Archivos de Zootecnia
Journal website: https://www.uco.es/ucopress/az/index.php/az/

Principal component analysis of morphometric measures of horses of the Brazilian Pony breed

Bartholazzi Junior, A.@; David, C.M.G.; Rua, M.A.S.; González, A.R.M.; Maretto, V.; Matos, L.F.; Quirino, C.R.

Universidade Estadual do Norte Fluminense Darcy Ribeiro - UENF, Campos dos Goytacazes, RJ, Brasil.

Additional keywords
Linear measurements.
Mares.
Morphology.
Multivariate analysis.
Stallions.

SUMMARY

The Brazilian Pony is a recent breed, with registration of animals only starting in 1970, since when it has been continually improved. Body morphometry is important for selective breeding of horses, because it is one of the main elements used to characterize breeds. The objective of this study was to apply principal component analysis (PCA) to the main morphometric measures of Brazilian Pony stallions and mares to identify those that contribute the most to explain the total variance in each sex. Fourteen linear measures were obtained from 281 adult animals and the data were used for to compute descriptive statistics and correlation coefficients as well as for analysis of variance and principal component analysis. The morphometric measures of the animals showed great variation in the two sexes. The correlations between the variables were positive and generally of large magnitude. For the stallions, only two components were necessary to explain at least 80% of the total variance, while for the females, three components were needed. After the methodology for discarding of variables, the variables head width, neck length and chest height were identified as the measures that explain most of variations in Brazilian Pony horses and should be uses for breed selection and control.

Análise de componentes principais de medidas morfométricas de equinos da raça Pônei Brasileiro

Palavras chave adicionais
Análises multivariadas.
Éguas.
Garanhões.
Medidas lineares.
Morfologia.

RESUMO

O Pônei Brasileiro é uma raça recente que iniciou o registro dos animais a partir do ano de 1970, e vem sendo selecionada continuamente principalmente na sua morfologia para aperfeiçoamento e padronização racial. O objetivo do estudo foi avaliar através da análise componentes principais medidas morfométricas de garanhões e éguas pôneis da raça Pônei Brasileiro para identificar as que mais contribuem para a explicação da variância total em cada sexo. Foram tomadas 14 medidas lineares de um total de 281 animais adultos e foram realizadas a análise descritiva, análise de variância, correlações e análise de componentes principais. As medidas morfométricas dos animais apresentaram grande variação nos dois sexos. As correlações entre as variáveis foram positivas e, em geral, de alta magnitude. Para os garanhões foram necessários apenas dois componentes e para as fêmeas foram necessários apenas três componentes para explicar pelo menos 80% da variação total. Após metodologia para descarte de variáveis foram identificadas as variáveis largura da cabeça, comprimento do pescoço e altura do tórax como as medidas que explicam a maior parte da variação dos animais da raça Pônei Brasileiro e devem ser utilizadas para seleção e controle racial.

Information
Cronología del artículo.
Recibido/Received:
Aceptado/Accepted:
On-line: 15.10.2020.
Correspondencia a los autores/Contact e-mail:
junior_barth@hotmail.com.

INTRODUCTION

The Brazilian Pony is a recent breed, with the first registration of animals occurring in 1970, with the founding of the Brazilian Association of Piquira and Pony Horses (Bergmann et al., 1997a, 1997b, Costa et al., 1998, 2001a, 2001b; Quirino et al., 2012; Bartholazzi Junior et al., 2017, 2018).

Horses of the Brazilian Pony breed are being selected continuously, as reported by Costa et al. (2001b), who observed a reduction in size of the animals in the genetic trend of linear measurements. These horses are dual purpose (riding and light traction), with all the coat colors/patterns common to horses. Their withers height cannot be more than 100 cm for males and 105 cm for females, with the ideal being 90 cm (ABCCPO-

NEI, 2018). They are used mainly in leisure activities for children, including initiation in horsemanship, as well as competition at shows.

The body size and conformation are important for horse breeds and are subject to strong selection pressure. Breeder associations typically select horses based on functional criteria and encourage the breeding of animals with body structure most suitable for specific functions, with correct skeletal conformation being a key determinant of the body type (Brooks et al., 2010).

Principal component analysis is a multivariate statistical technique that enables linear transformation of a set of original (correlated) variables into a substantially smaller set of (uncorrelated) variables, seeking to maintain most of the features as the original data (Hongyu, Jorge and Junior, 2016)entre as t\u00e9cnicas de multivariadas, a an\u00e1lise de componentes principais (ACP. This method allows excluding variables that have smaller influence on the variance of a group of animals, facilitating selection of traits for a breed.

Various studies have applied principal component analysis to data on horses, but there are no works investigating the Brazilian Pony breed. The objective of this study was to apply principal component analysis to morphometric measures of horses of the Brazilian Pony breed to identify the linear measurements that contribute the most to explain the total variance in each sex.

