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Original study

Genetic parameters of body conformation and performance traits of Wielkopolski horses registered in the successive volumes of the Herdbook

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Abstract

The study covered 11 376 horses registered in the six successive volumes of the Wielkopolski Herdbook. The level of variability in the body conformation indices and in the performance value indices was analysed. The genetic basis parameters for the body conformation and performance traits of the Wielkopolski horses were assessed. A high level of heritability was identified for the wither height (h^2=0.566) and cannon circumference (h^2=0.418), with an average heritability level of the other analysed characteristics (ranging from h^2=0.205 – for the stallion performance test results to h^2=0.350 – in the case of chest circumference). On the other hand, genetic correlation between the analysed indices produced the highest values for the relationship between wither height and cannon (r_G=0.636) and chest (r_G=0.551) circumference, as well as for the interrelation between the above dimensions and the following body structure indices: »boniness« (r_G=0.690) and »bulkiness« (r_G=0.541). Considering the extensive scope of the study – and the fact that the breed population was registered in the Wielkopolski Herdbook – the authors suggested the advisability of using the results of the present study for the modification of breeding programs with a view to improve the breed in question, both its principal population and the one included in the program of gene-pool protection.

Keywords: Wielkopolski horse, body conformation traits, performance traits, heritability, correlation

Abbreviations: h^2: heritability, r_G: genetic correlation

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Introduction

The study analysed body conformation indices (wither height, chest and cannon circumference, »bulkiness« and »boniness«, as well as collective body conformation quality) and performance characteristics (performance test results – stallions exclusively) of 11 376 Wielkopolski horses (including 4 354 stallions and 7 022 mares) registered in the six successive volumes of the relevant Herdbook. A high heritability of wither height and cannon circumference was observed in the horse population under analysis, with an average level of genetic conditioning of the other body conformation and performance traits. Genetic correlations between the analysed characteristics revealed a high (breeding-wise) level of interrelation for the three dimensions and the corresponding body structure indices. As the entire Wielkopolski breeding population was included in the genetic and populational analysis, the use of the obtained genetic parameters of the body conformation and performance traits was recommended in modifying breed improvement programs, both in developing the principal population and the subpopulation covered by the program of gene-pool protection.

The Wielkopolski breed had been created by crossbreeding local stock with German half-breds, among which animals of Trakehner and East-Prussian origin had played an especially important role in the development of the Masurian variety (breed). The Poznan variety had been, in turn, partially derived from Beber, Graditz and Westphalian horses, whereas the development of the so-called Pomeranian Griffins had been strongly influenced by Hanoverian breeders. The discussed varieties – among which Poznan horses constituted a vast majority, with a more limited participation of the Masurian breed (chiefly used as breeder stallions) and a »residual« share of the »Pomeranian Griffins« – have been integrated (since 1963) into a single Wielkopolski breed. At one point (Prawocheński *et al.* 1959, Biernacki *et al.* 1961, Kukawski 1995), it constituted the most numerous single-breed population among hot-blooded half-breds kept in Poland. Wielkopolski breeding was characterised by a particularly high level of organisation and indispensable discipline at the time, which made it possible for the breed to dominate domestic horse farming and sports. Nevertheless, the situation of Wielkopolski breeding systematically worsened – chiefly due to the then (1960-90) exceptional political and economic conditions – which has made the present level of psychophysical capacity of the animals deviate from that of other foreign half-breeds that are »dominant« in the present-day breeding and production of »high-performing« sports horses.

For the reasons mentioned above, any further breeding development of Wielkopolski horses requires a study of the fundamental genetic parameters of their body conformation and performance traits. Such knowledge will enable an advanced and rational modification of the prospective breeding program. Consequently, the present work was aimed at assessing the genetic conditions of the body conformation and performance traits of Wielkopolski horses listed in the successive volumes of the relevant Herdbook (Wielkopolski Herdbook) – on the basis of specific numerical indices.

