Spanish Journal of Agricultural Research
19 (1), e0401, 10 pages (2021)
eISSN: 2171-9292
https://doi.org/10.5424/sjar/2021191-16576
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)

RESEARCH ARTICLE

OPEN ACCESS

Phenotypic diversity of horse breeds used in sports activities, employing multivariate analysis

Marcos P. G. Rezende[1], Julio C. Souza[2,3], Carlos H. M. Malhado[1], Paulo L. S. Carneiro[1], Johnny I. M. Araujo[1], Leonardo G Sitorski[4], Riccardo Moretti[5,6] and Riccardo Bozzi[5]

[1]State University of Southwest of Bahia. Jequiezinho, Jequié 45205-490, Brazil [2]Federal University of Mato Grosso do Sul. Paranaíba, Mato Grosso do Sul, Brazil [3]Current address: Visiting Research in University of Kent, United Kingdom [4]North Dakota State University, Dept. Animal Sciences. Fargo, ND, USA [5]University of Florence, Dept. Agriculture, Food, Environment and Forestry. Firenze, Italy [6]Current affiliation: University of Turin, Dept. Veterinary Sciences, Turin, Italy

Abstract

Aim of study: Sports involving horses have notable financial importance. Breeds are evaluated to find the best-suited ones for a specific sport category. Phenotypic diversity using biometric markers was evaluated for Quarter Horse (QH), Arabic (AR), English Thoroughbred (ET), and Brazilian Equestrian (BE) horse breeds.

Area of study: Mato Grosso do Sul-Brazil.

Material and methods: Lengths, widths, and circumference measures of 268 horses were collected. These measures were used to estimate conformation indexes. The size-free canonical discriminant analysis was used to remove the size effect on the animal's shape. The similarity among breeds (by sex) was evaluated employing multivariate analysis (canonical analysis, MANOVA, principal components, Euclidean distances, and grouping through complete linkage), considering all linear measures and conformation indexes (included in the analysis of principal components).

Main results: Four canonical variables (CANs), each one representing an equation to interpret the morpho-functionality of breeds "sustentation", "structure", "frame", and "equilibrium", were retained. The breeds presented differences when the CANs were simultaneously considered. Differences mainly were the size and the thickness of the body as well as the ability of the animal to move. ET, QH, and BE demonstrate a well-defined biometric profile. These three breeds clustered separately from AR breed.

Research highlights: Canonical variables allow to verify the functional aptitudes since the responses were close to conformation indices commonly used as horse skill estimators. The implementation of these variables as selection criteria in horse breeding programs require further studies in larger populations of horses for a confirmation of the present results.

Additional key words: aptitudes; body structure; conformation; functionality; morphology.

Abbreviations used: AR (Arabic); BE (Brazilian Equestrian); BI (body index); BW (estimated body weight); CAN (canonical analysis); CDA (canonical discriminant analysis); DTI (dactyl-thoracic index); ET (English Thoroughbred); F (females); KP (knee perimeter); M (males); PCA (principal component analysis); QH (Quarter Horse); RBI (relative body index); SBL (shoulder blade length); WRRI (withers and rump relative index).

Authors' contributions: MPGR, JCS, and LS: data collection and article writing; CHMM: statistical data analysis; PLSC and RB: coordinators of the research; JIMA and RM: final review of the article.

Citation: Rezende, MPG; Souza, JC; Malhado, CHM; Carneiro, PLS; Araujo, JIM; Sitorski, LG; Moretti, R; Bozzi, R (2021). Phenotypic diversity of horse breeds used in sports activities, employing multivariate analysis. Spanish Journal of Agricultural Research, Volume 19, Issue 1, e0401. https://doi.org/10.5424/sjar/2021191-16576

Received: 20 Feb 2020. **Accepted:** 17 Mar 2021.

Funding: The authors received no specific funding for this work

Competing interests: The authors have declared that no competing interests exist.

Correspondence should be addressed to Marcos Paulo Gonçalves-de-Rezende: mpgrezende@gmail.com

Introduction

The morpho-functionality of horses is the result of the adaptation to the environment through natural selection, which gradually leads to the development of specific locomotor properties (Cano *et al.*, 2001). So that the men tamed and bred horses according to their needs (Edwards, 1992), and this process influenced the considerable morpho-functional divergence between the modern equine breeds.

The dimensions and proportions of the equine body can influence its physical structure, as well as the quality of the movements required for functional work or sports (Santos *et al.*, 2017). Consequently, the horse performance during physical activity is largely related to the animal's shape (Rezende *et al.*, 2018). In this sense, the use of linear measurements taken from the equine body could play a relevant role and has been widely used for this purpose, as well as for selection, genetic improvement and breed differentiation (Parés-Casanova, 2010).