MATERIAL AND METHODS

This study was approved by the Ethics Committee on Animal Experimentation of Norte Fluminense State University (UENF Protocol no. 245), in accordance with the Brazilian Society of Laboratory Animal Science/ Brazilian College of Animal Experimentation (SBCAL/ COBEA).

Animals

We evaluated a total of 281 adult ponies (older than three years), composed of 92 stallions and 189 mares, in the state of Rio de Janeiro, Brazil. The animals were maintained, with the feeding and management specific to each sex, with predominance of extensive grazing for the females and confinement of males in individual stalls. The farms are mainly engaged in breeding animals for show purposes, based on the animals' morphometric measures.

Morphometric measures

For the morphometric measurements, the animals were positioned with the limbs parallel on a flat and firm surface. The measurements were performed using a zoometric hypsometer, metal tape measure and zoometric compass.

We studied the 14 linear measurements described below, according to Bartholazzi Junior et al. (2017)biometric indexes, morphological indexes and evaluate the effect of gender. Linear measurements and the body indexes of these measures were performed in relation to the height at withers and different morphological indexes (body index, work index 1 and work index 2: withers height, croup height, head length, neck length, back-loin length, croup length, body length, head width, chest width, croup width, thorax height, front cannon length, thorax circumference and head circumference.

Statistical analysis

The consistency of the all the measures (mean, standard deviation and coefficient of variation) was verified, then the data were submitted to analysis of variance by the PROC GLM, and the means of the stallions and mares were compared by the t-test of the SAS® 9.2 software (SAS Inst., Inc., Cary, NC). The pairwise correlations were estimated between the morphometric measures by the PROC CORR of the SAS® 9.2 software (SAS Inst., Inc., Cary, NC). The correlations of the variables were compared between stallion and mares. Initially, Z values for each correlation were obtained according to the following equation.

$$Z_n=(0,5) * log((1+r)/(1-r))$$

where, *log* is the logarithm and *r* is the correlation value.

Subsequently, a Z score between the two groups was obtained according to the following equation.

$$Z_{12}=(Z_1-Z_2)/SEZ_{12}$$

where, *SEZ* is the standard error between the groups, obtained according to the following equation

$$SEZ_{12}=\sqrt{(1/(n1-3)+1/(n2-3))}$$

where, *n* is the number of observations for the correlation.

The Z value obtained for the correlations of the two groups were compared with the Z score table with normal distribution to obtain significance.

The measure of sampling adequacy of Kaiser-Meyer-Olkin (KMO) was tested in SPSS Statistics for Windows, version 16.0 (SPSS Inc., Chicago, Ill., USA); component analysis must only be performed if the KMO is greater than 0.50 (Fávero et al., 2009). Finally, principal component analysis was performed for each sex by the PROC PRINCOMP of the SAS® 9.2 software (SAS Inst., Inc., Cary, NC), with selection of the principal components where the sum of the eigenvalues was able to explain at least 80% of the total variance (Johnson and Wichern, 1998).

The disposal of variables was carried out according to the methodology of Mardia, Kent and Bibby (1979) to identify the most important variables, where, after the first analysis, the variable with the highest factor loading in the last component will be discarded and subsequently a new analysis will be performed. Thereafter, the variable with the highest factor loading will always be discarding until reaching a result with all variables showing high factor loading.

RESULTS

Descriptive statistics and analysis of variance

The descriptive statistics and comparison of the means of adult Brazilian Pony stallions (n=92) and mares (n=189) are presented in **Table I**. The animals

had average withers heights of 82.42 cm for males and 86.48 cm for females, and mean body lengths of 84.46 cm for males and 91.39 cm for females. The morphometric measures with highest coefficients of variation were croup length (19.55%) of stallions and back-loin length (19.22%) of mares.

The mares had larger measures than the stallions (P <0.05) for head width, head length, head circumference, withers height, croup height, thorax circumference, front cannon length, back-loin length, croup length, croup width and body length (**Table I**).

The measures of neck length, thorax height and chest width did not differ significantly (P >0.05) between the stallions and mares of the Brazilian Pony breed.

Correlations

As a lot of measures were significantly different between stallions and mares, the correlations and the main components were estimated for each sex. The pairwise correlations between the morphological measures are presented in **Table II** for the stallions and mares. Among the stallions, the correlations between the morphological measures were medium to high, with the smallest correlation being between croup length and neck length (r= 0.16) and the highest being between croup height and withers height (r= 0.97) and between body length and thorax circumference (r= 0.94).

Among the mares, the smallest correlation was between croup length and neck length (r= -0.09), as was the case of the males, and the largest correlations were between croup height and withers height (r= 0.97) and between withers height and body length (r= 0.90). In general, the neck length metric had the smallest correlations with the other morphological measures among both the stallions and mares. The biggest difference was between head width and head length, with a correlation of 0.78 in stallions and 0.42 in mares.

