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Analysis of fertility in Simmental cattle – genetic and environmental effects on female fertility

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ABSTRACT. The objectives of the study were to estimate genetic parameters for some fertility traits and to evaluate the effects of month of calving, first calving year, and age at first calving on four fertility traits of Polish Simmental cows. Lactation records from the first two lactations of 2 413 Simmental cows were analysed. The data came from the Polish National Recording System (SYMLEK), made available by the Polish Federation of Cattle Breeders and Dairy Farmers. The cows, born between 1995 and 2016, were daughters of 335 sires. The analysed parameters were interval from first service to conception for heifers (IFSh) and for cows in second parity (IFS2), interval from first calving to first insemination (CTFI) and days open (DO). The BLUPf90 package and a Bayesian method via Gibbs sampling were used to estimate (co)variance components. Mean IFSh was approx. 14 days and mean IFS2 was more than 26 days. Average length of CTFI was approx. 80 days, and of DO approx. 106 days. All heritabilities were low and ranged from 0.041 (CTFI) to 0.104 (IFS2). Genetic correlations were moderate to high, with two exceptions: the correlation of IFS2 with CTFI (0.186) and with IFSh (−0.284). IFSh was highly genetically correlated with CTFI, IFS2 and DO. It is recommended to supplement the selection index with interval from first service to conception for both heifers and cows in second parity, to enable effective improvement of female fertility scores in the Simmental population in Poland.

Introduction

Over many decades in the not-distant past, genetic selection of dairy cattle populations was focused on increased milk yield and good milk quality. Due to rapid technological progress in computing and the application of more advanced statistical methods in breeding value estimation programs, great progress in the genetics of milk production was achieved, but as a consequence, many traits connected with udder and legs health as well as reproduction of cows deteriorated, causing significant economic losses for breeders.

At the turn of the 20th and 21st centuries, selection programs in many countries began to be altered towards a more balanced breeding goal, oriented on the functional as well as the production traits. Functional traits encompassing health, fertility and longevity, as well as traits related to the calving process, milking temperament and milking speed, now play an important role in the selection indices used in dairy cattle breeding. The focus on a balanced breeding goal in which functional traits are taken into account also stems from breeders' and consumers' concern for animal welfare (Miglior et al., 2017).

There are methods of controlling the estrous cycle, ovulation induction, and timed insemination, but dairy cow fertility has declined, especially in high-producing herds (Jaśkowski et al., 2006). This trend is confirmed by the antagonistic genetic relationship between yield and female fertility reported in many studies over the years (Kadarmideen et al., 2003; González-Recio et al., 2006; Abe et al., 2009; Zink et al., 2012). Lucy (2001) suggested that selection for higher yield of dairy cows might lead to decreasing female fertility because the reproductive physiology of dairy cattle has changed over the years as a response to genetic selection for milk production.

Poor fertility increases the cost of milk production through higher culling rates, veterinary costs, higher number of inseminations and longer calving intervals (Brzáková et al., 2019), and worse fertility is the major limiting factor for cow longevity (Wathes et al., 2008). Hayes et al. (1992) found that many environmental factors have a very strong influence on fertility traits. Fertility can change with cow age and is often dependent on a cow's previous performance. Some authors have speculated that the higher culling risk for cows that first calved at later age might be due to fertility problems (Wathes et al., 2008; 2014; Sung et al., 2016). Additionally, high ambient temperature adversely affects both milk production and fertility in dairy cows. Heat stress during the summer disrupts several reproductive processes, contributing to reduced milk production and lowering the conception rate of dairy cows (Wolfenson and Roth, 2019). Among the factors influencing the reproductive performance of cattle, herd management also plays a very important role (Martinez-Castillero et al., 2020). Jaśkowski et al. (2006) noted that nutritional mistakes during the transition period, as well as unilateral selection for high milk production, could considerably worsen the fertility of dairy cows. High-yielding cows require sufficient body energy for milk production; very often they experience a negative energy balance in early stages of lactation. A long-lasting negative energy balance affects reproductive performance and is associated with greater female fertility problems (Zink et al., 2011).