Biometric markers are useful in the identification of the degree of divergence in specific aptitudes between genetic groups (Rezende *et al.*, 2016) and as indicators of adaptive or selective differences between populations (Biagiotti *et al.*, 2013). Thus, biometrics is an important tool helping in the identification of the animal's ability to perform a specific physical effort. Furthermore, biometrics serves as a diagnosis of the qualities, problems, and orientation of mating, to improve certain characteristics in the progenies (Mello & Schmidt, 2008), and to assist in genetic improvement programs (Brooks *et al.*, 2010).

Sports involving horses have notable financial importance. Thus, purebred and crossbred animals are selected to find the animal that is best suited for a specific sport category. Understanding phenotypic differentiation allows to identify specific abilities between breeds (Kane *et al.*, 1996). In addition, the morphological characterization of the equine is directly related to its economic value, since breeders search for animals with well-defined patterns of body proportions and movement balance, characteristics that are already well established for the different breeds (Meira *et al.*, 2013). Zootechnical indexes are another useful tool composed combining body measures to examine the aptitudes and the abilities of domestic animals (Rezende *et al.*, 2015).

Studies on morphological measures generally include several variables, and multivariate analysis is helpful to interpret the results contributing or guiding breed selection for morpho-functional characteristics (Rezende *et al.*, 2016). Therefore, considering that body conformation is useful in evaluating and comparing breeds, the objective of this study was to evaluate the phenotypic diversity among four horse breeds using biometric markers and multivariate analysis.

Material and methods

Data

Two hundred and sixty-eight adult horses, both males (M) and females (F), were used in this study. Quarter Horse (QH, M = 46 and F = 97), English Thoroughbred (ET, M = 18 and F = 23), Arabic (AR, M = 21 and F = 32) and Brazilian Equestrian (BE, M = 15 and F = 16) horse breeds were evaluated. All evaluations were performed separately for each breed and sex forming a total of 8 groups. The animals belonged to horse riding centres in Brazil and their age ranged between 5 and 15 years. Linear measurements were taken on the horses (Fig. 1) with the aid of a measuring tape and a specific ruler according to methodologies described by Oom & Ferreira (1987). Descriptive statistics of linear measurements can be found in Table 1.

These measures were used to estimate five conformation indexes, according to the methodologies described by Martin-Rosset (1983), Oom & Ferreira (1987) and Franci *et al.* (1989), being: i) withers and rump relative index (WRRI, *i.e.*, withers height divided by rump height); ii) dactyl-thoracic index (DTI, *i.e.*, cannon bone perimeter divided by thoracic perimeter); iii) body index (BI, *i.e.*, body length divided by the thoracic perimeter); iv) relative body index (RBI, *i.e.*, body length multiplied by the constant 100 and divided by the height of the withers); v) estimated body weight (BW, *i.e.*, the value for thoracic perimeter is elevated to the cube and next multiplied by 80).

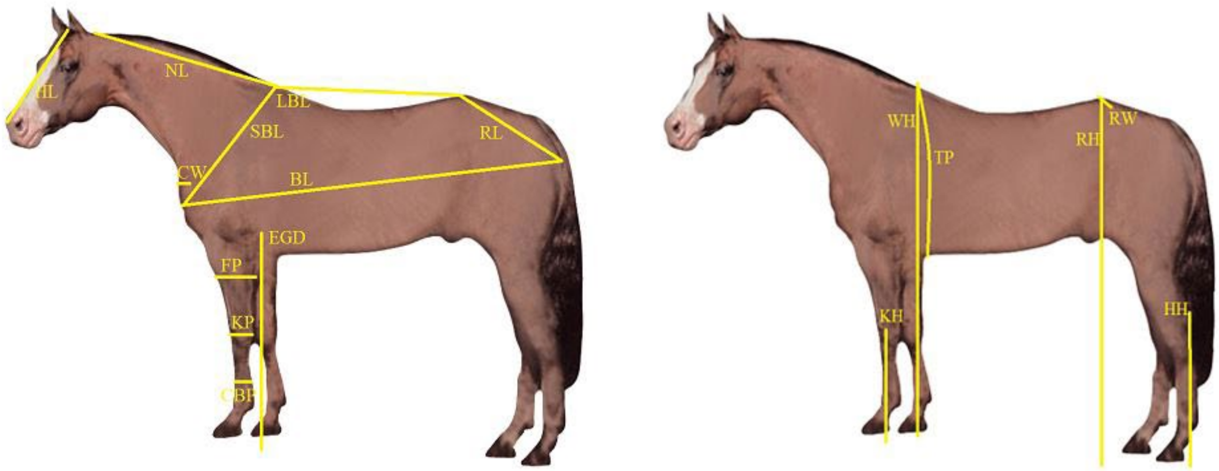

Figure 1. Measures linear evaluated in the horses: thoracic perimeter (TP), withers height (WH), body length (BL), head length (HL), neck length (NL), shoulder blade length (SBL), lumbar-back length (LBL), rump length (RL), knee height (KH), knee perimeter (KP), rump height (RH), cannon bone perimeter (CBP), rump width (RW), chest width (CW), hock height (HH), elbow to the ground distance (EGD), and forearm perimeter (FP). The measures were assessed in centimeters (cm).