Material and methods

The study concerned biometric indices of body conformation traits of 11 376 pedigree Wielkopolski horses (including 4 354 stallions and 7 022 mares) registered in the six successive volumes of the Wielkopolski Herdbook. The indices in question comprised the dimensions listed in the »Kwlkp« (height at withers, chest and cannon circumference – in cm), calculated body structure indices (»bulkiness« – as the ratio of chest circumference and wither height – expressed in %) and »boniness« (a corresponding ratio for the cannon circumference), as well as a collective assessment of body conformation correctness and performance test results (only for stallions). The horses in question were listed in the following »Kwlkp« volumes: (volume I – 1 205 stallions and 1 428 mares; volume II – 673 and 1 306, respectively; vol. III – 516 and 952; vol. IV – 493 and 839; vol. V – 554 and 1 022; vol. VI – 913 and 1 475). The records constituted sufficient evidence for organised breeding, mainly between 1965 and 2005. The REML method (VCE 4 software; v. 4.2.5.; Groeneveld 1993) was used to assess the genetic parameters of the body conformation and performance traits under analysis. The heritability of the body conformation and performance traits and genetic correlations between them were determined. Additionally, basic statistical profiles were defined for the analysed indices. Significant differences between the mean values were investigated using the t-Student test.

Results

Before starting the discussion of the obtained results, it has to be stated that the present study covered the largest population of hot-blooded horses – registered in a herdbook and assessed in a uniform manner – among the breeds maintained in Poland. The available domestic equinological research did not comprise works dealing with comparable numbers of horses. Consequently, the assessed genetic parameters of the body conformation and performance traits of the Wielkopolski horses should be regarded as having – at least – a satisfactory level of authoritativeness for breeding purposes. In order to present the pattern of variability in the indices of body conformation/performance characteristics of the analysed Wielkopolski horses, tables 1 and 2 contain statistical profiles of the indices that show a relatively unequal (though statistically highly significant in many cases) increase of the mean value (Table 1) for wither height and chest and cannon circumference – within the Wielkopolski breeding stock registered in the successive volumes of the Herdbook, a gradual and statistically highly significant decrease (Table 2) of the »bulkiness« index, and (to a different extent as regards statistical significance) variation in the »boniness« index and collective body conformation assessment.

In turn, a highly significant increase in the mean value of the three fundamental dimensions (i.e. wither height and chest and cannon circumference) was observed in a different representation (Table 1 and 2) of the analysed characteristics of the horses registered in »Kwlkp« vol. I and VI (i.e. at the beginning and at the end of the Wielkopolski breeding period under analysis). On the other hand, the »bulkiness« index was found to significantly and profoundly decrease. As for the other body conformation and performance of the analysed horses, the »boniness« index was observed to somewhat increase (though it reached a statistically high level of significance only in the mares). The average result of the collective

body conformation assessment was even found to have »deteriorated« (highly significantly in statistic terms) in the mares, whereas no regular patterns were observed in this area in the case of the stallions. Moreover, the statistical analysis of the Wielkopolski horse body conformation indices identified (Table 1 and 2) a relatively prominent sexual dimorphism, as the stallions were superior to the mares in statistically highly significant average results for: wither height, cannon circumference and »boniness« index, as well as collective body conformation assessment (which is self-evident considering the selection criteria). On the other hand, the mares achieved better results for the mean chest circumference and »bulkiness« index. The above pattern was observed (as a rule) both for the horses registered in the particular volumes of the Herdbook and cumulatively, as well as in the comparison of the horses registered in vol. I and VI of the »Kwlkp«. When analysing the performance test results of the Wielkopolski stallions, a relatively small rise in the test values was observed in individual animals from particular volumes of the Herdbook. In many cases, the rise was of statistical importance.