Mares showed higher correlations (P <0.05) than stallions between WH measurements with ThH, ThH with CrH and ChW. In general, most of the correlations that showed statistical differences (P <0.05) were higher in the stallions (**Table II**). Most of the differences were between the correlations involving the measures HW, HL, HC and ChW. The correlations between NL, FCL and CrW with the other variables did not presented different (P >0.05) correlations between males and females.

Principal components

Due to the differences observed in means and correlations of measurements between males and females, the principal components were estimated separately for each sex. The measure of sampling adequacy of Kaiser-Meyer-Olkin (KMO) was 0.911 for stallions and 0.907 for mares. The principal component analyzes could be performed from these results.

For the Brazilian Pony stallions, only two principal components (PC) were necessary to explain at least

Table I. Means and standard deviation of the morphometric measures of the Brazilian Pony breed based on sex (Médias e desvios padrão das medidas morfométricas da raça Pônei Brasileiro de acordo com o sexo).

	Stallions			Mares		
Variable	Mean cm	SD	CV %	Mean cm	SD	CV %
HW	15.32	1.54	10.02	15.76*	1.63	10.34
HL	35.45	3.58	10.10	37.16*	4.82	12.98
HC	59.63	6.40	10.73	61.88*	6.47	10.45
NL	41.92	6.39	15.24	41.33	6.30	15.23
WH	82.42	8.76	10.63	86.48*	8.00	9.25
ThH	42.60	4.73	11.11	43.28	4.38	10.11
CrH	83.27	8.25	9.90	87.83*	8.06	9.18
ThC	102.62	15.24	14.85	110.85*	15.06	13.59
ChW	21.91	3.48	15.87	22.38	2.94	13.15
HCL	15.46	1.74	11.27	16.13*	1.82	11.30
BLL	37.21	6.37	17.13	42.13*	8.10	19.22
CrL	23.94	4.68	19.55	26.06*	4.56	17.49
CrW	28.53	4.85	17.01	31.18*	4.32	13.86
BL	84.46	11.57	13.70	91.39*	10.66	11.66

Means in the same row followed by the t-test at 5% probability (*= P <0.05). HW: Head width. HL: Head length. HC: Head circumference. NL: Neck length. WH: Withers height. ThH: Thorax height. CrH: Croup height. ThC: Thorax circumference. ChW: Chest width. HCL: Hind cannon length. BLL: Back-loin length. CrL: Croup length. CrW: Croup width. BL: Body length. SD: standard deviation. CV: coefficient of variation.

Table II. Eigenvalues and percentages of variance explained by the principal components of morphometric measures in Brazilian Pony breed stallions (Autovalores e porcentagem da variância explicada pelo component principal das medidas morfométricas de garanhões da raça Pônei Brasileiro).

Principal Component	Eigenvalue	Difference	Variance	Cumulative Variance
PC1	10.231	9.112	0.731	0.731
PC2	1.119	0.402	0.080	0.811
PC3	0.717	0.342	0.051	0.862
PC4	0.375	0.050	0.027	0.889
PC5	0.325	0.015	0.023	0.912
PC6	0.310	0.043	0.022	0.934
PC7	0.267	0.057	0.019	0.953
PC8	0.210	0.043	0.015	0.968
PC9	0.167	0.065	0.012	0.980
PC10	0.101	0.019	0.007	0.987
PC11	0.082	0.035	0.006	0.993
PC12	0.047	0.014	0.003	0.997
PC13	0.033	0.018	0.002	0.999
PC14	0.015	-	0.001	1.000

PC: Principal component.

80% of the total variance of the morphometric measures analyzed. The eigenvalues and percentages of variance explained by the principal components for the stallions are presented in **Table III**. Only PC1 and PC2 had eigenvalues higher than 1, together representing 81.1% of the cumulative variance observed in the morphometric measures of the stallions.

The eigenvalues and percentages of variance explained by the principal components for the mares are presented in **Table IV**. In the PC of the morphometric measures of mares, three principal components explained at least 80% of the total variance presented (85.1%). However, as for the stallions, only PC1 and PC2 had eigenvalues greater than 1.

The estimated component loadings of the morphometric measures for each principal component are presented in **Table V** for the stallions and in **Table VI** for the mares. In the first component of the PCA of the stallions, all the morphometric measures contributed almost equally to the composition of the variance of the animals. The factor loadings of the measures varied from only 0.299 for body length to 0.194 for front cannon length. In the second component, the variables thorax height and front cannon length presented high factor loading (0.444 and 0.604, respectively) and suggested that these are the main variables responsible for the greatest variation in stallions, since in the first component the factor loading were similar between variables.

