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Effect of inbreeding on reproduction performance in breeds included in conservation programs

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In Poland, the pig breeds included in the conservation program (Złotnicka White, Złotnicka Spotted and Puławska) are at particular risk of decreased production due to an increase in inbreeding. In recent years, despite mating designed to minimize inbreeding, this parameter has gradually increased within these breeds. Therefore, a study was undertaken to determine the effect of inbreeding of sows and their litters on the rearing performance of the piglets. The subjects were 6,025 sows of native breeds (2,971 Puławska, 1,323 Złotnicka White and 1,731 Złotnicka Spotted) born between 2003 and 2011. Data were collected for a total of 23,829 litters and the number of piglets born and reared was noted. The results showed that in comparison to dam inbreeding, litter inbreeding had a greater effect on the number of piglets born and reared. Among the Złotnicka breeds, sows in which inbreeding was greater than 12.5% gave birth to and reared slightly fewer piglets in the second and later parities, but the differences were not significant. An increase in dam inbreeding to 6.25% was found to improve the reproductive performance of sows, increasing the number of piglets born in the fourth and later parities in the Złotnicka Spotted breed (P≤0.05) and the number of piglets reared in the second and third litters of Złotnicka White sows (P≤0.05). Litter inbreeding greater than 12.5% had significantly reduced the number of piglets born and reared, especially in the first parities of the Złotnicka breeds (P≤0.05). These relationships were not observed for the Puławska breed.

KEY WORDS: native pig breeds / inbred dams / litter inbreeding / reproductive performance

The level of relationship and inbreeding of animals fundamentally influences their genetic value. Excessive inbreeding primarily causes a reduction in traits associated with viability and fertility. An increase in the inbreeding coefficient of a sow and her offspring leads to a decrease in litter size and weight, an increase in the number of deaths, and a decrease in the growth rate of the piglets [1, 2, 5, 6, 9]. Reproductive traits in boars show a deterioration as well, including reduced libido [2, 5] and decreased genital weight [6]. Inbreeding may also be one of the factors contributing to increased susceptibility to stress, expressed as higher levels of stress hormones in the blood [11]. The negative effect of inbreeding on the functional characteristics of cattle has been shown to be greater when the inbreeding coefficient is higher than 12.5% [14]. In the case of pigs, the negative effects of inbreeding can be observed in individuals in which the inbreeding coefficient exceeds just 10% [13].

In Poland, pig breeds with small populations, included in genetic resources conservation programmes (Złotnicka White, Złotnicka Spotted and Puławska), seem to be particularly threatened by this phenomenon. In these breeds, despite breeding aimed at minimizing inbreeding, a gradual increase in this parameter has been observed in recent years [15]. For this reason a study was undertaken to evaluate the effect of inbreeding of sows of native breeds and inbreeding of piglets on their rearing results.

Material and methods

The study was conducted on 6,025 sows of native breeds (2,971 sows of the Puławska breed, 1,323 Złotnicka White sows and 1,731 Złotnicka Spotted sows) born in the years 2003-2011. For the sows, data were collected regarding their litters, i.e. the number of piglets born and the number of piglets reared. Information on a total of 23,829 litters was collected. About 6% of litters were weighed on day 21 of life. Inbreeding of the sows and their litters was analysed based on pedigree data. Inbreeding coefficients (F) were calculated using the method described by Meuwissen and Luo [8], recommended for large populations, which involves computing the relationship matrix between individuals in the data set. Calculations were performed using software developed by Cole [3]. Sows and their litters were divided into six groups according to their inbreeding coefficients. Group 1 comprised individuals with an inbreeding coefficient of F=0 (control), and the other groups had inbreeding coefficients in the ranges of $0.00001 \leq F < 0.0313$; $0.0313 \leq F < 0.0625$; $0.0625 \leq F < 0.0938$; $0.0938 \leq F < 0.125$; and $F \geq 0.125$. The ranges were based on the method proposed by Mroczko [9]. Information on the litters was divided into three groups: 1 – first litters (6,025 litters), 2 – second and third litters (8,089 litters), and 3 – fourth and subsequent litters (9,715 litters). Statistical analysis of the data was performed using StatSoft, Inc. (2011) STATISTICA software version 10 (www.statsoft.com). Calculations were done separately for each

breed. Differences between groups were estimated by analysis of variance (ANOVA) using the following models:

$Y_{ijk} = a_i + b_j + e_{ij}$

where:

a_i – litter number group (i=1-3)
b_j – sow inbreeding coefficient group (j=1-6)

$Y_{ijk} = a_i + b_j + e_{ij}$

where:

a_i – litter number group (i=1-3)
b_j – litter inbreeding coefficient group (j=1-6)

The significance of differences between groups was tested by the Tukey test for different sample sizes.