A separate important question is the heritability of specific body conformation and performance traits (Table 3) by the analysed Wielkopolski horses. The highest level of heritability was determined for the height at the withers ($h^2=0.566 \pm 0.011$) and cannon circumference ($h^2=0.418 \pm 0.006$). Based on the levels of the obtained values (h^2), the heritability of the discussed biometric body conformation indices should be defined as high in the case of wither height and cannon circumference – according to Kownacki's classification (Kownacki 1982), who assumed h^2 ranging from 0.00 to 0.20 as a low hereditability level; h^2 – from 0.21 to 0.40 as average; h^2 – 0.41-0.60 as high, and h^2 – 0.61-0.80 as very high. The fact lends the above indices an exceptionally high breeding significance. The other analysed Wielkopolski body conformation traits, in turn, had average heritability (ranging from $h^2=0.350 \pm 0.010$ – for chest circumference to $h^2=0.246 \pm 0.006$ – for the collective body conformation assessment). On the other hand, the heritability of the performance index (analysed as stallion performance test results – with an estimated $h^2=0.205 \pm 0.025$) should be rather interpreted as »bordering« between low and average values. The reliability of the heritability ratios (h^2) for the particular body conformation traits should not be (as a rule) put in question, as the standard errors (SE) in their estimation always had insignificant numerical values.

When assessing the genetic relationship between the analysed Wielkopolski body conformation and performance characteristics (Table 4), the particular levels were found to be very diverse. Nevertheless – considering that only values of $r_G \geq 0.5$ are commonly taken into account in breeding – significant levels were identified for the genetic interrelation between wither height and cannon ($r_G=0.636$) and chest ($r_G=0.551$) circumference. Moreover, the circumference of: the cannon and the chest was genetically correlated with corresponding indices of: »boniness« ($r_G=0.690$) and »bulkiness« ($r_G=0.541$), respectively. However, the other analysed body conformation/performance characteristics did not display similarly significant genetic correlation. It should be noted that the standard errors (SE) in assessing the genetic correlations – for all the cases – had insignificant numerical values, which substantially increases the reliability and breeding usefulness of the obtained parameters of genetic interrelation between the body conformation and performance characteristics of the Wielkopolski horses.

Table 1
A statistic profile of the horse population for wither height, chest circumference, cannon circumference and body weight

Parameter	Sex	Value	Wielkopolski Herdbook vol. I	II	III	IV	V	VI	I-VI
Wither height	stallions	n	1 205	673	516	493	554	913	4 354
		$\bar{x}$	158.88 ABCDE**	160.18 AFGH**	160.11 BIJK**	161.88 CFILM**	164.88 DGJLN**	166.36 EHKMN**	161.90 **
		s	3.75	3.83	3.58	4.16	4.21	3.44	4.80
		min	148	150	146	147	155	155	146
		max	171	172	169	173	178	179	179
	mares	n	1 428	1 306	952	838	1 022	1 475	7 021
		$\bar{x}$	158.07 ABCDE**	159.10 AFGH**	159.05 BIJK**	161.15 CFILM**	163.53 DGJLN**	164.51 EHKMN**	160.91 **
		s	3.75	3.89	3.81	4.19	3.92	3.87	4.64
		min	142	147	146	149	148	153	142
		max	173	174	172	175	176	176	176
Chest circumference	stallions	n	1 205	673	516	493	554	913	4 354
		$\bar{x}$	189.82 ABCD	191.10 AEFGH**	189.89 EIJK**	191.73 BFILM**	195.39 CGJLN**	195.06 DHKMN**	192.05 **
		s	5.49	5.04	4.87	5.03	5.64	5.08	5.72
		min	173	177	178	180	168	165	165
		max	208	205	207	207	222	220	222
	mares	n	1 428	1 306	952	838	1 022	1 475	7 021
		$\bar{x}$	189.97 ABCDE	191.68 AFGHI**	192.13 BFJKL**	193.22 CGJMN**	196.10 DHKMO**	196.60 EILNO**	193.25 **
		s	6.01	6.38	6.51	6.52	6.31	6.54	6.85
		min	165	170	161	174	173	178	161
		max	220	212	218	215	218	221	221
Cannon circumference	stallions	n	1 205	673	516	493	554	913	4 354
		$\bar{x}$	20.83 ABCDE**	21.08 AfGHI**	20.97 BfJKL**	21.24 CGJMN**	21.76 DHKMo**	21.87 EILNo**	21.27 **
		s	0.81	0.77	0.71	0.82	0.84	0.74	0.89
		min	18.5	18.5	18.5	19.5	19.5	20.0	18.5
		max	23.5	23.5	23.0	24.0	24.0	24.0	24.0
	mares	n	14.28	1 306	951	838	1 022	1 475	7 020
		$\bar{x}$	20.04 ABCDE**	20.22 AfGHI**	20.31 BfJKL**	20.57 CGJMN**	20.94 DHKM**	20.97 EILN**	20.50 **
		s	0.75	0.77	0.76	0.81	0.80	0.77	0.86
		min	17.5	18.0	18.0	18.0	18.5	18.0	17.5
		max	22.5	23.0	23.0	23.5	23.0	23.0	23.5
Body weight	stallions	n	1 205	673	516	493	554	913	4 354
		$\bar{x}$	548.53 ABCD**	559.47 AEFGH**	548.88 EIJK**	565.05 BFILM**	598.21 CGJLN**	594.94 DHKMN**	568.19 **
		s	47.64	44.47	42.43	44.79	52.05	46.46	50.97
		min	414	444	451	467	379	359	359
		max	720	689	710	710	875	852	875
	mares	n	1 428	1 306	952	838	1 022	1 475	7 021
		$\bar{x}$	550.09 ABCDE**	565.27 AFGHI**	569.35 BFJKL**	579.03 CGJMN**	605.19 DHKMO**	609.94 EILNO**	579.57**
		s	52.78	56.81	58.30	58.57	58.34	61.36	61.96
		min	359	393	334	421	414	451	334
		max	852	762	829	795	829	864	864