Table III. Eigenvalues and percentage of variance explained by the principal components of morphometric measures in Braziliam Poni breed mares (Autovalores e porcentagem da variância explicada pelo componente principal das medidas morfométricas de éguas da raça Pônei Brasileiro**).**

Principal Component	Eigenvalue	Difference	Variance (%)	Cumulative Variance (%)
PC1	9.979	8.814	0.713	0.713
PC2	1.165	0.392	0.083	0.796
PC3	0.773	0.397	0.055	0.851
PC4	0.376	0.044	0.027	0.878
PC5	0.331	0.019	0.024	0.902
PC6	0.313	0.051	0.022	0.924
PC7	0.262	0.048	0.019	0.943
PC8	0.213	0.043	0.015	0.958
PC9	0.170	0.011	0.012	0.970
PC10	0.159	0.034	0.011	0.982
PC11	0.126	0.061	0.009	0.991
PC12	0.065	0.027	0.005	0.995
PC13	0.037	0.007	0.003	0.998
PC14	0.031	-	0.002	1.000

PC: Principal Component.

Likewise, for the mares in the first component all the morphometric measures also contributed nearly equally to the composition of the variance, with positive loadings varying from only 0.304 for body length to 0.196 for front cannon length. In the second principal component of mares, the highest loading was for front cannon length (0.611) and neck length (-0.518). In the third component, thorax height had the highest loading (0.645). These would be the most important variables to explain the variance in females.

To allow the disposal of variables, new analyzes were performed removing variables with the highest factor loading in the last component, until reaching a result where all variables have high factor loading. The variables considered important presented in the final factor loadings analysis were greater than 0.57 in the first component (**Table VII**).

Only two principal components (PC) were necessary to explain at least 80% of the total variance in stallions and mares. The PC1 and PC2 had 83.48% and 84.99% of cumulative variance observed (for the stallions and mares, respectively). The variables head length, head circumference, withers height, croup height, thorax circumference, chest width, front cannon length, back-loin length, croup length, croup width and body length were discarded for both stallion and mares. Thus, the variables that should explain the greatest variation in animals and be evaluated would be the measures of head width, neck length and thorax height in stallions and mares.

Estimated factor loadings for the first component ranged from 0.570 to 0.584 for stallions and 0.577 to 0.581 for mares (**Table VII**). In the second component, the variables with the highest estimated factor loadings were neck length and thorax height for both stallions and mares, these would be the most important variables to explain the variation in animals.

DISCUSSION

The averages of the morphometric measures evaluated in this study were mostly lower to those observed by Costa et al. (2001a) mainly at the withers height, croup height, and body length. These results are in according with Costa et al. (2001a), that in their study observed a genetic tendency in decreasing the size of the animals for almost all the linear measurements of the ponies.

The correlations between the morphological measurements were generally medium to high and corroborate with the results found by Bartholazzi Junior et al. (2017)biometric indexes, morphological indexes and evaluate the effect of gender. Linear measurements and the body indexes of these measures were performed in relation to the height at withers and different morphological indexes (body index, work index 1 and work index 2. These findings are important in the principal component analyzes, since this analysis transforms a group of correlated variables into a group of uncorrelated variables.

The coefficients of variation of the morphometric measures of stallions and mares of the Brazilian Pony

breed presented large variation between the animals of each sex, possibly because of different lineages. These coefficients were higher than those observed for other breeds. Pinto et al. (2008) reported coefficients of variation of morphometric measures in males and females of the Margalarga Marchador breed ranging from 1.83 to 7.83%. Lage et al. (2009), evaluating linear measurements of the same breed, observed coefficients of variation below 9%, such as 1.81 % for withers height.

Pascual Moro and Intxausti del Casal (1998) conducted a zoometric study of the Vasto-Pottoka pony breed in Spain, finding mean withers height of 125.7 cm for females and 125.4 cm for males, and reported the highest coefficient of variation for chest width (19.8%) and the lowest one for withers height (2.6%). Among the animals of that breed, although the coefficients of variation were high, for most of the morphometric measures the variation was lower than observed in our study of the Brazilian Pony breed.

The correlation has a direct effect on principal component analysis. According to Manly (2008), principal component analysis should only be applied when the original variables are correlated, and produces the best results if the variables are highly correlated either positively or negatively. The correlations found in our study were of medium to high magnitude for most of the measures, allowing application of principal component analysis and supporting the results obtained.

The differences observed in the magnitudes of the correlations among the measurements of the stallions compared to the correlations of the measurements of the mares were due to the differences observed in some measurements between the sexes. These results indicate a behavior different from the body proportions between males and females, and also justify the analysis of principal components separately for each gender. These differences, possibly, are due to the more rigorous selection for males or by the sexual differentiation in the breed (Bartholazzi Junior et al., 2017)biometric indexes, morphological indexes and evaluate the effect of gender. Linear measurements and the body indexes of these measures were performed in relation to the height at withers and different morphological indexes (body index, work index 1 and work index 2.

The lower magnitude of the correlations observed in the females indicates the greater variation in the body proportions of the mares and corroborates with the possibility of a less rigorous selection for the females.