The relationship between production traits andfertility can vary from herd to herd, breed to breed, and individual to individual within a breed (Windig et al., 2005). Dual-purpose breeds such as the Simmental breed are less susceptible to herd-level influences than dairy breeds such as Holstein-Friesians or Brown Swiss (Toledo-Alvarado et al., 2017).

Direct selection for fertility is difficult: there is no single measure of fertility, and the traits used for improving fertility are lowly heritable (Kadarmideen et al., 2003; Jamrozik et al., 2005; Zink et al., 2011; 2012; Guo et al., 2014; Buaban et al., 2015; Miglior et al., 2017; Muuttoranta et al., 2019). Traits connected with reproduction and used all over the world in breeding programs include calving interval, interval between calving and first insemination, interval between first and successful insemination, interval between first calving and conception (days open), non-return rates, insemination index, age at first calving, and age at first service (Brzáková et al., 2019). Additionally, linear type traits such as body condition score (BCS) and feet and legs traits are incorporated into selection indexes for fertility (Zink et al., 2011).

Interbull, the international organization involved in the harmonisation and improvement of methods of performance testing and genetic evaluation, has conducted genetic evaluation of female fertility traits since 2007 (Interbull, 2021). Among the more common traits used for assessing fertility of dairy cows are interval from calving to first insemination, non-return rate, conception rate, interval between first and successful insemination, and days open (Muuttoranta et al., 2019).

In Poland, a fertility subindex has been part of the selection index used in Simmental cattle breeding over the last 15 years. Four fertility traits are included in the subindex: conception rate of heifers, conception rate of cows, length of interval from calving to first insemination, and days open, with the strongest weight placed on conception rate for heifers (70%) and equal weights of 10% on the other three traits. Conception rate is defined as the ratio of 100 to the number of inseminations up to success (IZOO, 2023). In Germany, two service periods – intervals from first to last insemination of heifers and of cows – are traits included in the breeding value evaluation for female fertility (VIT, 2023). For international harmonisation of fertility traits, it is worth considering inclusion of the same two traits in the evaluation system in Poland. Here we note that the extent to which new traits are correlated with traits already in a selection system should be verified.

The objectives of this study were twofold: firstly, to estimate genetic parameters for interval from first service to conception for heifers and for cows in second parity, interval from first calving to first insemination, and days open; and secondly, to evaluate the effects of month of calving, first calving year and age at first calving on the above-mentioned fertility traits of Polish Simmental cows. The results may be used to develop management guidelines for Simmental cattle in Poland.

Material and methods

Data

Lactation records from the first two lactations of 2 413 Simmental cows were analysed. The data came from the Polish National Recording System (SYMLEK) and were made available by the Polish Federation of Cattle Breeders and Dairy Farmers. Polish population of Simmentals is small, and cows of this breed are traditionally kept on small farms (with a few animals) mainly in the south-eastern part of Poland. According to the Polish Federation of Cattle Breeders and Dairy Farmers, the number of Simmental cows included in the routine breeding value evaluation is approximately 10 000.

The cows, born between 1995 and 2016, were daughters of 335 sires. The cows calved for the first time at age 18–48 months in 189 herds between 1998 and 2018. On average, there were approx. 13 cows per herd (with a standard deviation of 35.31). The distribution of herd size is presented in Figure 1. Two seasons of calving were assumed (October–March, April–September).

