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Variability of semen traits of boars used in artificial insemination

HELIODOR WIERZBICKI, IWONA GÓRSKA, ANNA MACIERZYŃSKA, MAREK KMIEĆ*

Department of Genetics and Animal Breeding, Wrocław University of Environmental and Life Sciences, Kożuchowska 7, 51-631 Wrocław, Poland
*Department of Genetics and Animal Breeding, The West Pomeranian University of Technology, Doktora Judyma 6, 70-310 Szczecin, Poland

Wierzbicki H., Górska I., Macierzyńska A., Kmieć M.
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Summary

6689 ejaculates collected from 89 boars (Polish Large White, Polish Landrace, Duroc, Hampshire, Pietrain, Duroc × Hampshire, Hampshire × Pietrain, Polish Synthetic Line 880 and Line 990, PIC) were used to study the influence of age, genotype (breed) and selected environmental factors on the variability of semen characteristics (semen volume, sperm concentration, percentage of live sperms, total number of sperms, number of insemination doses). Heritability and repeatability of these traits, estimated using DFREML and a single-trait repeatability model, were computed as well. The examined boars were at the age of 221-585 days. The data were collected in two Polish AI stations over the period of 1997-2002. The year of semen collection, AI station, age and genotype of boars were the factors which caused significant differences in the studied semen traits. Dynamic changes of semen traits were observed at the beginning of the reproductive performance of boars, and an increase in mean values of semen traits was noted as the boars were getting older. The best ejaculates for AI purposes were obtained from the Polish Synthetic Line 880 and Line 990 boars, and the worst were obtained from PIC. The estimated heritabilities (ranging from 0.12 to 0.60) and repeatabilities (ranging from 0.40 to 0.76) indicate that effective selection improving the studied semen traits is possible.

Keywords: boar, heritability, repeatability, semen traits

Artificial insemination (AI) has become an important procedure in the reproduction of pigs. Therefore, the number of boars used as sires is limited and the strict examination of reproductive traits of individuals kept in AI stations is necessary. A boar's reproductive ability can be considered in terms of quantitative semen traits and selected factors which determine those traits (19). By increasing the accuracy of the selection of AI sires for the volume and quality of semen, it may be possible to further reduce the numbers of boars and thereby improve the profitability of AI stations (19, 30).

The variability of boar's semen traits, determined by genotype and environmental factors, has been widely studied (8, 10-12, 16, 20, 24-29). This variability is mainly caused by differences between breeds which determine animals' eligibility to be used for AI. The influence of boar genotype on quantitative semen traits is ambiguous. Thus, there is no pre-eminent breed for all semen traits (9, 24, 28).

The heritability of reproductive traits is believed to be low, and this makes selection difficult. However, the heritability of semen characteristics has been estimated at different levels: low (0.02-0.10), moderately low (0.11-0.25), medium (0.26-0.39), moderately high (0.40-0.50), and high (over 0.50) (1-4, 6, 7, 25, 27, 28). The largest discrepancy of heritabilities was found for the total number of sperms in ejaculate. The heritability of semen volume was also estimated at many different levels – from moderately low to high.

The aim of the present study was to determine the effect of age, breed (genotype) and selected environmental factors on the variability of semen characteristics. The heritability and repeatability of the studied traits were estimated as well. Properly defined and estimated genetic and environmental factors affecting semen traits are essential for the artificial insemination industry to provide customers with high quality insemination doses.

Material and methods

Data. A data set consisting of 6,658 ejaculates collected from 89 boars was analyzed. The boars were used in two Polish AI stations. On average 75 ejaculates per boar were collected. The analyzed boars were at the age of 221-585 days and were allocated into three age groups: I (221-342 days), II (343-464 days) and III (465-585 days). The ejaculates were collected in two seasons (first season: January-June, second season: July-December) in 1997-2002. Five traits for each ejaculate were examined: semen volume – SV [ml], sperm concentration – SC [$\times 10^3/mm^3$], percentage of live sperms – PAS [%], total number of sperms – TNS [bn], number of insemination doses – NID. Semen volume was measured using a graduated cylinder, sperm concentration was determined by photocolorimetry, percentage of live sperms was evaluated microscopically, and the total number of sperms was calculated as follows: TNS = SV*SC/1000.