Table IV. Correlations of the morphometric measures in Brazilian Pony breed stallions (Correlações das medidas morfométricas de garanhões da raça Pônei Brasileiro**).**

	HW	HL	HC	NL	WH	ThH	CrH	ThC	ChW	HCL	BLL	CrL	CrW	BL
HW	-													
HL	0.78	-												
HC	0.83	0.81	-											
NL	0.37	0.38	0.58	-										
WH	0.76	0.78	0.83	0.58	-									
ThH	0.48	0.56	0.50	0.47	0.75	-								
Agar	0.74	0.76	0.81	0.62	0.97	0.72	-							
ThC	0.78	0.79	0.92	0.60	0.83	0.44	0.83	-						
ChW	0.73	0.70	0.84	0.39	0.68	0.36	0.69	0.90	-					
HCL	0.49	0.56	0.52	0.22	0.64	0.58	0.62	0.47	0.36	-				
BLL	0.47	0.48	0.74	0.38	0.69	0.54	0.66	0.73	0.39	0.65	-			
CrL	0.67	0.67	0.80	0.16	0.66	0.52	0.65	0.81	0.73	0.45	0.25	-		
CrW	0.75	0.71	0.88	0.44	0.78	0.59	0.75	0.90	0.82	0.49	0.51	0.75	-	
BL	0.81	0.80	0.90	0.55	0.90	0.57	0.88	0.94	0.84	0.50	0.60	0.71	0.86	-

HW: Head width. HL: Head length. HC: Head circumference. NL: Neck length. WH: Withers height. ThH: Thorax height. CrH: Croup height. ThC: Thorax circumference. ChW: Chest width. HCL: Hind cannon length. BLL: Back-loin length. CrL: Croup length. CrW: Croup width. BL: Body length.

The measure of sampling adequacy of Kaiser-Meyer-Olkin (KMO) was greater than 0.90 for stallions and mares. High values (between 0.5 and 1.0) indicate that the analysis by principal components is appropriate, while below 0.5 indicate that the analysis is inadequate. A value between 0.90 to 1 is considered very good for principal component analysis (Fávero et al., 2009).

In addition, these results indicate that there is a very good relationship among the magnitudes of the linear correlation coefficients observed with the partial correlation coefficients, and that the model is highly adjusted to the data.

In the principal component analysis here, very few components were necessary to explain at least

Table V. Correlations of the morphometric measures in Brazilian Pony breed mares (Correlações das medidas morfométricas de éguas da raça Pônei Brasileiro).

	HW	HL	HC	NL	WH	ThH	CrH	ThC	ChW	HCL	BLL	CrL	CrW	BL
HW	-													
HL	0.42	-												
HC	0.67	0.69	-											
NL	0.23	0.23	0.50	-										
WH	0.55	0.48	0.82	0.47	-									
ThH	0.55	0.67	0.60	0.53	0.86	-								
Agar	0.55	0.48	0.80	0.52	0.97	0.85	-							
ThC	0.70	0.67	0.85	0.48	0.84	0.55	0.82	-						
ChW	0.51	0.35	0.73	0.17	0.64	0.58	0.63	0.82	-					
HCL	0.31	0.35	0.50	0.17	0.61	0.61	0.59	0.52	0.55	-				
BLL	0.21	0.19	0.75	0.50	0.62	0.62	0.63	0.79	0.42	0.69	-			
CrL	0.54	0.45	0.66	-0.09	0.53	0.54	0.49	0.73	0.58	0.34	0.04	-		
CrW	0.60	0.51	0.77	0.28	0.75	0.61	0.75	0.80	0.67	0.40	0.50	0.62	-	
BL	0.60	0.49	0.84	0.44	0.90	0.70	0.90	0.90	0.68	0.53	0.66	0.60	0.81	-

HW: Head width. HL: Head length. HC: Head circumference. NL: Neck length. WH: Withers height. ThH: Thorax height. CrH: Croup height. ThC: Thorax circumference. ChW: Chest width. HCL: Hind cannon length. BLL: Back-loin length. CrL: Croup length. CrW: Croup width. BL: Body length.

Table VI. Estimated component loadings for principal component analysis of morphometric measures in Brazilian Pony stallions (Cargas estimadas de componentes para análise de componentes principais de medidas morfométricas de garanhões da raça Pônei Brasileiro).