Results and discussion

The general characteristics of the populations are presented in Table 1. The mean inbreeding coefficient of the sows of the Puławska and Złotnicka Spotted breeds was higher than the mean inbreeding coefficient of the litters of these breeds. This pattern was reversed in the Złotnicka White breed. The lower value of the inbreeding coeffi-

Table 1
Means and standard deviations (SD) of the coefficient of inbreeding (%) and reproductive performance of Puławska, Złotnicka White and Złotnicka Spotted sows

Trait	Breed					
	Puławska		Złotnicka White		Złotnicka Spotted	
	mean	SD	mean	SD	mean	SD
Dam inbreeding (%)	0.56	2.38	0.84	3.18	0.92	3.49
Litter inbreeding (%)	0.44	2.30	1.39	5.08	0.48	2.96
Number of piglets born	10.88	1.78	9.50	2.60	8.95	2.60
Number of piglets reared	10.00	1.43	8.44	2.60	7.93	2.62
Litter weight at 21 days (kg)	58.85	9.04	46.80	23.58	44.40	22.68
Piglet weight at 21 days (kg)	5.84	0.72	5.29	2.41	5.81	2.76

cient of the piglets relative to the inbreeding coefficient of their dams may indicate the effectiveness of measures taken within these breeds to reduce the level of inbreeding in protected populations. In a study by Köck et al. [7] on two Austrian breeds, Large White and Landrace, inbreeding was significantly higher in the litters (2.23% and 1.24%, respectively) than in their dams (2.02% and 0.93%, respectively). Farkas et al. [4], on

Table 2
Mean reproductive performance of Puławska sows with different levels of inbreeding

Parity	Range of sow inbreeding coefficients (%)					
	0.00 (n)	0.001-3.13 (n)	3.13-6.25 (n)	6.25-9.38 (n)	9.38-12.5 (n)	≥12.5 (n)
			Number of piglets born			
1	10.15 (1177)	10.19 (1196)	10.31 (262)	10.16 (192)	10.50 (30)	10.26 (114)
2 and 3	11.07 (1680)	11.00 (1534)	11.26 (308)	10.99 (297)	11.08 (40)	11.03 (144)
4 and later	11.37 (3182)	11.34 (1201)	11.41 (216)	11.19 (285)	10.79 (34)	11.14 (136)
			Number of piglets at 21 days of age			
1	9.41 (1177)	9.48 (1196)	9.63 (262)	9.55 (192)	9.70 (30)	9.52 (114)
2 and 3	10.15 (1680)	10.13 (1534)	10.40 (308)	10.25 (297)	10.82 (40)	10.24 (144)
4 and later	10.28 (3182)	10.27 (1201)	10.69 (216)	10.42 (285)	10.41 (34)	10.39 (136)
			Litter weight at 21 days of age			
1	52.44 (43)	57.34 (58)	56.64 (11)	50.00 (2)	59.00 (2)	58.60 (5)
2 and 3	59.91 (86)	59.99 (76)	60.75 (12)	62.57 (7)	64.00 (1)	60.00 (7)
4 and later	59.47 (81)	59.87 (31)	–	61.89 (9)	–	62.75 (4)
			Piglet weight at 21 days of age			
1	5.58 (43)	5.93 (58)	5.86 (11)	5.59 (2)	6.22 (2)	6.02 (5)
2 and 3	5.79 (86)	5.88 (76	5.82 (12)	5.93 (7)	5.82 (1)	6.02 (7)
4 and later	5.84 (81)	5.70 (31)	–	5.70 (9)	–	6.00 (4)

(n) – number of litters

the other hand, obtained lower inbreeding coefficients in litters (0.496%) than in their dams (0.537%) in the Hungarian Large White breed, but the pattern was reversed in the Hungarian Landrace breed (0.887% for litters and 0.798% for their mothers).