The data were collected from purebred boars: Polish Large White (PLW), Polish Landrace (PL), Duroc (D), Hampshire (H), Pietrain (P), from crossbred boars: Duroc × Pietrain (D × P), Duroc × Hampshire (D × H), Hampshire × Pietrain (H × P), a group of Polish Synthetic Line 880 (L880) and Line 990 (L990) boars, and hybrid PIC boars.

Statistical analysis. The GLM (General Linear Models) procedure with the following model was applied for all reproductive traits:

$$Y_{ijklmnop} = \mu + V_i + M_j + Y_k + S_l + A_m + St_n + B_o + (StY)_{nk} + (StS)_{nl} + (BY)_{ok} + (BA)_{om} + e_{ijklmnop}$$

where:

$Y_{ijklmnop}$ – the value measured on the p-th trait,
μ – the population mean,
V_i – the effect of the i-th sire (i = 1, 2,…, 89),
M_j – the effect of the j-th dam (j = 1, 2,…, 164),
Y_k – the effect of the k-th year (k = 1997, 1998,…, 2002),
S_l – the effect of the l-th season (l = 1, 2),
A_m – the effect of the m-th age group (m = 1, 2, 3),
St_n – the effect of the n-th AI station (n = 1, 2),
B_o – the effect of the o-th breed or combination of breeds (o = 1, 2,…, 10),
$(StY)_{nk}$ – the effect of the n-th AI station and the k-th year interaction,
$(StS)_{nl}$ – the effect of the n-th AI station and the l-th season interaction,
$(BY)_{ok}$ – the effect of the o-th breed or combination of breeds and the effect of the k-th year interaction,
$(BA)_{om}$ – the effect of the o-th breed or combination of breeds and the effect of the m-th age group interaction,
$e_{ijklmnop}$ – the residual effect, E(e) = 0, var(e) = $I\sigma^2_e$.

All analyzed traits were statistically characterized by the arithmetic mean ($\bar{x}$), standard deviation (sd) and coefficient of variation (cv). Duncan test was used for testing the significance of differences between means within groups (age, year, AI station, breed, season). Phenotypic trends estimated as regression of average values of semen traits on time were computed as well. All statistical analyses were conducted using the SAS (23).

The DFREML (17) was used to estimate heritabilities and repeatabilities. The following single-trait repeatability model was used:

$$y = X\beta\ Z_1\alpha + Z_2pe + e,$$

where:

$E(\alpha) = E(pe) = E(e) = 0,$
$Var(\alpha) = A\sigma^2_\alpha,\ Var(pe) = I\sigma^2_{pe},\ Var(e) = I\sigma^2_e = R,$
$Var(y) = Z_1AZ_1'\sigma^2_\alpha + Z_2I\sigma^2_{pe}Z_2' + R,$
y – vector of observations,
β – vector of fixed effects,
α – vector of random animal effects,
pe – vector of random permanent environmental effects and non-additive genetic effects,
e – vector of random residual effects,
X – incidence matrix relating records to fixed effects,
Z_1 – incidence matrix relating records to animal effects,
Z_2 – incidence matrix relating records to permanent environmental effects,
A – relationship matrix,
I – identity matrix.

Results and discussion

Statistical characteristics. The statistical characteristic of the studied traits is shown in table 1. Coefficients of variation and values of standard deviation indicate the lowest variability of PAS and the highest variability of SV, TNS and NID. The mean value of SV was usually lower than the same value reported in other studies (5, 18, 25, 27, 29).

Tab. 1. Means ($\bar{x}$), standard deviations (sd) and coefficients of variation (cv) of the studied traits (n = 6658)

Trait	$\bar{x}$	sd	cv [%]
Semen volume [ml]	221.15	77.33	34.97
Sperm concentration [$\times 10^3/mm^3$]	595.83	123.83	20.78
Percentage of live sperms [%]	72.58	4.85	6.68
Total number of sperms [bn]	93.33	31.89	34.17
Number of insemination doses	24.52	7.99	32.61

Smital et al. (25) found an identical mean value of TNS with a comparable value of the coefficient of variation (36.23%). A similar mean value of this trait was also reported by Wolf and Smital (28, 29). However, it was estimated for the data set consisting of 151,755 ejaculates of 2077 boars representing 6 breed groups. Kmieć et al. (12) reported a lower mean value of TNS, amounting to 79.1 bn, with a standard deviation of 25 bn.

Smital et al. (25) found a much higher mean value of NID. This research was conducted on 210,733 ejaculates of 2,862 boars from 19 breed groups. Gączarzewicz et al. (5) analyzed 174 ejaculates of boars from 13 breed groups and obtained the mean value of NID at the level of 31.4.