Table 1. Descriptive statistics of linear measurements considering the four breeds of horses.

	Female				Male			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
				Arabic				
TP	195.00	1.22	194.00	197.00	198.00	2.16	196.00	201.00
WH	149.40	5.50	143.00	158.00	157.25	3.40	153.00	160.00
BL	140.20	6.94	133.00	150.00	144.25	3.40	141.00	149.00
HL	61.80	3.19	57.00	66.00	61.75	5.62	56.00	69.00
NL	61.40	4.72	56.00	69.00	67.25	2.06	65.00	69.00
SBL	58.00	4.90	52.00	65.00	58.25	2.99	55.00	62.00
LBL	56.20	3.11	53.00	60.00	54.75	5.50	47.00	60.00
RL	46.60	5.94	41.00	56.00	42.00	2.00	39.00	43.00
KH	47.60	3.91	42.00	53.00	49.00	4.24	44.00	53.00
KP	34.00	0.71	33.00	35.00	35.00	0.82	34.00	36.00
RH	143.80	4.44	140.00	151.00	147.25	4.92	140.00	151.00
CBP	23.40	1.14	22.00	25.00	24.25	0.96	23.00	25.00
RW	44.40	3.44	41.00	50.00	44.75	0.50	44.00	45.00
CW	41.00	4.90	34.00	47.00	40.00	4.32	36.00	46.00
HH	58.00	9.27	44.00	70.00	56.75	6.55	47.00	61.00
EGD	98.20	8.20	90.00	112.00	92.75	4.86	90.00	100.00
FP	46.00	4.74	40.00	51.00	49.00	2.45	47.00	52.00
				Brazilian Equestrian				
TP	195.00	8.89	188.00	210.00	196.40	10.33	188.00	214.00
WH	149.40	5.90	141.00	155.00	150.80	3.19	147.00	155.00
BL	143.60	5.32	140.00	153.00	144.20	6.76	133.00	150.00
HL	65.40	2.07	63.00	68.00	65.60	2.79	61.00	68.00
NL	62.00	3.94	59.00	68.00	61.00	3.81	57.00	66.00
SBL	56.80	6.38	47.00	62.00	61.80	4.92	56.00	68.00
LBL	60.40	2.19	58.00	62.00	58.40	1.52	57.00	60.00
RL	46.80	2.28	43.00	49.00	46.80	3.90	43.00	52.00
KH	50.60	2.19	48.00	54.00	51.60	1.82	49.00	54.00
KP	33.80	1.30	32.00	35.00	33.80	0.84	33.00	35.00
RH	143.40	5.41	137.00	151.00	143.60	2.70	139.00	146.00
CBP	23.00	1.00	22.00	24.00	23.40	0.55	23.00	24.00
RW	46.80	3.90	41.00	51.00	46.80	1.64	45.00	49.00
CW	39.40	4.34	36.00	47.00	43.20	4.97	35.00	47.00
HH	59.00	5.87	52.00	65.00	59.20	1.92	57.00	62.00
EGD	101.60	4.72	97.00	108.00	105.80	5.93	100.00	115.00
FP	47.40	3.44	44.00	52.00	47.20	1.10	46.00	48.00
				English Thoroughbred				
TP	170.40	11.08	156.00	184.00	169.11	7.66	160.00	183.00
WH	140.80	12.26	119.00	148.00	140.22	5.87	130.00	152.00
BL	145.20	6.91	134.00	153.00	142.33	4.92	136.00	150.00
HL	64.40	2.97	60.00	68.00	62.44	2.60	59.00	67.00

Thoracic perimeter (TP), withers height (WH), body length (BL), head length (HL), neck length (NL), shoulder blade length (SBL), lumbar-back length (LBL), rump length (RL), knee height (KH), knee perimeter (KP), rump height (RH), cannon bone perimeter (CBP), rump width (RW), chest width (CW), hock height (HH), elbow to the ground distance (EGD), forearm perimeter (FP). Units in centimetres.

Table 1 (cont.). Descriptive statistics of linear measurements considering the four breeds of horses.