The results on the influence of the inbreeding coefficient of sows of individual breeds on their reproductive performance are presented in Tables 2-4.

Table 3
Reproductive performance of Złotnicka White sows with different levels of inbreeding

Parity	Range of sow inbreeding coefficients (%)					
	0.00 (n)	0.001-3.13 (n)	3.13-6.25 (n)	6.25-9.38 (n)	9.38-12.5 (n)	≥12.5 (n)
			Number of piglets born			
1	8.54 (735)	8,62 (357)	8.57 (132)	8.68 (54)	9.66 (3)	8.81 (42)
2 and 3	9.59 (977)	9,39 (411)	9.80 (119)	9.36 (68)	10.20 (5)	9.16 (61)
4 and later	10.24 (1659)	9,76 (249)	9.79 (57)	10.01 (84)	10.11 (9)	10.06 (66)
			Number of piglets at 21 days of age			
1	7.32 (735)	7.46 (357)	7.75 (132)	7.78 (54)	8.33 (3)	7.40 (42)
2 and 3	8.47[a] (977)	8.52[b] (411)	9.39[abc] (119)	8.63 (68)	10.20 (5)	7.98[c] (61)
4 and later	8.75 (1659)	8.63 (249)	8.64 (57)	9.01 (84)	9.67 (9)	8.44 (66)
			Litter weight at 21 days of age			
1	42.02 (54)	47.69 (26)	30.00 (6)	26.00 (1)	46.00 (1)	55.67 (3)
2 and 3	44.78 (76)	47.53 (55)	49.00 (6)	49.00 (4)	67.00 (2)	61.00 (2)
4 and later	46.37 (114)	52.52 (25)	59.11 (9)	51.00 (10)	56.33 (6)	63.60 (5)
			Piglet weight at 21 days of age			
1	5.08 (54)	6.32 (26)	3.41 (6)	2.89 (1)	6.57 (1)	6.58 (3)
2 and 3	5.04 (76)	5.19 (55)	5.84 (6)	5.04 (4)	7.02 (2)	6.43 (2)
4 and later	5.22 (114)	5.67 (25)	6.51 (9)	5.49 (10)	5.76 (6)	6.45 (5)

(n) – number of litters; means in rows with the same lower case letters (a, b, c) differ significantly at $P \leq 0.05$

Analysis of data on the reproductive performance of Puławska sows (Table 2) showed no negative effect of inbreeding of sows on the number of piglets born and piglets reared in the first, second and third litters. In the fourth and subsequent litters, there was a slight (statistically insignificant) decrease in the number of piglets born and an increase in the number of piglets reared to 21 days of age. The differences in these characteristics between the group of sows with a value of F≥12.5% and the group of sows with a coefficient of F=0% were 0.23 fewer and 0.11 more piglets, respectively.

In the two Złotnicka breeds (Tables 3 and 4), a high level of maternal inbreeding also had a slight negative impact on reproductive performance. Comparison within these two breeds of the results of sows whose inbreeding coefficient was F≥12.5% with non-inbred sows showed a decrease in the number of piglets born and piglets reared in nearly all litters. Exceptions were the number of piglets born and piglets reared in the first litters of the Złotnicka White breed and the number of piglets born in the second and third litters of the Złotnicka Spotted breed. These differences, however, were not confirmed statistically. The minor effect of inbreeding exceeding F=12.5% in the sows of these breeds, mainly involving a decrease in the number of piglets born and piglets reared, is in line with the results of research by other authors. Farkas et al. [4], in their study on Hungarian Large White and Landrace sows, also showed that inbreeding in the sow (10%) slightly decreased the number of piglets born, by 0.197 and 0.122, respectively. Similarly, Köck et al. [7], in their study on the Austrian pig breeds Landrace and Large White, showed a slight negative effect of inbreeding in the mothers (F=10%) on their reproductive performance, including the number of live-born piglets and reared piglets.