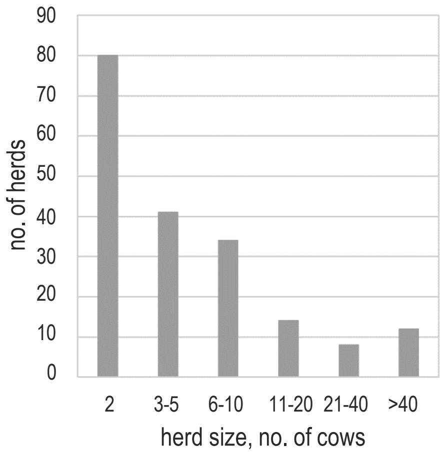

Figure 1. Herd size distribution of Simmental cows in Poland

Statistical analyses

Fertility measures were calculated as interval measures based on calving and insemination dates. The following fertility traits were analysed:

1. IFS (days) – interval from first service to conception for heifers (IFSh) and for second parity cows (IFS2),
2. CTFI (days) – interval from first calving to first insemination,
3. DO (days) – days open, i.e. interval between first calving and conception.

Data were restricted to a minimum of 2 daughters per sire and a minimum of 2 contemporaries per herd-year of first calving or first insemination subclasses. More than 80% of half-sib family groups in the restricted file comprised 2–10 cows (Table 1). When the restrictions were imposed, approximately 25% of Polish Simmental data remained for analysis.

Table 1. Distribution of size of progeny groups in the file restricted to 10 daughters per sire

Number of daughters	Number of sires
2	89
3–4	100
5–10	84
>10	62
Total	335

The BLUPf90 package and a Bayesian method through via Gibbs sampling were used to estimate the (co)variance components (Misztal, 2008). The linear model used for IFSh and IFS2 was as follows:

$$Y_{ijkl} = a_i + HYI_j + M_k + \beta \cdot AFI_l + \varepsilon_{ijkl},$$

where: Y_{ijkl} – IFSh or IFS2 for the *i*-th cow insemination for the first time in the *j*-th herd-year (*HYI*) subclass in the *k*-th month of year of first insemination (*M*) at the /-th age (AFI); a_i – random additive genetic effect (with 4 597 levels); HYI_j – fixed effect of herd-year of first insemination (with 490 and 493 levels in first and second parities, respectively); M_k – fixed effect of month of year of first insemination (with 12 levels); β – linear regression of Y on age at first insemination (*AFI*); AFI_l – age at first insemination (9–38 and 20–50 months in first and second parities, respectively); ε_{ijkl} – residual effect.

The following linear model for CTFI and DO was used:

$$Y_{iikl} = a_i + HY_i + M_k + \beta \cdot AFC_l + \varepsilon_{iikl},$$

where: Y_{ijkl} – CTFI or DO for the *i*-th cow calved for the first time in the *j*-th herd-year (*HY*) subclass in the *k*-th month of year of first calving (*M*) at the at /-th age (AFC); a_i – random additive genetic effect (with 4 597 levels); HY_j – fixed effect of herd-year of first calving (with 487 levels); M_k – fixed effect of month of year of first calving (with 12 levels); β – linear regression of Y on age at first calving (*AFC*); AFC_l – age at first calving (18–48 months); ε_{ijkl} – residual effect.

A total of 100 000 samples of (co)variance components were generated, with the first 10 000 samples discarded as burn-in. From the remaining 90 000 samples, only every fifth sample was written for use in further calculations.

The effects of month of calving, first calving year and age at first calving on CTFI, DO, IFSh and IFS2 were analysed using the Kruskal-Wallis test with the Dunn post-hoc test. Statistical procedures were performed using R software (R Core Team, 2022) with the PMCMRplus package (PMCMR-plus, 2023).