	Female				Male			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
NL	60.00	4.95	52.00	65.00	58.22	4.79	51.00	65.00
SBL	49.80	3.77	44.00	53.00	51.33	3.84	47.00	59.00
LBL	52.80	4.09	49.00	58.00	54.56	2.96	51.00	61.00
RL	48.20	4.27	44.00	53.00	48.89	2.03	44.00	51.00
KH	41.20	4.09	34.00	44.00	42.78	2.11	40.00	47.00
KP	28.60	1.67	26.00	30.00	28.33	1.32	26.00	30.00
RH	140.00	11.34	120.00	148.00	140.22	4.21	133.00	149.00
CBP	18.20	0.84	17.00	19.00	19.00	0.71	18.00	20.00
RW	49.20	2.77	45.00	52.00	48.00	1.73	44.00	50.00
CW	34.40	4.45	29.00	40.00	33.00	2.96	28.00	37.00
HH	52.40	5.03	44.00	57.00	52.67	2.24	50.00	57.00
EGD	80.20	7.60	68.00	87.00	80.00	3.50	75.00	87.00
FP	43.20	3.56	39.00	47.00	45.44	3.75	40.00	51.00
				Quarter Horse				
TP	169.19	9.24	147.00	188.00	171.33	6.72	146.00	177.00
WH	141.41	7.46	121.00	154.00	143.67	6.90	119.00	153.00
BL	142.47	6.84	125.00	154.00	143.71	6.36	125.00	153.00
HL	61.14	4.33	52.00	72.00	59.63	2.73	52.00	65.00
NL	56.63	5.29	42.00	72.00	57.71	3.80	47.00	65.00
SBL	46.74	5.90	29.00	59.00	47.92	4.47	34.00	58.00
LBL	51.97	3.27	44.00	63.00	51.21	2.72	47.00	56.00
RL	48.97	4.27	37.00	57.00	51.00	3.48	43.00	56.00
KH	42.84	3.14	33.00	50.00	42.88	2.69	34.00	47.00
KP	29.19	1.44	26.00	32.00	29.13	1.30	24.00	31.00
RH	141.32	6.74	121.00	154.00	143.46	6.03	119.00	150.00
CBP	18.85	1.13	15.00	22.00	18.83	0.96	16.00	20.00
RW	48.79	3.30	41.00	57.00	49.67	2.53	43.00	55.00
CW	34.42	3.10	27.00	43.00	35.25	2.47	30.00	41.00
HH	81.92	4.91	62.00	90.00	83.29	4.64	67.00	91.00
EGD	46.49	4.49	36.00	58.00	47.46	4.08	40.00	55.00
FP	46.49	4.49	36.00	58.00	47.46	4.08	40.00	55.00

Thoracic perimeter (TP), withers height (WH), body length (BL), head length (HL), neck length (NL), shoulder blade length (SBL), lumbar-back length (LBL), rump length (RL), knee height (KH), knee perimeter (KP), rump height (RH), cannon bone perimeter (CBP), rump width (RW), chest width (CW), hock height (HH), elbow to the ground distance (EGD), forearm perimeter (FP). Units in centimetres.

Data analysis

We performed size-free canonical discriminant analysis (CDA) for all linear measurements to remove the size effect on the animal's shape (Peres-Neto, 1995), using SAS software (2017). Residual values obtained from CDA were submitted to canonical analysis in order to reduce the number of variables. The number of extracted canonical variables was defined according to the variance criterion. The inflection point on the eigenvalues curve was used to determine the number of canonical variables to be considered. The meaning of the canonical variables was established according to the canonical weights' explication of the variables in each canonical variable.

These canonical variables were subsequently used as input variables in MANOVA. As a complementary analysis, a heatmap graph was generated to assess diversity between the breeds (by sex), using the gplots package of R software (2018). The package uses the hierarchical grouping analysis, with the average Euclidean distance as a measure of dissimilarity with grouping through a method of complete linkage. The unbiased approach was calculated by resampling with multiple scale initialization to check the support of nodes in the formed clusters. An unbiased approach with minimum values equal to or above 95% was the criterion for the formation of groups strongly supported by the data in the cluster.

The principal component analysis (PCA) was performed using the following traits: canonical variables, WRRI, DTI, BI, RBI, and BW. The number of extracted PCAs was defined according to the variance criterion (*i.e.*, the inflection point in the graph of the eigenvalues curve). Major components were used to construct a biplot graph where each line represents a Gn point with a coordinate (gi_1, gi_2), i = 1, …, n, and each column a vector starts at the origin to the point Hm with a coordinate (hj_1, hj_2), j = 1, …, p, *i.e.* the vectors represent the variables (before mentioned) and the points represent the breeds (by sex). The biplot graph was developed using Past software (Hammer *et al.*, 2001).

Results

Canonical variables and MANOVA for evaluated measures in horses

The analysis of the inflection point on the eigenvalue curve of the canonical analysis allows to reduce the original number of traits to four canonical variables (CAN), which were able to explain 95% of the variation among the breeds (Table 2). The canonical variables were labelled as follows: “sustentation”, “structure”, “frame” and “equilibrium”.

The simultaneous evaluation of the canonical variables through MANOVA, evidenced differences between the breeds as well as between males and females of AR breed. The other breeds showed a well-defined biometric profile with no differences between animals of different sexes, which could introduce a certain degree of bias.

