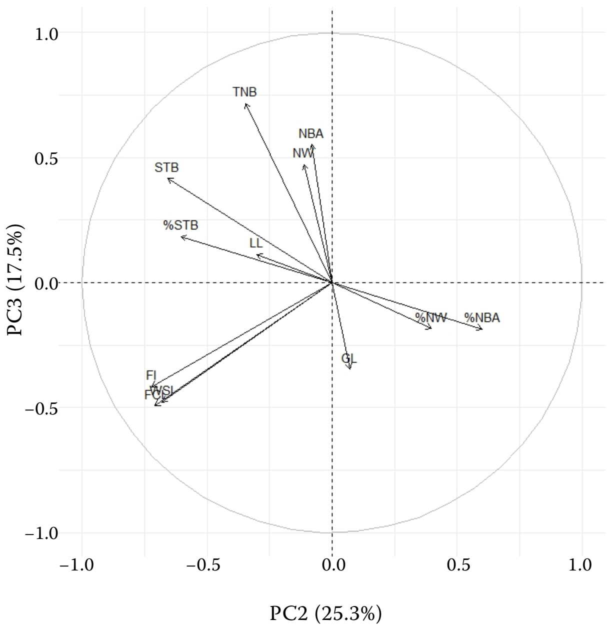

Figure 3. The scatterplot of loadings of PC2 against PC3. Direction and length of the vectors representing the influence of the respective traits on the principal components, with pairs of traits located close to each other in the graph being positively correlated and those on the opposite sides being negatively correlated

tion length and the traits related to litter (litter size and the numbers of piglets born alive and weaned). Gestation length correlated with neither the number of stillborn piglets nor the length of the farrowing interval.

The graph for the second against the third principal components (Figure 3) shows strong positive correlations between litter size and the number of stillborn piglets, and between the traits related to reproductive cycle length, that is, the lengths of the weaning-to-conception, farrowing-to-conception, and farrowing intervals.

DISCUSSION

We found strong positive phenotypic correlations between the litter-related traits, the strongest of which being that between litter size and the number of piglets born alive (0.90), a result confirming observations by Zhang et al. (2016a), Lukac et al. (2016), Lee et al. (2015), and Popovac et al. (2012), in whose studies this correlation ranged from 0.90 to 0.92. Some others, however, reported slightly different estimates, but all were quite close to 0.90 [0.98 in Zhang et al. (2016b), 0.97 in Radovic et al. (2016), 0.86 in Oh et al. (2006), and 0.83 in Ye et al. (2018)].

Litter size was weakly positively correlated (0.33) with the number of stillborn piglets, like in Zhang et al. (2016a), who reported a phenotypic correlation of 0.36 between these traits. Popovac et al. (2012), however, reported a slightly smaller value of 0.26. They also reported a weak negative correlation between the numbers of piglets born alive and stillborn (−0.16), a similar value to that we observed (−0.10). Neither these coefficients nor that reported by Zhang et al. (2016a) were statistically significant, but the one estimated by Ye et al. (2018) was (−0.29, significant at $P \leq 0.05$). Such a negative correlation between these traits may result from the fact that larger litters often require longer labour, thereby increasing a risk of premature termination of the umbilical cord and the resulting risk of hypoxia, especially among the last-born piglets (Panzardi et al. 2013). Small litters can suffer from different problems, however. For example, heavy piglets – and small litters often consist of heavier piglets than do large litters – can bring about problems during farrowing, possibly extending the period

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between subsequent parturitions in a given litter, which in turn increases the probability of having a dead piglet (Vallet et al. 2010). Thus, our results may indicate that the litters in our study had optimal sizes and weights, and that the farrowing processes were successful.

We observed high correlation coefficients between the number of weaned piglets and litter size (0.68) and the number of piglets born alive (0.78), higher than those reported by other researchers, namely 0.63 and 0.57 in Lukac et al. (2016) and 0.48 and 0.59 in Oh et al. (2006). So high values of these correlation coefficients we obtained in the study may indicate that the conditions in which the animals were kept and the piglets were raised were optimal. Popovac et al. (2012) observed much lower values of these coefficients: 0.23 and 0.28, respectively, both statistically significant. Radovic et al. (2016), however, did not detect any statistical significance of these coefficients in their study, a possible reason being the farm's attempt to equalise the litters. Variation in phenotypic correlations between the litter-related traits (litter size and the numbers of piglets born alive and weaned) may result from the fact that different sows, and particularly sows of different breeds, differ in behaviour, milk production, and how careful they are as mothers (Schwarz et al. 2009) – but also from environmental factors, including feeding and herd management. Lukac et al. (2016) observed higher correlation coefficients between litter-related traits in multiparous sows than in primiparous ones, an observation likely indicating that the reproductive capacity increases with age. This interpretation led Lukac et al. (2016) to conclude that another important factor affecting this variation in correlation coefficients may be the number of farrowings a sow has had.