In neither of the Złotnicka breeds (Tables 3 and 4), however, was there a linear relationship clearly indicating that inbreeding had a negative influence on these traits. In the group of Złotnicka White sows in the inbreeding range of 3.13%≤F≤6.24%, the number of piglets at 21 days was highest (P≤0.05) in the second and third litters, while the Złotnicka Spotted sows with the same inbreeding value had significantly more piglets born in the fourth and subsequent litters as compared to sows with a lower coefficient (by 1.1 piglets at P≤0.05). Mroczko and Różycki [10] also showed no linear relationship between increased inbreeding and a decrease in the number of piglets born and reared in Polish Large White and Polish Landrace sows. Sows with an inbreeding coefficient of 0.001% to 9.38% had more piglets born and reared in the first and second litters than non-inbred sows. The authors also found that sows with an inbreeding level of more than 12.5% had significantly fewer piglets born and reared in their first and second litters, but only in comparison with sows with an inbreeding coefficient from 0.01% to 9.38%.

Table 4
Reproductive performance of Złotnicka Spotted sows with different levels of inbreeding

Parity	Range of sow inbreeding coefficients (%)					
	0.00 (n)	0.001-3.13 (n)	3.13-6.25 (n)	6.25-9.38 (n)	9.38-12.5 (n)	≥12.5 (n)
			Number of piglets born			
1	8.23 (824)	8.28 (657)	8.02 (203)	7.00 (6)	–	8.02 (41)
2 and 3	8.87 (1214)	9.00 (895)	9.30 (282)	10.13 (8)	–	9.22 (46)
4 and later	9.30^{a} (1585)	9.35^{b} (767)	10.41^{ab} (136)	10.33 (9)	–	8.88 (40)
			Number of piglets at 21 days of age			
1	7.06 (824)	7.11 (657)	6.80 (203)	7.00 (7)	–	6.54 (41)
2 and 3	8.04 (1214)	8.08 (895)	8.20 (282)	9.25 (8)	–	7.76 (46)
4 and later	8.26 (1585)	8.31 (767)	9.13 (136)	10.11 (9)	–	8.5 (40)
			Litter weight at 21 days of age			
1	46.02 (63)	37.08 (103)	42.55 (29)	–	–	38.13 (8)
2 and 3	48.72 (104)	51.77 (79)	43.17 (46)	–	–	44.83 (6)
4 and later	43.25 (104)	43.84 (58)	59.50 (18)	–	–	39.33 (3)
			Piglet weight at 21 days of age			
1	6.10 (63)	5.65 (103)	5.32 (29)	–	–	4.65 (8)
2 and 3	6.30 (104)	6.87^{A} (79)	4.99^{A} (46)	–	–	6.17 (6)
4 and later	5.93 (104)	5.66 (58)	6.99 (18)	–	–	5.62 (3)

(n) – number of litters; means in rows with the same lower case letters (a, b, c) differ significantly at P≤0.05; means with the same capital letters (A) differ significantly at P≤0.01

A negative influence of an increasing level of maternal inbreeding on the results of piglet rearing, i.e. a reduction in their weight, was shown only in the Złotnicka Spotted breed. Piglets from the second and third litters of sows with an inbreeding coefficient of 3.13%≤F≤6.24% weighed significantly (P≤0.01) less than piglets from sows with

a lower inbreeding coefficient (0.01%≤F≤3.13%). Similarly, Mroczko and Różycki [10], in the case of piglets reared to 21 days of age, obtained a statistically significantly lower weight for litters of sows with an inbreeding coefficient in the range of 6.26-9.38% and above 12.5% as compared to litters of sows with an inbreeding coefficient of F=0.

Table 5
Rearing performance of piglets of Puławska sows from litters with different levels of inbreeding

Parity	Range of sow inbreeding coefficients (%)					
	0.00 (n)	0.001-3.13 (n)	3.13-6.25 (n)	6.25-9.38 (n)	9.38-12.5 (n)	≥12.5 (n)
			Number of piglets born			
1	10.10 (2535)	10.24 (296)	10.51 (64)	10.39 (33)	–	10.16 (43)
2 and 3	11.01 (3424)	11.13 (386)	11.21 (92)	11.39 (57)	10.67 (3)	10.95 (41)
4 and later	11.28 (4431)	11.19 (470)	12.2 (81)	11.89 (46)	10.00 (2)	11.29 (24)
			Number of piglets at 21 days of age			
1	9.41 (2535)	9.38 (296)	9.53 (64)	9.57 (33)	–	9.53 (43)
2 and 3	10.14 (3424)	10.22 (386)	10.05 (92)	10.47 (57)	10.67 (3)	10.24 (41)
4 and later	10.30 (4431)	10.22 (470)	10.67 (81)	10.47 (46)	10.00 (2)	10.37 (24)
			Litter weight at 21 days of age			
1	54.36 (112)	58.13 (15)	59.13 (8)	54.33 (3)	–	–
2 and 3	59.79 (156)	61.96 (24)	63.50 (6)	46.00 (1)	–	60.50 (2)
4 and later	60.57 (101)	60.14 (14)	64.50 (2)	62.17 (6)	–	60.00 (2)
			Piglet weight at 21 days of age			
1	5.77 (112)	6.08 (15)	5.66 (8)	5.62 (3)	–	–
2 and 3	5.83 (156)	5.94 (24)	5.89 (6)	5.11 (1)	–	5.76 (2)
4 and later	5.89 (101)	5.80 (14)	6.15 (2)	5.75 (6)	–	6.02 (2)