Heatmap considering the breeds

Heatmap dendrogram discriminated two large groups with differences from the unbiased approach of 100%

Table 2. Canonical analysis of linear measurements considering the four breeds of horses.

	Sustentation	Structure	Frame	Equilibrium
TP	1.30	**-1.20**	-0.14	-0.53
WH	0.16	**-0.72**	-0.38	0.14
BL	-0.01	0.23	-0.11	0.48
HL	-0.31	0.48	0.20	-0.33
NL	-0.15	-0.02	-0.14	-0.77
SBL	0.30	0.58	0.00	**-1.08**
LBL	0.50	0.54	-0.27	-0.62
RL	-0.46	-0.16	0.63	-0.60
KH	-0.01	0.33	0.36	-0.27
KP	0.75	-0.12	-0.46	**1.09**
RH	-0.73	-0.04	-0.63	0.39
CBP	**1.29**	0.49	-0.27	0.42
RW	-0.69	0.45	0.04	0.25
CW	0.15	0.32	0.35	0.65
HH	-0.12	-0.55	0.05	-0.67
EGD	0.59	0.62	**1.64**	0.71
FP	0.04	-0.21	0.06	0.05
Explication	80%	10%	4%	1%

Thoracic perimeter (TP), withers height (WH), body length (BL), head length (HL), neck length (NL), shoulder blade length (SBL), lumbar-back length (LBL), rump length (RL), knee height (KH), knee perimeter (KP), rump height (RH), cannon bone perimeter (CBP), rump width (RW), chest width (CW), hock height (HH), elbow to the ground distance (EGD), forearm perimeter (FP). The values in bold represent greater values.

(Fig. 2). In the largest group, three subgroups were formed with a value of the unbiased approach bigger than 95%. Heatmap representation clearly demonstrates that differences between sexes of the same breed tend to be smaller than the differences between different breeds. The co-optic correlation coefficient of the dendrogram was 0.96 (data not shown), strongly supporting the analysis as well. In general, one pair (AR vs. other breeds) and three sub-groups (ET vs. BE vs. QH) with the unbiased approach above 95% were formed.

Principal components (PCA) considering the canonical variable and body conformation indexes

The first two principal components represented 78.16% of the variation between breeds considering the canonical variables and the body conformation indexes (Fig. 3). The canonical variable "sustentation" is localized close to both "equilibrium" and body conformation indexes WRRI, with QH and ET breeds, regardless of sex, being the ones that were opposed to these variables, consequently, presenting lower values.

The canonical variable "structure" is close to body conformation indexes RBI, BI, and QH and ET breeds; whereas the canonical variable "frame" is closer to body conformation indexes DTI, BW, and BE breed. On the other hand, the canonical variables "structure" and "frame" are the more distant from AR breed.

Discussion

Canonical variables considering the linear measurement

The canonical variables were able to verify the functional aptitudes of the horses since they were positioned were close to conformation indices commonly used as horse skill estimators. The efficiency of using multivariate analysis for the evaluation of phenotypic diversity between breeds has also been reported by other authors in horses (Rezende *et al.*, 2018) and other species of domestic animals (Rezende *et al.*, 2017; Figueiredo *et al.*, 2019). The canonical variable "sustentation" indicates the relationship between the mass of the animal and its limbs; indeed, animals with greater values for this parameter tend to be classified as hypermetric (large-sized), while those with average and low values are classified as eumetric (medium-sized) and hypometric (small-sized), respectively.

A hypermetric animal is able to perform sports requiring stronger members, such as barrier sports (*i.e.*, show jumping). In general, "sustentation" has been used for prediction in association with body balance and it is also related to the strength of the hind legs, well-sprung ribs, well-muscled chest, contributing also to the development of cardiorespiratory capacity (Thomas, 2005). Furthermore, Jones (1987) emphasized that it exists a relationship between the depth and the width of the breast and the resistance of the animal, as a wide pectoral region indicates the presence of well-developed lungs and chest muscles.