Analysing the traits related to reproductive cycle length, we observed positive correlations between the length of the weaning-to-conception interval and the lengths of both the farrowing-to-conception (0.96) and the farrowing (0.97) intervals. These two traits were also strongly positively correlated (0.98), an understandable phenomenon because the length of the weaning-to-conception interval, along with lactation length, is the primary factor behind the length of both these intervals. It is difficult to compare our results with the current knowledge, since studies on phenotypic correlations between indicators characterising reproductive cycle length in pigs are missing. We might thus consider other livestock species, although even then such studies are scarce. Lopez et al.'s (2019) study is among the exceptions. Examining reproduction-related parameters in Korean cattle, Hanwoo, the authors estimated the phenotypic correlation between the number of days open and the length of the calving interval at 0.93, a similar value to the corresponding coefficient in our research.

Gestation length in sows varies only a little, most of the time being 115 days (Sasaki and Koketsu 2007), thus only slightly affecting the lengths of the farrowing-to-conception and farrowing intervals. Our results confirm this, with the respective correlation coefficients being 0.16 and 0.01. Mostly regulated by the farmer, lactation length depends on production intensity (Weaver et al. 2014), and so this trait should be correlated only loosely – or not at all – with the lengths of the farrowing-to-conception and farrowing intervals. It was so in our study, with the respective correlation coefficients of 0.25 and 0.29.

As was the case with correlations between the traits related to reproductive cycle length, only a few studies have reported correlations between these traits and those related to litter. For example Ziedina et al. (2011) showed that the length of the non-productive period did not correlate with the numbers of piglets born alive, stillborn and weaned (the respective coefficients were −0.02, 0.01 and 0.04). Our study provided similar results, with the respective correlation coefficients of 0.02, −0.04 and 0.10, all being non-significant at the significance level of 0.05. Studying whether litter size is related to the length of the weaning-to-conception interval, Imboonta et al. (2007) observed similar values of phenotypic correlations, ranging from −0.05 to 0.03. Some authors have pointed out a positive relation between the length of the non-productive period and litter size (Tantasuparuk et al. 2000), which may be associated with the better replenishment of energy reserves after lactation (Segura Correra et al. 2014). Finding this relation as non-significant, just as Kemp and Soede (1996) did, our results, however, did not confirm these observations.

Many authors have reported close relationships between gestation length and litter-related traits (Sasaki and Koketsu 2007; Chen et al. 2010), a phenomenon possibly related to the limited uterine capacity (Rosendo et al. 2012) and duration of the

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parturition (Panzardi et al. 2013). All these authors observed that sows giving birth to the largest litters often had the shortest gestation. Our results partially confirmed this phenomenon, with statistically significant, negative but weak correlations between gestation length and litter size (−0.22) and the number of piglets born alive per litter (−0.22); gestation length, however, did not correlate with the number of stillborn piglets (−0.03). Zhang et al. (2016a) reported similar though weaker correlations (−0.14, −0.11, −0.07, respectively).

The most fertile sows usually have the shortest gestations and the longest lactation. This is so because if the farm uses a production system in which all piglets born during a particular week are weaned on the same day, a shorter gestation extends lactation. We can see this phenomenon in our results, which showed weak but positive and statistically significant correlations between lactation length and litter size (0.12), the number of piglets born alive (0.15), and the number of weaned piglets (0.13); and a weak but negative and statistically significant correlation between lactation and gestation lengths (−0.25).

CONCLUSIONS

We obtained very strong positive phenotypic correlations for several traits related to both litter size and reproductive cycle length, and very strong negative correlations for several traits related to litter size. For most pairs of traits of which one trait is related to litter and the other to reproductive cycle length, however, we did not find any statistically significant phenotypic correlations, and most of those that proved significant – whether negative or positive – were mostly weak or very weak.

Phenotypic correlations between reproductive traits related to both litter size and reproductive cycle length have seldom been estimated in sows. Since phenotypic correlations combine genetic and environmental factors, such studies can provide a useful tool to verify herd management and the course of reproductive cycle. The approach we used, i.e. combining univariate correlation analysis with multivariate principal component analysis, enabled us to analyse relationships between the studied traits more deeply than we would when using only univariate methods. Using phenotypic correlations as a tool for enhancing breeding progress gives one an opportunity to improve economically important traits related to reproduction, although only within traits related to either litter size or reproductive cycle length, but not both at the same time.

Conflict of interest

The authors declare no conflict of interest.

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