(n) – number of litters

Table 6
Rearing performance of piglets of Złotnicka White sows from litters with different levels of inbreeding

Parity	Range of sow inbreeding coefficients (%)					
	0.00 (n)	0.001-3.13 (n)	3.13-6.25 (n)	6.25-9.38 (n)	9.38-12.5 (n)	≥12.5 (n)
	Number of piglets born					
1	8.66[a] (1075)	8.89[b] (123)	9.50 (12)	8.25 (12)	4.00 (1)	8.11[ab] (100)
2 and 3	9.58 (1243)	9.68 (237)	9.10 (30)	9.66 (12)	11.00 (1)	9.31 (118)
4 and later	10.06 (1776)	10.28 (256)	9.07 (43)	9.83 (6)	–	10.47 (43)
	Number of piglets at 21 days of age					
1	7.58[a] (1075)	7.39[b] (123)	8.67 (12)	7.92 (12)	3.00 (1)	6.64[ab] (100)
2 and 3	8.68[a] (1243)	8.45 (237)	9.10 (30)	9.25 (12)	10.00 (1)	8.16[a] (118)
4 and later	8.98 (1776)	8.97 (256)	7.95 (43)	8.33 (6)	–	8.65 (43)
	Litter weight at 21 days of age					
1	42.78 (79)	37.00 (7)	–	–	–	23.20 (5)
2 and 3	45.54 (117)	47.05 (19)	72.75 (4)	33.00 (2)	–	35.33 (3)
4 and later	51.37 (135)	48.62 (29)	40.50 (2)	72.00 (1)	–	30.00 (2)
	Piglet weight at 21 days of age					
1	5.39 (79)	4.23 (7)	–	–	–	3.56 (5)
2 and 3	5.11 (117)	5.20 (19)	7.26 (4)	3.50 (2)	–	4.22 (3)
4 and later	5.69 (135)	4.65 (29)	4.05 (2)	8.00 (1)	–	3.75 (2)

(n) – number of litters; means in rows with the same lower case letters (a, b, c) differ significantly at P≤0.05

Ivanchuk et al. [6] also found that inbred piglets weighed 7.4-8.6% less at weaning than non-inbred piglets.

Analysis of the effect of piglet inbreeding on their rearing results in the Puławska breed (Table 5) revealed no negative effect of this parameter on the number of piglets born and reared in successive litters or on their weight at 21 days of age. In the Złotnic-

Table 7
Rearing performance of piglets of Złotnicka Spotted sows from litters with different levels of inbreeding

Parity	Range of sow inbreeding coefficients (%)					
	0.00 (n)	0.001-3.13 (n)	3.13-6.25 (n)	6.25-9.38 (n)	9.38-12.5 (n)	≥12.5 (n)
			Number of piglets born			
1	8.18^{a} (1493)	8.35^{b} (147)	9.58^{A} (19)	12.00 (1)	–	7.41^{Aab} (71)
2 and 3	8.98 (2250)	9.33 (121)	9.77^{a} (22)	12.15 (13)	–	8.97^{a} (39)
4 and later	9.31 (2371)	10.11 (124)	10.96 (24)	9.06 (17)	–	8.00 (1)
			Number of piglets at 21 days of age			
1	7.08^{a} (1493)	7.04^{b} (147)	6.21 (19)	9.00 (1)	–	5.93^{ab} (71)
2 and 3	8.08 (2250)	8.17 (121)	8.68 (22)	10.30 (13)	–	7.56 (39)
4 and later	8.30 (2371)	9.02 (124)	8.63 (24)	8.65 (17)	–	6.00 (1)
			Litter weight at 21 days of age			
1	41.17 (168)	40.75 (20)	59.00 (1)	–	–	31.07 (14)
2 and 3	48.07 (187)	43.34 (32)	26.00 (1)	44.89 (9)	–	40.67 (6)
4 and later	45.16 (154)	39.40 (25)	44.33 (3)	37.00 (1)	–	–
			Piglet weight at 21 days of age			
1	5.77 (168)	5.14 (20)	8.43 (1)	–	–	4.99 (14)
2 and 3	6.15 (187)	5.67 (32)	2.89 (1)	4.44 (9)	–	5.43 (6)
4 and later	5.81 (154)	4.75 (25)	5.67 (3)	4.63 (1)	–	–