The mean values for the stallions and mares significantly differ at **$P \leq 0.01$, *$P \leq 0.05$. The mean values in the lines referring to vol. I-VI marked with the same letter are significantly different at: uppercase letters – $P \leq 0.01$, lowerrcase letters – $P \leq 0.05$.

Table 2
A statistical profile of the horse population under analysis for the chest circumference index, cannon circumference index, collective body conformation assessment and performance test results

Parameter	Sex	Value	Wielkopolski Herdbook vol. I	II	III	IV	V	VI	I-VI
Chest circumference index	stallions	n	1 205	673	516	493	554	913	4 354
		$\bar{x}$	119.50 ABCD**	119.34 EFGH**	118.64 AEI**	118.51 BFJ**	118.55 CGK**	117.28 DHIJK**	118.67 **
		S	3.17	3.30	3.57	3.91	3.62	3.13	3.47
		min	109.1	110.4	110.4	110.2	104.3	98.8	98.8
		max	130.6	128.8	129.0	134.7	135.4	133.3	135.4
	mares	n	1 428	1 306	952	838	1 022	1 475	7 021
		$\bar{x}$	120.20 ABCDE**	120.49 AFGHI**	120.83 BFJKL**	119.93 CGJM**	119.95 DHKN**	119.53 EILMN**	120.13 **
		S	3.39	3.49	3.96	3.60	3.70	3.64	3.63
		min	105.1	109.8	103.2	105.5	104.2	108.5	103.2
		max	134.6	136.4	132.9	132.7	133.7	135.0	136.4
Cannon circumference index	stallions	n	1 205	673	516	493	554	913	4 354
		$\bar{x}$	13.11 A**	13.16 **	13.10 B**	13.12 c**	13.20 ABc**	13.14 **	13.14 **
		S	0.41	0.39	0.37	0.40	0.38	0.38	0.39
		min	11.9	12.0	12.1	12.0	12.1	11.8	11.8
		max	14.3	14.5	14.2	14.4	14.3	14.3	14.5
	mares	n	1 428	1 306	951	838	1 022	1 475	7 020
		$\bar{x}$	12.68 ABCD**	12.71 Ef**	12.77 Ae**	12.76 B**	12.81 CFg**	12.75 Dg**	12.74 **
		S	0.39	0.39	0.39	0.38	0.41	0.41	0.40
		min	11.3	11.3	11.6	11.7	11.4	11.4	11.3
		max	14.0	14.2	14.2	14.1	14.2	14.2	14.2
Collective body Conformation assessment	stallions	n	1 203	670	516	491	552	913	4 345
		$\bar{x}$	79.26 ABCd**	78.61 AEF**	78.70 BGH**	78.59 CIJ**	79.48 dEGIk**	79.33 FHJk**	79.06 **
		S	3.18	2.37	1.92	2.07	1.92	1.51	2.38
		min	70	70	71	70	74	75	70
		max	90	87	86	89	86	84	90
	mares	n	1 425	1 303	950	837	1 018	1 475	7 008
		$\bar{x}$	79.09 ABCDE*	76.74 AFGH**	76.80 BIJK**	77.62 CFILM**	78.78 DGJL**	78.81 EHKM**	78.07 **
		S	4.72	3.67	3.33	2.79	2.30	1.84	3.45
		min	69	63	63	64	67	72	63
		max	97	87	97	85	85	84	97
Performance test result	stallions	n	622	535	346	274	416	566	2 759
		$\bar{x}$	4.17 aBCDE	4.29 afGHI	4.41 BfjK	4.46 CGL	4.56 DHjM	4.90 EIKLM	4.46
		S	0.68	0.71	0.73	0.69	0.70	0.86	0.78
		min	3	3	3	3	3	3	2
		max	6	5	5	5	5	6	6
	mares	n	-	-	-	-	-	-	-
		$\bar{x}$	-	-	-	-	-	-	-
		S	-	-	-	-	-	-	-
		min	-	-	-	-	-	-	-
		max	-	-	-	-	-	-	-