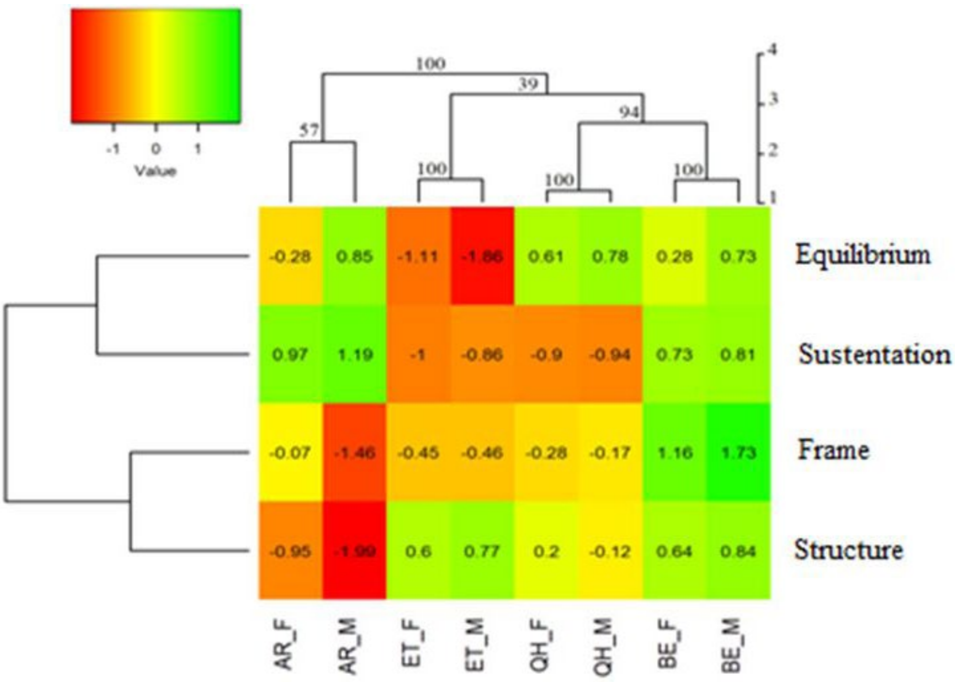

Figure 2. Heatmap of canonical variables considering the breeds (males (M) and females (F)): Arabic (AR), English Thoroughbreds (ET), Quarter Horse (QH), and Brazilian Equestrians (BE).

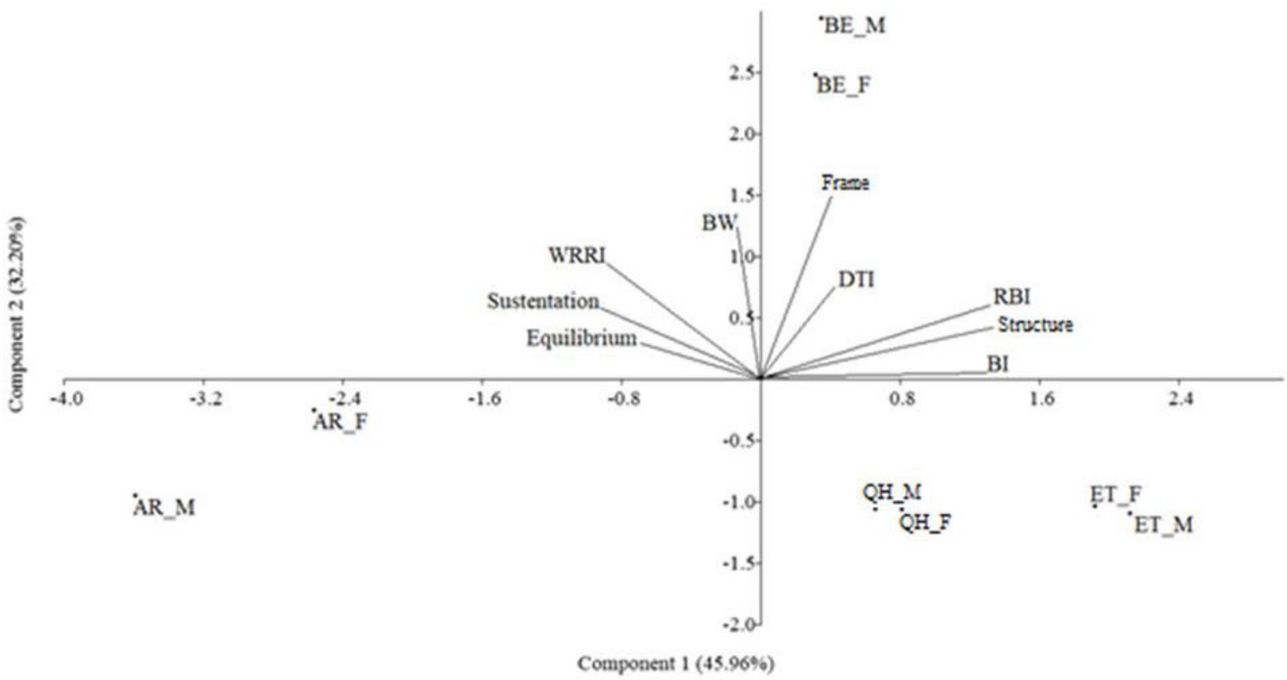

Figure 3. Biplot considering canonical variables, and conformation indexes for breeds (males (M) and females (F)): Arabic (AR), English Thoroughbreds (ET), Quarter Horse (QH), and Brazilian Equestrians (BE). WRRI: withers and rump relative index; DTI: dactyl-thoracic index; BI: body index; RBI: relative body index; BW: body weight.