SC has been widely examined. Most authors found the mean value of this trait lower than the one obtained in this study (18, 25, 27-29). Comparable results were reported by Kmieć et al. (12), who computed a similar mean value of PAS (70%) with the standard deviation of 1.15%.

Tab. 2. Means and standard deviations (in brackets) of semen traits in analyzed groups

Groups		Semen volume	Sperm concentration	Percentage of live sperms	Total number of sperms	Number of insemination doses
Age	I (n = 1897)	213.22^{B} (79.71)	583.63^{B} (120.87)	72.93^{A} (5.00)	88.71^{B} (30.59)	23.37^{B} (7.57)
	II (n = 2431)	222.22^{A} (76.96)	599.33^{A} (122.59)	72.43^{B} (4.73)	94.13^{A} (32.72)	24.86^{A} (8.18)
	III (n = 2311)	226.54^{A} (74.21)	601.86^{A} (127.04)	72.47^{B} (4.83)	96.23^{A} (30.59)	25.11^{A} (8.05)
Year	1997 (n = 323)	296.67^{A} (110.89)	524.78^{D} (75.09)	77.21^{A} (6.47)	118.71^{A} (45.01)	30.94^{A} (10.99)
	1998 (n = 1272)	234.13^{B} (84.96)	557.19^{C} (79.32)	72.37^{C} (4.49)	93.43^{C} (34.41)	25.31^{B} (8.67)
	1999 (n = 1919)	215.62^{C} (72.68)	570.05^{C} (128.22)	72.49^{C} (4.56)	87.08^{C} (30.59)	22.76^{C} (7.49)
	2000 (n = 1608)	232.81^{B} (75.70)	613.46^{B} (140.25)	73.72^{B} (5.69)	101.31^{B} (30.34)	25.05^{B} (7.85)
	2001 (n = 1232)	192.03^{D} (50.47)	663.27^{B} (109.26)	70.85^{D} (2.91)	89.49^{CD} (24.98)	23.87^{C} (6.63)
	2002 (n = 304)	177.99^{E} (28.62)	629.31^{B} (102.41)	70.00^{E} (0.00)	78.62^{E} (18.25)	25.36^{B} (5.63)
Season	I (n = 2863)	221.05 (79.62)	602.42^{A} (128.53)	72.68 (4.83)	94.14 (32.49)	24.51 (8.23)
	II (n = 3795)	221.24 (75.57)	590.87^{B} (119.95)	72.51 (4.86)	92.72 (31.42)	24.53 (7.82)
AI station	I (n = 1733)	283.38^{A} (91.68)	479.83^{A} (47.64)	79.57^{A} (4.56)	109.32^{A} (40.83)	28.32^{A} (10.39)
	II (n = 4925)	199.26^{B} (57.31)	636.65^{B} (116.31)	70.12^{B} (1.09)	87.70^{B} (25.83)	23.22^{B} (6.49)

Explanation: A, B, C, D, E – means marked with different letters are significantly different at $P \leq 0.01$

Age effect. Means and standard deviations of the selected semen traits for age groups are given in table 2. Results show that the mean values of SV, SC, PAS, TNS and NID differ significantly between the studied age groups: 1st (221-342 days), 2nd (343-464 days), and 3rd (465-585 days). SV significantly increased in the 3rd age group as compared to the others. The difference between the 2nd and the 3rd age group was statistically insignificant. A similar relationship was found for SC, TNS and NID. The mean value of PAS was significantly higher for the 1st age group as compared to the others.

It has been shown that SV increased along with a boar's age (24). In our study the mean value of SV also increased with a boar's age, but was higher than in other studies for all age groups (13, 16, 26).

SC tended to increase from the 343rd day of a boar's life (tab. 2). The same observation was made by Szostak (26). Smital (24) reported contrary results: SC decreased along with a boar's age. There were also studies indicating that SC did not change noticeably with a boar's age (16).

TNS increased with a boar's age (tab. 2). Similar results were reported by Oh (19), Smital (24), Wolf and Smital (29). According to Wolf and Smital (29) a higher number of sperms in ejaculates of older boars can be an implication of growth and development of a boar's testicles.