The mean values for the stallions and mares significantly differ at $^{**}P \leq 0.01$, $^{*}P \leq 0.05$. The mean values in the lines referring to vol. I-VI marked with the same letter are significantly different at: uppercase letters – $P \leq 0.01$, lowerrcase letters – $P \leq 0.05$.

Table 3
Heritability factors for the body conformation and performance traits of the Wielkopolski horses listed in the »Kwlkp«

Parameter	h^2	SE
Wither height	0.566	0.011
Chest circumference	0.350	0.010
Cannon circumference	0.418	0.006
Chest circumference index	0.331	0.011
Cannon circumference index	0.347	0.006
Collective body conformation assessment	0.246	0.006
Performance test result	0.205	0.025

Table 4
Factors of genetic correlation between the analysed body conformation and performance traits of the Wielkopolski horses registered in the »Kwlkp«.

1.	Wither height	r_G	1.						
		SE							
2.	Chest circumference	r_G	0.551	2.					
		SE	0.013						
3.	Cannon circumference	r_G	0.636	0.570	3.				
		SE	0.008	0.017					
4.	Chest circumference index	r_G	−0.404	0.541	−0.017	4.			
		SE	0.014	0.016	0.023				
5.	Cannon circumference index	r_G	−0.120	0.215	0.690	0.355	5.		
		SE	0.015	0.025	0.009	0.025			
6.	Collective body conformation assessment	r_G	0.150	0.351	0.313	0.233	0.262	6.	
		SE	0.022	0.026	0.023	0.026	0.030		
7.	Performance test result	r_G	0.083	0.124	0.050	0.050	−0.080	0.141	7.
		SE	0.020	0.054	0.027	0.057	0.028	0.030	