Regarding "structure", thoracic perimeter and withers height measures showed the highest values as indicators of the conformation of the body frame of the animals. The result highlights that the horse's chest must be broad, deep and muscular to provide desirable physical vigour (Zamborlini *et al.*, 1996; McManus *et al.*, 2005). Animals with high values for this canonical variable are smaller, more robust, and with a deep thoracic region. A similar profile is desirable in racing animals, requiring strength and/or traction, plucking, and changing directions quickly.

For "frame" CAN, elbow to the ground distance measure showed the highest value, representing thus whether the horse is near to the ground (short animal) or not (tall animal). However, this isolated measurement does not allow a correct conclusion on the profile analysed for "frame". A short animal with a compact body frame has a short-limbed profile (strength), while a tall animal with a thin body frame has a dolicomorphic profile (racing). An animal with intermediate characteristics is considered a mesomorphic animal or double purpose one (Cieslak *et al.*, 2017; Rezende *et al.*, 2018).

Lastly, in the "equilibrium" CAN, the overrepresented values are those referred to SBL and KP measures. Both measurements have a strong relationship with the animal's gait. An animal with an appropriate SBL angle, associated with a lower LBL, and a well-formed croup allows a greater balance of the animal during walking. Jones (1987) demonstrated that the scapula acts on the force generated by turning further in displacement capacity.

According to Torres & Jardim (1992), when both the shoulder and the crop are short, the lumbar back tends to be longer and defective which makes the animal pretty unsuitable for any kind of equestrian task. Indeed, higher SBL values favour the amplitude of the forelegs stride, contributing to greater animal flexibility (Inglês & Vianna, 2004) and KP contributes to the sustentation of body mass. In general, these canonical variables could be used as selection criteria in breeding programs, searching for horses with high coordination, meeting the breeder expectation regarding the horse's function (riding, sport, and traction animals).

Body conformation indexes

Considering the conformation indexes, WRRI measures the equilibrium between withers height and rump height. In general, uniformity between locomotor members is expected (McManus *et al.*, 2005), because a high inequality may be an effect of an abnormal opening of the articular angles of the thoracic and pelvic limbs, which may impair both the gait and the resistance of the animal. Thus, a value of 1 represents an animal with thoracic and pelvic limbs of the same height (equilibrium). A balanced horse presents less wear in their joints, and as a result, is more suitable to continue in sports activities and have a longer working life (Thomas, 2005).

The balance is the basis of all movements that affect performance. Finer balance not only reduces the chances of injury to the animals but also improves the comfort level of the rider (Rezende *et al.*, 2018). However, animals with small value for WRRI have a higher rump concerning the withers. This higher rump, in addition to croup length, hock height, hip height, and width of the croup, contributes to their greater speed and/or impulse (start sprinting) (Gonçalves *et al.*, 2011).

It is also noteworthy that narrow croup approximates the distance between hind limbs, not allowing a good distance from the hocks and hooves (Andrade, 2002). Moreover, Pinto *et al.* (2005) pointed out that the main function of the hindquarters of a horse is to generate the force required for propulsion.

The DTI index is used to estimate the structure of the animal, with the following classification: hypermetric (DTI > 11.5), eumetric (10.5 ≤ DTI ≤ 10.8), and hypometric (DTI < 10.5). Therefore, it differentiates animal's body conformation or structure in a small size, medium-size, or larger size (Rezende *et al.*, 2018). The BW is also used for classification purposes of the body structure; hypermetric animals have BW > 550 kg, eumetric 350 ≤ BW ≤ 550 kg and ellipometric BW < 350 kg (McManus *et al.*, 2005).

The BI and RBI are conformation indexes for sporting ability prediction. A high BI value classifies equines as dolicomorphic profile (BI > 0.90), a medium one classifies them as mesomorphic animals (0.86 ≤ BI ≤ 0.88), and low value as short-limbed profile (BI < 0.85). On the other hand, higher RBI values highlight animals that are proportionally longer than tall.

An equine with an RBI index equal to 100 indicates an animal with proportional body length to height, *i.e.* intermediate animals for riding and traction. Values above 100 indicate animals with a body length proportionally greater than their height (traction), and values below 100 indicate animals with a body length proportionally lower than their height (riding aptitude) (Rezende *et al.*, 2016). According to Stashak & Hill (2006), the length and the height of the animal must be similar in order to facilitate the synchronization and coordination of its movements.

An animal with a dolicomorphic profile is more suitable for speed performances. It has a taller stature, and a thin barrel because, morphofunctionally, equines breeds tend to have greater body length and height compared with the thoracic depth (Pimentel *et al.*, 2014). It is common for an animal with a dolicomorphic profile to have pelvic limbs that are higher than their thoracic limbs (Rezende *et al.*, 2016).