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14
HW	0.264	-0.082	-0.269	-0.082	0.528	-0.093	0.609	-0.380	-0.011	0.104	-0.154	0.074	-0.032	0.012
HL	0.276	0.048	-0.128	-0.317	0.063	0.073	0.242	0.832	-0.181	0.104	-0.008	-0.019	0.004	0.019
HC	0.293	-0.124	-0.201	0.058	0.015	-0.125	0.022	-0.013	0.207	-0.294	0.746	-0.379	-0.060	-0.067
NL	0.218	-0.294	0.645	0.403	-0.086	0.165	0.356	0.106	0.185	0.189	0.134	0.153	-0.012	0.058
WH	0.297	0.146	0.166	-0.027	-0.206	-0.025	0.048	-0.152	-0.305	-0.208	-0.179	-0.357	-0.153	0.689
ThH	0.216	0.444	0.475	-0.255	0.405	-0.330	-0.278	-0.048	-0.024	0.072	0.221	0.226	-0.080	-0.026
CrH	0.295	0.100	0.198	-0.101	-0.213	0.160	0.045	-0.194	-0.312	0.077	-0.159	-0.388	-0.075	-0.677
ThC	0.293	-0.213	-0.158	0.102	-0.097	-0.015	-0.188	0.028	-0.062	-0.263	-0.120	0.448	-0.698	-0.111
ChW	0.263	-0.350	-0.178	0.122	0.173	0.138	-0.467	-0.081	-0.306	0.585	0.128	-0.044	0.103	0.154
HCL	0.194	0.604	-0.205	0.371	0.118	0.607	-0.047	-0.001	0.151	-0.016	0.039	0.084	0.015	0.032
BLL	0.250	0.295	-0.248	0.281	-0.474	-0.560	0.112	-0.002	0.064	0.324	-0.023	0.163	0.147	-0.033
CrL	0.268	-0.071	-0.020	-0.620	-0.349	0.275	-0.044	-0.224	0.459	0.137	0.016	0.190	0.103	0.109
CrW	0.287	-0.120	0.031	0.149	0.240	-0.178	-0.291	0.171	0.534	-0.098	-0.510	-0.331	0.101	-0.051
BL	0.299	-0.145	0.019	0.055	-0.007	0.017	-0.082	-0.036	-0.280	-0.506	-0.038	0.342	0.648	-0.070

PC: Principal component. HW: Head width. HL: Head length. HC: Head circumference. NL: Neck length. WH: Withers height. ThH: Thorax height. CrH: Croup height. ThC: Thorax circumference. ChW: Chest width. HCL: Hind cannon length. BLL: Back-loin length. CrL: Croup length. CrW: Croup width. BL: Body length.

80% of the total variance, as proposed by Johnson and Wichern (1998). This can be explained by the high correlations between the traits. Among the stallions, the morphometric measures were more strongly correlated than for the mares, and only two principal components were necessary to explain 80% of the total variance, while for the mares, three were necessary.

Principal component analysis allows identifying the variables that have the greatest contribution to the accumulated variance. The measures that contribute the most to explain the phenotypic variation of the animals are the traits that present the highest component loadings among the components of highest variance (Cruz, Carneiro and Regazzi, 2014).

Pinto et al. (2008) evaluated linear and angular measurements (totaling 36 traits) of foals with different ages of the Mangalarga Marchador breed, and at 12 months of age, five principal components were neces-

Table VII. Estimated component loadings for principal component analysis of morphometric measures in Brazilian Pony mares (Cargas estimadas de componentes para análise de componentes principais de medidas morfométricas de éguas da raça Pônei Brasileiro**).**

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14
HW	0.268	-0.226	-0.094	-0.097	0.117	0.631	0.332	0.221	-0.368	0.369	-0.093	0.082	-0.032	0.002
HL	0.268	-0.314	0.114	-0.188	-0.155	-0.077	0.451	0.228	0.169	-0.500	0.448	0.089	0.088	-0.032
HC	0.278	0.041	-0.280	-0.026	-0.033	0.120	0.197	-0.684	0.409	0.273	0.259	-0.089	-0.037	0.029
NL	0.214	-0.518	0.243	0.493	0.303	0.082	-0.363	0.099	0.353	0.106	0.057	0.052	0.016	-0.033
WH	0.303	0.014	0.188	-0.110	-0.048	0.006	-0.094	-0.217	-0.113	-0.169	-0.230	0.027	-0.271	-0.796
ThH	0.244	0.070	0.645	-0.095	-0.253	-0.083	-0.115	-0.268	-0.275	0.223	0.103	0.223	0.352	0.212
CrH	0.303	-0.025	0.198	-0.105	-0.081	0.042	-0.082	-0.042	-0.005	-0.209	-0.221	-0.308	-0.624	0.513
ThC	0.290	0.078	-0.316	0.063	0.015	0.053	-0.082	-0.100	0.077	-0.344	-0.422	0.640	0.169	0.213
ChW	0.252	0.227	-0.217	0.648	-0.521	0.053	-0.053	0.135	-0.238	-0.047	0.213	-0.123	-0.033	-0.050
HCL	0.196	0.611	0.314	0.138	0.192	0.035	0.329	0.318	0.423	0.130	-0.154	-0.011	0.032	-0.050
BLL	0.259	0.346	-0.128	-0.167	0.500	0.027	-0.370	0.080	-0.231	-0.098	0.540	0.094	-0.103	0.025
CrL	0.267	-0.146	-0.148	0.150	0.265	-0.723	0.320	0.009	-0.276	0.262	-0.109	0.023	-0.096	0.030
CrW	0.270	-0.055	-0.228	-0.423	-0.379	-0.186	-0.348	0.405	0.281	0.381	-0.028	0.026	0.009	-0.056
BL	0.304	-0.016	-0.116	-0.084	0.154	0.024	-0.092	-0.023	-0.069	-0.212	-0.238	-0.628	0.594	0.008

PC: Principal component. HW: Head width. HL: Head length. HC: Head circumference. NL: Neck length. WH: Withers height. ThH: Thorax height. CrH: Croup height. ThC: Thorax circumference. ChW: Chest width. HCL: Hind cannon length. BLL: Back-loin length. CrL: Croup length. CrW: Croup width. BL: Body length.

sary for the males and six for the females to explain at least 80% of the total variance.