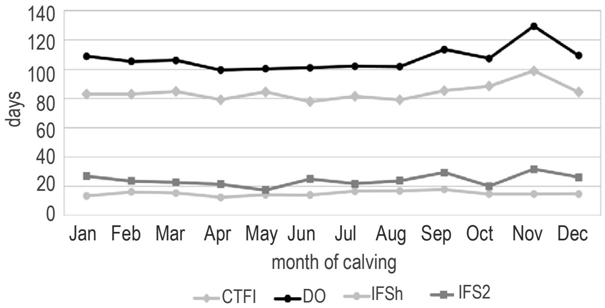

Figure 2. Phenotypic trends of interval from first service to conception for heifers (IFSh, $P = 0.1631$) and cows in second parity (IFS2, $P = 0.06305$), interval from first calving to first insemination (CTFI, $P < 0.0001$), and days open (DO, $P < 0.0001$), by calving month

Results

Descriptive statistics

Table 2 shows the means and standard deviations of interval from first to successful insemination before first (IFSh) and second (IFS2) parities, as well as interval from first calving to first insemination (CTFI), and days open (DO), i.e., the interval between first calving and conception of Simmental cows. The average length of IFSh was approx. 14 days; the average length of IFS2 was longer (more than 26 days). IFSh ranged from 1 to 176 days, and IFS2 from 1 to 220 days, with a value of 1 indicating success at first insemination. Approx. 75% of the heifers and more than 60% of the cows became pregnant at the first insemination.

Table 2. Descriptive statistics of female fertility traits of Simmental cows

Trait	Mean	Standard deviation	Minimum	Maximum
IFSh	14.3	29.9	1	176
IFS2	26.7	44.1	1	220
CTFI	80.8	44.5	20	647
DO	106.4	60.7	22	647

IFSh – interval from first service to conception for heifers, IFS2 – interval from first service to conception for cows in second parity, CTFI – interval from first calving to first insemination, DO – days open

Environmental effects

The changes in fertility of cattle are related to climatic conditions during calving. Figure 2 illustrates how the analysed fertility traits depended on month of calving. Generally, reproductive efficiency was lower in autumn and higher in spring. The shortest IFS, which indicates the ability of a cow to conceive, was for spring-calving cows: for heifers in April (approx. 12 days) and for cows in second parity in May (approx. 17 days). The shortest DO (approx. 100 days), also associated with a cow's conceiving ability, was observed for cows calving in April. The shortest CTFI (approx. 78 days), representing a cow's ability to renew cycling after calving, was observed when cows calved during June. The longest IFSh (approx. 18 days) was observed for heifers calving in September. Cows calving in November had the longest IFS2, CTFI and DO (approx. 32, 99 and 130 days, respectively). There were significant differences ($P < 0.05$) between month of calving in CTFI and DO, and non-significant differences ($P > 0.05$) in IFSh and IFS2. Both CTFI and DO differed significantly between cows calving in November and those calving in other months. Additionally, CTFI differed significantly between cows that calved in March and August, as well as between April and May. For DO there were significant differences between cows calved in May and January or in May and March.

The decision on when to start breeding is based primarily on the age of the heifer. The common practice among breeders is to breed heifers at approximately 15 months of age, giving it a chance to calve at the age of 2 years. Figure 3 demonstrates how age at first calving influences IFS, CTFI and DO.

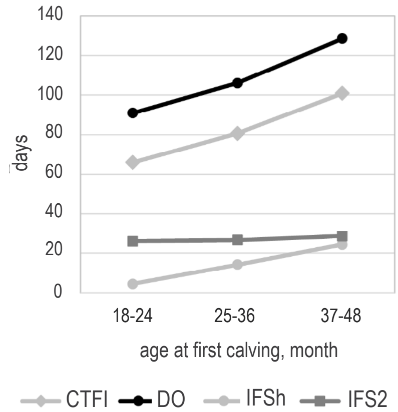

Figure 3. Phenotypic trends of interval from first service to conception for heifers (IFSh, $P < 0.0001$) and cows in second parity (IFS2, $P = 0.6451$), interval from first calving to first insemination (CTFI, $P < 0.0001$), and days open (DO, $P < 0.0001$), by age at first calving

There were significant differences (P < 0.05) in CTFI, DO and IFSh between the age-of-first-calving groups. All three age groups (18–24, 35–36, 37–48 months) showed significant differences for CTFI and DO. IFSh for the youngest heifers (calving at 18–24 months) differed significantly from IFSh for heifers calving at 25–36 or 37–48 months. Heifers that calved at 18–24 months tended to have lower values for all calving intervals (IFSh, CTFI and DO). Age at first calving only slightly influenced the interval from first to successful insemination of cows (IFS2). IFSh, CTFI and DO lasted longer for cows that calved at the age of 37–48 months. This might be a consequence of the fact that the latecalving animals were inclined to become too fat.