Discussion

It is extremely difficult to compare the present results with those of other researchers – as regards studies concerning Wielkopolski horses published in local equinological journals – since our observations refer to the entire breeding population of Wielkopolski horses registered in the breed herdbook. On the other hand, the remaining scientific works (or, in a large part, popular science publications) generally had (to a greater or smaller extent) a rather preparatory nature. Otherwise, Wielkopolski horses constituted only one of the hot-blooded half-bred horse groups under analysis in them. Moreover, the publications refer to far less numerous groups of scientifically analysed animals, with a part of the animals

not even (sometimes) listed in the mentioned Herdbook (Kaproń 1981, Kaproń *et al.* 1993, Kaproń *et al.* 1994, Kaproń *et al.* 1996a, 1996b, Kaproń *et al.* 1998, Kaproń *et al.* 2010). Nevertheless, it is proper to point out a tendency that has already been identified in relation to the discussed breed population. The most extensive research on ongoing changes in the body conformation and performance characteristics of Wielkopolski horses (representing a breed group of hot-blooded horses) was (chronologically) first conducted by Kaproń (1981), followed by Chrzanowski (1988) who mainly analysed the »admixture« of Thoroughbred English blood (exceptionally intensive in 1970-85) that has gradually led to a transformation of the »universal« usefulness profile of the breed population into a definitely more saddle-type one. The change in question was brought about mostly through a fairly evident increase in Wielkopolski wither height followed (though to a lesser degree) by a certain rise in the chest and cannon circumference, which caused a gradual decrease of the »bulkiness« and »boniness« indices, towards levels typical of saddle horses. Additionally, Kaproń – who analysed the effect of the Thoroughbred English blood »admixture« on Wielkopolski useful capacity sets – identified (Kaproń 1981) a positive influence of the addition on the level of the motor capacity (chiefly in connection with steeplechasing fitness) and jumping ability (displayed in showjumping events) of the horses.

What should be separately considered, however, is the problem of a lack of clear-cut tendencies in the collective Wielkopolski body conformation assessment. *Nota bene* such assessments have been performed subjectively according to the quality classification scale employed since late 50s of the 20th century), though its highly limited breeding usefulness has been repeatedly shown (Kaproń *et al.* 2010) and partially already proved, with a suggestion of (also evidently subjective but apparently more adequate for the present situation) new solutions that have been tested against the old method. Moreover, the fact of a substantial »deterioration« in the average results of the assessment of body conformation correctness in the mares does not seem to result from a declining »breeding quality« but – probably – chiefly stems from a routine and (perhaps) too inconsistent and rather »non-committal« use of the »superannuated« method for assessing the assets and defects in the body conformation of horses.

On the other hand, research on the genetic parameters of body conformation and performance traits of Wielkopolski horses was initiated by Kownacki *et al.* (1982) and later continued by Kaproń *et al.* (1996a,b). It concerned e.g. the genetic conditioning of stallion performance test results in training centres and variability in the degree of conformation trait heritability, depending on the statistical model of variability assessment (Kaproń *et al.* 1998). The results of the above research essentially do not diverge from the observations described in the present work, though the papers sometimes present higher levels: e.g. the heritability of body conformation traits identified by Kownacki *et al.* (1982) or the genetic parameters of the performance traits of training centre stallions determined by Kaproń *et al.* (1996a). It should, however, be stressed that the cited research refers to a definitely lower number of Wielkopolski horses, the majority of which, nevertheless, was listed in the herdbook. The abundance of Polish equinological studies relating to Wielkopolski horses precludes a detailed analysis of their results. However, in conclusion, it must be stated that (regardless of their substantive extent), as a rule, the studies indicate tendencies that have been unreservedly confirmed by the results of the present investigation.

In conclusion, the present study provides the grounds to formulate the following conclusions:

1. The analysis of the average levels of the body conformation indices of the Wielkopolski horses – registered in the »peripheral« volumes of the Herdbook (i.e. vol. I and VI) – revealed a highly significant increase in the wither height and chest and cannon circumference, with a similarly significant decrease of the »bulkiness« and »boniness« (only in mares) indices.
2. As regards the results of the assessment of body conformation correctness (concerning horses listed in »Kwlkp« vol. I and VI), no clear-cut and regular tendencies were identified. Highly significant »deterioration« of the correctness was even observed in the mares. This, however, is connected with the largely limited usefulness of the previous assessment method for breeding purposes and should provide motivation for attempts to devise new solutions in this area.
3. In turn, the analysis of the performance parameters revealed a highly significant increase of the average level in the Wielkopolski stallions listed in vol. I and VI of the »Kwlkp«.
4. The study identified a high inheritability level for wither height and cannon circumference of the Wielkopolski horses – with an average genetic conditioning level of the other body conformation and performance traits of the discussed horse population.
5. A high level of genetic correlation was also observed between the three basic dimensions of the Wielkopolski horses (i.e. wither height and chest and cannon circumference) – which makes it possible to limit the number of the selection criteria in breeding attempts to improve the body conformation characteristics of the analysed breed to just one – namely: the height at the withers.
6. Considering the extent of the present study, it is evidently advisable to allow for its results – namely: the identified genetic parameters of the body conformation and performance traits of the Wielkopolski horses – in potential modifications of breeding improvement programs for the horse population in question. This suggestion is valid both for the principal population of the discussed breed and the subpopulation covered by the gene-pool protection program.

References

Biernacki S, Grabowski J, Gurski C, Hay H, Helak H, Kowalski J, Kukawski L, Marinowicz I, Matlawski C, Mucha W, Nowicki K (1961) [The Poznan Horse.] Instytut Zootechniki, Kraków, Poland [in Polish]

Chrzanowski S (1988) [The effect of improvement crossing with Thoroughbreds on the breeding results and practical value of Malopolski and Wielkopolski horses from state studs.] SGGW-AR Warszawa, Poland [in Polish]

Groeneveld E (1993) REML VCE – a multivariate multimodel restricted maximum likelihood (co)variance component estimation package. In: 1. Symposium des Institutes für Tierzucht und Tierhaltung der Martin-Luther-Universität Halle, Germany

Kaproń M (1981) [The influence of Thoroughbreds on the breeding and production of riding and multi-purpose horses in Poland.] Postdoctoral dissertation. Wydawnictwo Akademii Rolniczej, Lublin, Poland [in Polish]

Kaproń M, Janczarek I, Grochowski W, Danielewicz A (2010) [Relationship between two systems for conformation testing of half-blood stallions and results of official performance tests.] Rocz Nauk Zootech 37, 13-31 [in Polish]

Kaproń M, Pięta M, Kaproń H (1993) Heritability variation of conformation traits in Wielkopolski horse as affected by the statistical model used. Anim Sci Pap Rep 11,193-199

Kaproń M, Pięta M, Kaproń H (1994) Genetic relations between conformation traits of half-breed horses. Genet Pol 35, 109-114

Kaproń M, Zięba G, Łukaszewicz M, Kaproń H, Janczarek I (1996a) [Heritability of performance traits by stallions exercised at Polish training establishments in 1973-1992.] Pr Mater Zootech 49, 67-76 [in Polish]

Kaproń M, Zięba G, Łukaszewicz M, Kaproń H, Janczarek I (1996b) [Genetic and phenotypic correlations between performance traits in stallions exercised at Polish Training Establishments in 1973-1992.] Pr Mater Zootech 49, 77-90 [in Polish]

Kaproń M, Pięta M, Patkowski K, Kaproń H (1998) [Variability in genetic, phenotypic and environmental correlations between Wielkopolski body conformation traits relative to the statistical model of assessment.] Pr Mater Zootech 53, 57-63 [in Polish]

Kownacki M (1982) [Genetic conditions of performance traits in horses.] Zesz Probl Post Nauk Rol 264, 449-464 [in Polish]

Kukawski L (1995) [An outline of the history of organised horse breeding in Greater Poland in 1895-1995.] WZHK, Poznań, Poland [in Polish]

Prawocheński R, Komornicki T, Kurowski S, Pacyński J, Sosnowski A (1959) [The Mazury horse.] Instytut Zootechniki, Kraków, Poland [in Polish]

[Wielkopolski Herdbook.] (1965, 1966, 1971, 1972, 1976, 1977, 1981, 1982, 1990, 1992, 1998, 2000) PWRiL Vol. I-VI, Warszawa, Poland [in Polish]