(n) – number of litters; means in rows with the same lower case letters (a, b, c) differ significantly at P≤0.05; means with the same capital letters (A) differ significantly at P≤0.01

ka White breed (Table 6), on the other hand, an inbreeding coefficient exceeding 12.5% reduced the number of piglets born and reared, especially in the first litters. For these litters the difference in the number of piglets born between the groups with the lowest and highest inbreeding coefficients was –0.55 (P≤0.05), and the difference in the num-

ber of reared piglets was –0.94 (P≤0.05). In subsequent litters, these differences were slightly smaller and ranged from –0.27 piglets born to –0.52 piglets reared (P≤0.05) in the second and third litters. In the Złotnicka Spotted breed (Table 7), the effect of increased inbreeding in the litter was primarily observed as a reduction in the number of piglets born and reared in the first litters. In the litters with the highest inbreeding coefficients (F≥12.5%), as compared to litters with coefficients of F=0% and F=3.12%, there were 0.77 (P≤0.05) and 0.94 (P≤0.05) fewer piglets born and 1.15 (P≤0.05) and 1.11 (P≤0.05) fewer piglets reared, respectively.

A negative effect of litter inbreeding on piglet rearing results in first litters is also confirmed by the results of a study by Mroczko and Różycki [10]. The authors found that when the inbreeding coefficient exceeded 9.39% there was a significant decrease in the number of piglets born in these litters as compared to litters with a lower inbreeding coefficient and non-inbred litters. The differences for first litters ranged from –0.63 piglets born (F≥12.5% vs. F=0%) to –0.93 (9.39%<F<12.5% vs. F=0) piglets born. In the second and subsequent litters, the authors cited reported a greater negative effect of inbreeding in the litter (over 12.5%) on the number of piglets born and reared, with differences of –1.03 piglets born (F≥12.5% vs. F=0%) and –0.83 piglets reared (F≥12.5% vs. F=0%). A negative effect of a high inbreeding coefficient in piglets on litter size has also been noted in other studies. Hradecky [5] showed that litter inbreeding ranging from 18.75% to 43.75% significantly reduces the number of piglets born and piglets reared at 21 and 42 days of age. Rodrigáñez et al. [12], on the other hand, in an analysis of five families of Large White pigs, noted a varied effect of inbreeding on litter size. That study showed that the number of live-born piglets from litters with an inbreeding coefficient of 10% was decreased by 0.39.

In the present study, an increasing level of inbreeding to a value of F=9.37% was not observed to affect the number of piglets born and reared in any of the breeds. This is consistent with the results obtained by Mroczko and Różycki [10], who also showed no significant differences in the number of piglets born and reared between litters with inbreeding values from F=0% to F<9.38%.

To sum up, the results obtained indicate first of all that the level of litter inbreeding had a greater effect than inbreeding of the sow on the number of piglets born and reared in the Złotnicka breeds. In these breeds, sows with an inbreeding coefficient in excess of 12.5% gave birth to and reared slightly fewer piglets in their second and subsequent litters, but the differences were not statistically significant. On the other hand, an increase in inbreeding of sows to 6.25% resulted in improved reproductive performance, increasing the number of piglets born in the fourth and subsequent litters in the Złotnicka Spotted breed (P≤0.05) and the number of piglets reared in the second and third litters in the Złotnicka White breed (P≤0.05). Inbreeding of the litter exceeding

12.5% significantly decreased the number of piglets born and reared, especially in the first litters (P≤0.05). These relationships were not noted in the Puławska breed.

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