The changes in IFSh, IFS2, CTFI and DO with year of first calving are presented in Figure 4. For three traits (CTFI, DO, IFS2) there were significant differences (P < 0.05) between years of first calving. IFSh varied from approx. 10 days for cows that calved for the first time in 2001 to more than 26 days for cows first calving in 2003. IFS2 was lowest for cows calving for the first time in 1999 (approx. 12 days), and highest for those first calving in 2003 (approx. 28 days). CTFI ranged from 68 days in 2005 to 99 days in 1999. DO fluctuated from 90 to 118 days for cows calving for the first time in 2005 and 2007, respectively.

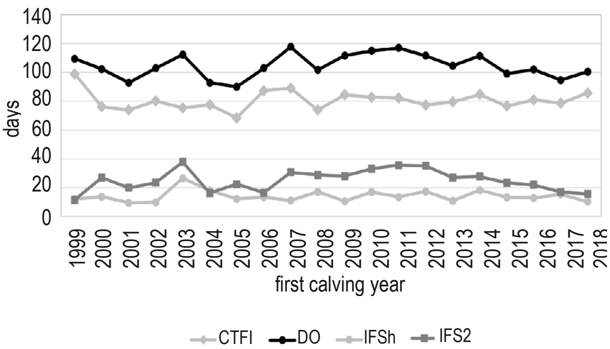

Figure 4. Phenotypic trends of interval from first service to conception for heifers (IFSh, P = 0.5939) and cows in second parity (IFS2, P < 0.0001), interval from first calving to first insemination (CTFI, P = 0.03967), and days open (DO, P = 0.02766), by first calving year

Heritabilities

The heritability of all analysed fertility traits is presented in Table 3. In general, all heritabilities were low and ranged from 0.041 (CTFI) to 0.104 (IFS2), with standard deviations between 0.022 and 0.040. Heritability of IFS was slightly lower for heifers (0.086) than for cows (0.104). Heritability of DO was similar to that of IFS for heifers (0.088).

Table 3. Estimated genetic (σ_G^2) and residual (σ_R^2) variance and heritability (h^2) of fertility traits of Simmental cows

Trait	σ_G^2		σ_R^2		h^2	
	mean	SD	mean	SD	mean	SD
IFSh	73.0	33.2	778.4	42.5	0.086	0.038
IFS2	195.1	75.8	1682.9	91.6	0.104	0.040
CTFI	67.9	37.2	1578.1	59.7	0.041	0.022
DO	289.9	112.4	2981.9	142.2	0.088	0.034

IFSh – interval from first service to conception for heifers, IFS2 – interval from first service to conception for cows in second parity, CTFI – interval from first calving to first insemination, DO – days open; SD – standard deviation

Genetic and phenotypic correlations

The genetic and phenotypic correlations among four female fertility traits are listed in Table 4. Genetic correlations were moderate to high with two exceptions: the correlation of IFS2 with IFSh (−0.284) and of IFS2 with CTFI (0.186). DO was highly positively correlated with IFS2 (0.852), whereas CTFI was highly negatively correlated with IFSh (−0.925). Most of the phenotypic correlations were low to moderate and in many cases instances, lower than the genetic ones. The phenotypic correlations were highest between DO and IFS2 (0.731) and between DO and CTFI (0.650).