Older boars (2nd and 3rd age groups) produced significantly higher NID. Results showing that older boars produced more insemination doses were also reported by Rutten et al. (22), Kondracki and Banaszewska (13), Kondracki et al. (14-16). The opposite tendency was found for PAS. Boars from the 1st age group (the youngest) produced semen with a significantly higher PAS as compared to the other two groups. A similar tendency was found by Rutten et al. (22).

Year effect. Table 2 presents means and standard deviations of all considered semen traits for all year groups. The mean values differ significantly between the studied years. The largest means of SV, PAS, TNS and NID were found in 1997. The lowest mean of SC was observed in 1997. The worst reproductive performance expressed as semen quality was noted in 2002, when SV, PAS and TNS dropped to the lowest means.

The annual phenotypic trends of the studied traits were also estimated. Out of the five traits only SC was characterized by a positive average annual trend, amounting to $30.7 \times 10^3/mm^3$. Negative annual phenotypic trends were estimated for SV (–15.13 ml), PAS (–0.72%), TNS (–2.54 bn) and NID (–0.49).

Season effect. Means within season groups and the significance of differences between them are presented in table 2. Results obtained show that the mean values of SV, PAS, TNS and NID did not differ significantly. Only SC differed significantly in both seasons.

Results reported by most authors (21, 22, 24, 29) indicated that significantly larger mean values of semen traits were found in the autumn-winter season than in the spring-summer season.

AI station effect. The boars were kept in two AI stations. It was found that the mean values of semen traits for boars kept in the first AI station differed from the means of semen traits for boars kept in the second AI station (tab. 2). SV, PAS, TNS and NID were significantly higher in the first AI station, whereas mean SC was higher in the second AI station.

Differences between the mean values of semen traits in both AI stations may have been brought about by different environmental conditions, feeding, the intensity of the boars' reproductive use, methods of semen collection or the accuracy of semen testing methods.

Tab. 3. Means and standard deviations (in brackets) of semen traits for particular breeds and breed combinations

Breed	Semen volume	Sperm concentration	Percentage of live sperms	Total number of sperms	Number of insemination doses
D (n = 83)	279.39^{A} (69.62)	477.77^{D} (40.91)	80.96^{A} (3.70)	109.42^{B} (30.27)	27.67^{B} (7.40)
D × H (n = 270)	216.59^{DE} (66.76)	593.59^{B} (111.24)	72.29^{E} (5.24)	92.30^{DE} (32.57)	24.42^{C} (8.03)
D × P (n = 1368)	213.91^{DE} (66.79)	637.34^{A} (123.64)	71.31^{EF} (3.66)	94.98^{CD} (28.38)	24.30^{C} (6.86)
H (n = 117)	267.52^{B} (108.39)	511.99^{C} (77.15)	74.19^{D} (5.29)	100.13^{C} (41.79)	27.17^{B} (10.95)
H × P (n = 936)	214.06^{DE} (61.76)	595.52^{B} (102.99)	70.89^{F} (3.14)	89.29^{DE} (26.43)	23.53^{C} (6.40)
PL (n = 1873)	220.58^{CD} (73.69)	606.08^{B} (124.73)	72.21^{E} (4.57)	93.79^{CD} (29.53)	24.96^{C} (7.68)
PIC (n = 226)	204.91^{E} (67.34)	460.53^{D} (43.39)	78.41^{B} (4.01)	74.72^{F} (28.29)	19.07^{D} (6.56)
P (n = 326)	236.69^{C} (88.00)	539.24^{C} (114.40)	75.67^{C} (5.60)	94.85^{CD} (36.03)	24.33^{C} (8.88)
L880, L990 (n = 294)	328.96^{A} (107.78)	523.38^{C} (89.32)	77.79^{B} (6.52)	132.43^{A} (46.52)	33.80^{A} (11.68)
PLW (n = 1165)	200.14^{E} (67.78)	608.59^{A} (129.44)	72.02^{E} (4.28)	85.67^{E} (28.50)	23.04^{C} (7.42)

Explanation: as in tab. 2

Tab. 4. Heritabilities (h^2), repeatabilities (t) and their standard errors (in brackets) for studied semen trait

	Semen volume	Sperm concentration	Percentage of live sperms	Total number of sperms	Number of insemination doses
h^2	0.56 (0.08)	0.28 (0.05)	0.60 (0.08)	0.42 (0.06)	0.12 (0.02)
t	0.65 (0.06)	0.43 (0.05)	0.76 (0.06)	0.55 (0.05)	0.40 (0.04)

Breed effect. The breed (genotype) of a boar was found to be an important factor affecting its reproductive performance (5, 14-16, 24, 26, 28, 29). Differences between semen characteristics of the investigated breeds and crossbreds are presented in table 3. The results show a pronounced variability of semen traits determined by a boar's breed. All examined semen traits were significantly different in the 10 boar breed groups (D, D × H, D × P, H, H × P, PL, PIC, P, L880, L990, PLW).