Komosa and Purzyc (2009) evaluated Konik and Hucul horses in Poland and found that six components were necessary to explain 66% of the total variability, represented by 25 metric traits. On the other hand, Hosseini et al. (2016) evaluated three Iranian horse breeds (Turkoman, Caspian and Kurdish) and found that two components were necessary to explain at least 70% of the total variance.

In the first principal component for the males and females, the morphometric measures had roughly equal contribution in composing the variance, so the component loadings were close to each other among the variables. Possibly, due to the correlation in the same (positive) direction among most variables. The variable with the lowest loading coefficient in the first component (front cannon length) presented the highest loading in the second component.

Brooks et al. (2010) evaluated morphological variations in horses by studying 1,215 animals of 65 breeds, ranging from Falabella and American Miniature ponies to horses of the Ardennais and Clydesdale breeds, finding that two principal components were necessary to explain 72.3% of the total variance of the 33 measures considered. The authors identified that size and thickness of the body had only small variations within specific breeds in comparison to the total variation observed. In the first principal component of their study, the loadings were positive and did not exceed 0.20. These findings were possible due to the different breeds evaluated and the variation of the measurements obtained among them. The results of the component loadings were similar to those observed in our study. Although we used a single breed, the morphological variation in our study also was high.

Following the methodology of Mardia, Kent and Bibby (1979), for discarding variables, we identified that the head width, neck length and thorax height variables explained the greatest variation of the animals and should be evaluated. These analyzes allowed the disposal of 11 study variables. For these results, only two components were also needed to explain at least 80% of the variation, as proposed by Johnson and Wichern (1998).

The selected variables represent different body regions (head, neck and body) and cover a general evaluation of animals. Comparing the measurements discarded by these regions, they showed a high correlation with the selected measurements, head width with head length and head circumference, thorax height with withers height, thorax height, croup height, thorax circumference, chest width, front cannon length, back-loin length, croup length, croup width and body length, except neck length which would be the only measurement of the neck.

The selection criteria indicated by the respective breeders' association (ABCCPONEI, 2018) must be adopted by the breeders to control the standardization of the breed. However, according to our results, the measures that explain most of the variation in the evaluated herds are head width, neck length and thorax height, and should be evaluated for the animals' racial standardization. Studies of morphometry, reproductive biology and congenital diseases are necessary to support the selection of animals with high genetic

potential and to guide crossings to avoid endogamy, to improve and expand the breed without loss of genetic diversity.

CONCLUSIONS

The morphometric measures of stallions and mares of the Brazilian Pony breed presented great variation within each sex. Only two components among the stallions and three among the mares were needed to explain at least 80% of the total variance. The principal component analysis was able to reduce the number of variables studied. The measures that explain most of the variations in the evaluated herds are head width, neck length and thorax height, and should be evaluated for the animals' racial standardization.

ACKOWLEGMENTS

This study was financed in part by the Office to Improve University Personnel (CAPES), finance Code 001, and partly by the National Council for Scientific and Technological Development (CNPq).

The authors thank the owners of the Capão, Kaikai and São Manoel horse breeding farms in Rio de Janeiro state for their cooperation in carrying out this work.

BIBLIOGRAPHY

ABCCPONEI (2018) *Brazilian Association of Pony Breeders. Racial pattern*. Available at: http://www.abccponei.org.br.

Bartholazzi Junior, A., Quirino, C. R., Matos, L. F., Vega, W. H. O., Rua, M. A. S., Castro, T., Freitas, A. C. B. and Ribeiro, M. D. S. (2017) 'Linear measurenents of horses of the Ponei Brasileiro breed', *Revista Electronica de Veterinaria*, 18(2).

Bartholazzi Junior, A., Quirino, C. R., Vega, W. H. O., Rua, M. A. S., David, C. M. G. and Jardim, J. G. (2018) 'Polymorphisms in the LASP1 gene allow selection for smaller stature in ponies', *Livestock Science*. Elsevier B.V., 216(September 2017), pp. 160–164. doi: 10.1016/j.livsci.2018.07.015.

Bergmann, J. A. G., Costa, M. D., Mourão, G. B. and Houri Neto, M. (1997a) 'Efeito da endogamia sobre características morfológicas em pôneis da Raça Brasileira', *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, 49(1), pp. 103–111.

Bergmann, J. A. G., Costa, M. D., Mourão, G. B. and Houri Neto, M. (1997b) 'Formaçäo e estrutura genética da raça pônei Brasileira', *Arq. bras. med. vet. zootec*, 49(2), pp. 251–259. Available at: http://bases.bireme.br/cgi-bin/wxislind.exe/iah/online/?IsisScript=iah/iah.xis&src=google&base=LILACS&lang=p&nextAction=lnk&exprSearch=264485&indexSearch=ID.