Table 4. Genetic (above diagonal) and phenotypic (below diagonal) correlations of fertility traits of Simmental cows

Trait	IFSh		IFS2		CTFI		DO	
	mean	SD	mean	SD	mean	SD	mean	SD
IFSh			-0.284	0.302	-0.925	0.051	-0.538	0.242
IFS2	0.015	0.055			0.186	0.315	0.852	0.095
CTFI	-0.065	0.033	-0.026	0.060			0.469	0.268
DO	-0.028	0.054	0.731	0.042	0.650	0.015		

IFSh – interval from first service to conception for heifers, IFS2 – interval from first service to conception for cows in second parity, CTFI – interval from first calving to first insemination, DO – days open; SD – standard deviation

Discussion

Descriptive statistics

Number of days between first service and conception increased, on average, from approx. 14 days for heifers (IFSh) to 27 days for cows in second parity (IFS2). Slightly higher results for IFS were obtained by Jamrozik et al. (2005) in the Ca- nadian Holstein Friesian population (16.3 days for IFSh and 32.5 days for IFS2). Otwinowska Mindur et al. (2022) found similar IFS values in Polish Holstein Friesians, with an average of approx. 16 days for heifers and approx. 33 and 37 days for cows in second and third lactations, respectively. Longer intervals from first to successful insemination (IFS) for heifers and cows were given by Kadarmideen et al. (2003), Zink et al. (2011), Toledo-Alvarado et al. (2017), Brzáková et al. (2019) and Muuttoranta et al. (2019). Brzáková et al. (2019) reported that the interval from first to successful insemination was approx. 23 days for heifers and more than 48 days for multiparous cows in a population of Holstein cows in the Czech Republic. Kadarmideen et al. (2003) found that the length of IFS decreased with successive pregnancies of Holstein cows in the United Kingdom. The interval from first to successful insemination obtained by Toledo-Alvarado et al. (2017) for Italian Simmental cows was 25 days, but those authors analysed the first three parities jointly.

Another fertility trait, i.e., interval from first calving to first insemination (CTFI), indicates the recovery of an animal's ability to recycle after calving, and is an indicator of post-partum return to reproductive function (Gonzales-Recio et al., 2006). In the present study, mean CTFI was approx. 81 days. Toledo-Alvarado et al. (2017) found slightly shorter CTFI (77.5 days) in the Italian Simmental population. Similar results for CTFI (approx. 80 days) were reported by Jagusiak and Zarnecki (2006) and Rzewuska and Strabel (2015) for Holstein Friesian cows in Poland. Otwinowska-Mindur et al. (2022) observed approx-imately 10 days longer CTFI (approx. 89 days) also in Polish Holstein-Friesian cows.

Days open (DO), the interval between first calving and conception, is a trait that represents the sum of the other two intervals, i.e., IFS and CTFI. Both DO and CTFI are influenced by a farmer's decisions about the length of the voluntary waiting period, the efficiency of oestrus detection, and the application of synchronisation products (Rzewus- ka and Strabel, 2015). The lower the DO values, the shorter (i.e. more preferable) the period between calving and conception. In our study, mean DO was approx. 106 days, similar to the results of Toledo-Alvarado et al. (2017) for the Italian Sim- mental population (approx. 102 days). Bujko et al. (2018) found longer mean DO in the Slovak Simmental population (approx. 122 days) than in our study. Jagusiak and Zarnecki (2006) reported a mean DO of 132 days and Otwinowska-Mindur et al. (2022) found mean DO of 121 days in the Polish Holstein-Friesian population.