The significantly largest mean NID was collected from L880 and L990 boars. The same boars were characterized by a significantly higher mean SV and TNS. However, the mean PAS of L880 and L990 boars was significantly lower than the mean PAS of D boars, and the mean SC was moderately low ($523.38 \times 10^3/mm^3$) in comparison with the other breeds.

The significantly lowest mean NID was found for PIC boars. This mean value was almost twice lower than those estimated for L800 and L990 boars. The mean SV, TNS and SC of PIC boars were also quite low. These findings indicate that this breed is hardly useful for artificial insemination.

The purebred D and H boars significantly outperformed crossbred boars (D × H, D × P, H × P) and sires P in terms of ejaculatory yield. The P, H and D boars demonstrated a significantly higher mean SV and PAS than crossbreds.

Boars' ejaculates with lower SV were characterized by larger SC and lower PAS and TNS (D × H, D × P, H × P, PL, PLW).

Genetic parameters. Table 4 presents heritabilities, repeatabilities and their standard errors for the semen traits under investigation. The estimates of genetic parameters are at levels from moderately low to high. The most heritable and repeatable trait was PAS (0.60 ± 0.08, 0.76 ± 0.06, respectively), whereas NID was the least heritable and repeatable trait (0.12 ± 0.02, 0.40 ± 0.04, respectively).

Smital et al. (25) reported similar values of heritability for SV (h^2 = 0.58), TNS (h^2 = 0.42), and larger values of heritability for SC (h^2 = 0.49) and NID (h^2 = 0.40). Clem et al. (1) examined ejaculates of 112 Yorkshire boars, and estimated the heritability of TNS at 0.64 (± 0.45).

Most authors, however, estimated lower heritabilities of boar semen traits as compared to the results of the present study (4, 6, 7, 27). Falkenberg et al. (4) computed heritabilities of 0.25 for SV, 0.23 for SC, 0.13 for PAS, and 0.02 for TNS. This research was based on 11,485 ejaculates of 3,418 boars. Estimates of heritability reported by Grandjot et al. (6, 7) were as follows: 0.14-0.18 for SV, 0.14-0.26 for SC, 0.17-0.25 for TNS. Wolf (27), who studied 215,830 ejaculates of 3,675 boars, reported heritability of 0.14-0.25 for SV and 0.13-0.20 for SC.

The estimates of repeatability computed in the present study were slightly higher than those reported by other authors. Oh (19) performed semen traits analysis and reported repeatabilities of 0.38 for SV, 0.37 for TNS, 0.09 for SC and 0.39 for NIS. A similar study was done by Wolf (27), who estimated the highest repeatability for SV (0.43-0.46), followed by SC (0.37-0.38) and TNS (0.29-0.30).

The heritabilities and repeatabilities estimated in this study and those reported by other authors (6, 7, 19, 27) indicate that an effective breeding program aimed at the improvement of semen characteristics can be implemented for boars used in AI.

Conclusion

This study conclusively shows that semen traits are influenced not only by a boar's genotype and age, but also by environmental factors such as year, season and AI station. Dynamic changes of semen traits were observed at the beginning of reproductive performance of boars, and an increase in mean values of semen traits was noted as the boars were getting older. The best ejaculates for AI purposes were obtained from the Polish Synthetic Line 880 and Line 990 boars, and the worst from PIC. Although non-genetic factors considerably affect sperm characteristics, the estimated heritabilities (ranging from 0.12 to 0.60) and repeatabilities (ranging from 0.40 to 0.76) indicate that an effective selection based on semen traits is possible. This, in turn, can effectively reduce the number of boars required in Polish AI centers. Much attention should be paid to current AI boar selection practices, as selection for increased meat content in the carcass and reduced backfat thickness can lead to reduced boar fertility as measured by semen characteristics.

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Author's address: dr hab. Heliodor Wierzbicki, Kożuchowska 7, 51-631 Wrocław, Poland; e-mail: heliodor.wierzbicki@up.wroc.pl