Brooks, S. A., Makvandi-Nejad, S., Chu, E., Allen, J. J., Streeter, C., Gu, E., McCleery, B., Murphy, B. A., Bellone, R. and Sutter, N. B. (2010) 'Morphological variation in the horse: Defining complex traits of body size and shape', *Animal Genetics*, 41(SUPPL. 2), pp. 159–165. doi: 10.1111/j.1365-2052.2010.02127.x.

Costa, M. D., Bergmann, J. A. G., Pereira, C. S., Pereira, J. C. C. and Rezende, A. S. C. (2001a) 'Tendência genética de medidas lineares de pôneis da raça Brasileira', *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*. Escola de Veterinária UFMG, 53(2), pp. 1–11. doi: 10.1590/S0102-09352001000200020.

Costa, M. D., Bergmann, J. A. G., Pereira, C. S., Pereira, J. C. C. and Rezende, A. S. C. (2001b) 'Tendência genética de medidas lineares de pôneis da raça Brasileira', *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, 53(2), pp. 1–11.

Costa, M. D., Bergmann, J. A. G., Pereira, C. S., Resende, A. and Pereira, J. C. C. (1998) 'Avaliação dos fatores genéticos e de ambientes que interferem nas medidas lineares dos Pôneis da raça Brasileira', *Revista Brasileira de Zootecnia*, 27(3), pp. 491–497.

Cruz, C. D., Carneiro, P. C. S. and Regazzi, A. J. (2014) *Modelos Biométricos Aplicados ao Melhoramento Genético*. 3rd edn. Viçosa, Minas Gerais: Editora UFV.

Fávero, L. P. L., Belfiore, P. P., Silva, F. L. da and Chan, B. L. (2009) *Análise de Dados - Modelagem multivariada para tomada de decisões*. Rio de Janeiro: Elsevier.

Hongyu, K., Jorge, G. and Junior, D. O. (2016) 'Principal Component Analysis : theory , interpretations and applications', *E&S - Engineering and Science*, 1, pp. 83–90. doi: 10.18607/ES20165053.

Hosseini, M., Shahrbabak, H. M., Zandi, M. B. and Fallahi, M. H. (2016) 'A morphometric survey among three Iranian horse breeds with multivariate analysis', *Journal of Animal Science and Technology*, 39(3), pp. 155–160. doi: 10.5398/medpet.2016.39.3.155.

Johnson, R. A. and Wichern, D. W. (1998) *Applied Multivariate Statistical Analysis*. 6th edn, *Education*. 6th edn. Madison: Prentice Hall International.

Komosa, M. and Purzyc, H. (2009) 'Konik and Hucul horses: A comparative study of exterior measurements', *Journal of Animal Science*, 87(7), pp. 2245–2254. doi: 10.2527/jas.2008-1501.

Lage, M. C. G. R., Bergmann, J. A. G., Procópio, A. M., Pereira, J. C. C. and Biondini, J. (2009) 'Associaçãoo entre medidas lineares e angulares de equinos da raça Mangalarga Marchador', *Arquivo Brasileiro de Medicina Veterinaria e Zootecnia*, 61(4), pp. 968–979. doi: 10.1590/S0102-09352009000400027.

Manly, B. F. J. (2008) *Métodos estatísticos multivariados: uma introdução*. 3rd edn. Porto Alegre: Bookman. Available at: https://www.bdpa.cnptia.embrapa.br/consulta/busca?b=ad&id=749178&biblioteca=vazio&busca=autoria:%22MANLY, B. F.%22&qFacets=autoria:%22MANLY, B. F.%22&sort=&paginacao=t&paginaAtual=1 (Accessed: 26 November 2018).

Mardia, K. V, Kent, J. T. and Bibby, J. M. (1979) *Multivariate analysis*. London: Academic Press.

Pascual Moro, I. and Intxausti del Casal, J. I. (1998) 'Estudio Zoométrico En La Raza Poni Vasco-Pottoka', *Arch. Zootec.*, 47, pp. 537–546.

Pinto, L. F. B., Almeida, F. Q. de, Quirino, C. R., Azevedo, P. C. N. de, Cabral, G. C., Santos, E. M. and Corassa, A. (2008) 'Evaluation of the sexual dimorphism in Mangalarga Marchador horses using discriminant analysis', *Livestock Science*. Elsevier B.V., 119(1–3), pp. 161–166. doi: 10.1016/j.livsci.2008.03.014.

Quirino, C. R., Matos, L. F., Bartholazzi Junior, A., Castro, T. de, Silva, R. C. and Silva, J. L. L. (2012) 'Caracterização de pôneis da raça brasileira através de medidas lineares.', *Actas Iberoamericanas de Conservación Animal*, 2, pp. 71–74.