The decision on when to start breeding is a management choice, often influenced by factors such as nutrition and growth rate during the rear- ing period. The fertility of animals would affect the mean and distribution of age at first calving on any farm (Wathes et al., 2008). Our present results show that age at first calving influenced female fertility traits such as IFSh, CTFI and DO. Wathes et al. (2014) observed that age at first calving could affect the fertility of cows during their first lactation and concluded that the economically optimal age at first calving, without any unfavourable consequences for future herd performance, was about 24 months. It was shown that both early- and late- calving heifers tended to have breeding problems afterwards (Wathes et al., 2008; 2014). Sung et al. (2016) suggested that the choice of first calving at a moderate age, from 24 to 28 months may save the expense related to replacing heifers, and thus increase farm incomes through higher milk yield. Our present results show that both calving month and year of first calving affected female fertility traits. Wolfenson and Roth (2019) found that sea- sonal differences in fertility between summer and winter had a significant influence on the economic outcome of breeders. They observed that successful conception for cows in summer was more expensive because more inseminations were required per pregnancy.

Heritabilities

Estimated heritability for female fertility traits was generally low (0.041–0.104) and consistent with results from previous studies (Kadarmideen et al., 2003; Jamrozik et al., 2005; González-Recio et al., 2006; Jagusiak and Żarnecki, 2006; Zink et al., 2011; Guo et al., 2014; Rzewuska and Strabel, 2015; Brzáková et al., 2019; Otwinowska-Mindur et al., 2022). Kadarmideen et al. (2003) and Brzáková et al. (2019) concluded that the low heritability of fertility traits indicated the strong influence of environmental effects such as herd or management on these traits. However, low heritability did not necessarily mean that there is not enough genetic variability to justify selection for those traits. In this paper, the heritability of IFS increased slightly with subsequent parity, ranging from 0.086 for heifers to 0.104 for cows in second parity. Brzáková et al. (2019) observed a similar trend in Czech Holstein cows, where heritability of IFS increased from 0.010 to 0.025; they also concluded that IFS was less influenced by farmers' decisions than traits such as CTFI or DO, because a farmer who decided to inseminate a cow continued the process until the cow became pregnant.

Genetic correlations

Among the genetic correlations estimated in this study, a strong positive genetic relationship was found between DO and IFS2 (0.852), indicating that animals would rank similarly for those two traits, meaning that genetic improvement of one of these traits could cause a correlated response in the second correlated trait. On the contrary, a very high but negative genetic correlation was estimated between IFSh and CTFI (−0.925). Kadarmideen et al. (2003) stated that high genetic correlations between some fertility traits might result from biological relationships between these traits. The relatively low genetic correlation between IFSh and IFS2 (−0.284) indicated that IFS for heifers and cows were not the same traits genetically, because the cow was not subjected to the same metabolic load than the heifer during pregnancy and during the lactation periods. Buaban et al. (2015) and Muuttoranta et al. (2019) wrote that cows have a greater metabolic load than heifers and need resources for recovery from pregnancy and for lactation, including peak of lactation. Also Abe et al. (2009) suggested that fertility traits in heifers and cows should not be considered as the same traits. Brzáková et al. (2019) obtained an even much lower genetic correlation between IFSh and IFS2 (−0.036), supporting that conclusion.

Conclusions

All analysed factors – age of first calving, month of first calving and year of first calving – affected the fertility traits ertility traits: interval from first service to conception for heifers (IFSh) and second- parity cows (IFS2), interval from first calving to first insemination (CTFI) and days open (DO) in the Polish Simmental population. Additional economic studies are needed to determine which age of first calving or season of calving are the most profitable for breeders.

The results indicate that two traits – interval from first service to conception for heifers (IFSh) and for cows in the second parity (IFS2) – could be used in genetic evaluations of Simmental cows in Poland. They might have a favourable correlated effect on fertility, so supplementing the selection index by incorporating both IFSh and IFS2 could lead to improved female fertility scores in the Simmental population.

We found strong positive genetic and phenotypic correlations between DO and IFS2, along with a strong negative genetic correlation between CTFI and IFSh. Importantly, the fertility traits we studied are typically lowly heritable, so breeding progress may be achieved over the longer term.

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Conflict of interest

The authors declare that there is no conflict of interest.

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