An animal with a short-limbed profile is suitable for physical work; it has a good anterior and posterior width, greater musculature, and thoracic depth. Thus, animals with superior thoracic limbs to their pelvic limbs are desirable for work. An animal with mesomorphic profile has the average aptitude to the other two previously mentioned; in other words, a horse with mesomorphic profile has double suitability, both for speed and for strength (Rezende *et al.*, 2018).

Phenotypic diversity between breeds (by sex) employing heatmap and biplot analysis

The divergences between the breeds observed for the CANs and the conformation indexes are related to different morpho-functional characteristics of the horses selected for sports activities. A biological interpretation of the distribution of both canonical variables and conformation indexes is possible, and it is possible to identify the concordance with the different abilities of the breeds. Observing the CANs coefficients, AR breed showed a different pattern from the other breeds, especially considering the "structure". Differences were observed only in AR between male and female animals. These sex differences in body measurements in the AR breed have also been reported by Sadek *et al.* (2006), Cervantes *et al.* (2009), and Rezende *et al.* (2014) and they are probably due to the higher values in females for "equilibrium" and lower values for "frame" and "structure" concerning males.

Arabian is one of the oldest and most influential horse breeds in the world (Głażewska, 2010), and results from mtDNA studies show that it exists a great diversity in the mtDNA sequences, indicating the heterogeneous origin of the breed (Bowling *et al.*, 2000).

As for the other breeds, a possible explanation of no significant differences between male and female animals could be the greater rigor in the presentation and the definitive registration of the animals, which allows a greater standardization of animals, and this is very clear in the heatmap when we look at the values for the canonical variables.

Comparing with the other breeds used in this study, the AR breed seems to have less robustness, and this is not ideal to perform activities requiring strength and/or traction, or also requiring starting and changing directions quickly. Another hypothesis for the variation within the AR animals, as well as its great phenotypic distance from the other breeds, can be associated with what shown by Glazewska *et al.* (2007) reporting that the genetic pool of modern AR horses was formed based on horses representing different breeds and populations.

The BE breed was the horse breed with the greatest body size and classified as a hypermetric. This is probably due to all the genetic information gathered during the process of the breed formation, using genetic compositions of animals with a large body frame (Dias *et al.*, 2000). This attitude meets the purpose followed to develop BE breed, which is barrier sports (*e.g.*, jumping show). The BE breed was formed selecting imported or national stallions registered in other associations, with a recognized aptitude for equestrian sports (jumping modalities, training, complete riding competitions pole, and endure), and among the main breeds that had the greatest influence on the formation of BE are Thoroughbred, Hanover, Westfalen, Holsteiner and Trakehner (Dias *et al.*, 2000).

The ET breed presented also higher values for BI and RBI indices supporting the classification of this breed in the dolichomorphic profile and its possible use in the long-distance sports and equine activities. The ET is a horse breed that is known for its use in horse racing. Indeed, ET has been developed by crossing some English mares to three Arabian stallions which were Turkish horse breeds imported from Ottoman Empire lands (Yilmaz & Ertugrul, 2012).

Differently, the QH breed has a phenotypic profile that reflects the ability to be superior to other breeds in short distance activities, as highlighted by Rezende *et al.* (2015). According to Coelho *et al.* (2011), QH has fast acceleration, strength, docility, sudden stops, great ability to change direction, and enormous ability to rotate on its axis.

In a similar work, Brooks *et al.* (2010) emphasized the importance of studies that relate linear measures to the functional characterization of horses and their relevance for the elaboration of crossing strategies that aim at genetic improvement.

In general, the differences between animals mainly represent the size and thickness of the body as well as the ability of the animal to move. ET, QH, and BE breeds demonstrate a well-defined biometric profile in both males and females, grouped at low distances. These three breeds were grouped closer between them than with AR.

The multivariate techniques were efficient in grouping the most similar horse breeds for both CANs and conformation indices, enabling the verification of the horses' functional aptitudes. Thus, it is possible to use these variables as indicators of animals with sports aptitude as well as in horse breeding programs as selection criteria. Further studies with higher number of animals and breeds could improve the accuracy of the present results.

References

Andrade LS (ed), 2002. Equine judgment manual, conformation versus function. Belo Horizonte: Equicenter Publicações. 114 pp.

Biagiotti D, Sarmento JLR, Oliveira A, Neto AAR, Santos GV, Santos NPS, Torres TS, Neri VS, 2013. Phenotypic characterization of Santa Inês sheep in the State of Piauí. Rev Bras Saúde Prod Anim 14: 29-42. https://doi.org/10.1590/S1519-99402013000100004

Bowling AT, Del Valle A, Bowling M, 2000. A pedigree-based study of mitochondrial D-loop DNA sequence variation among Arabian horses. Anim Gen 31: 1-7. https://doi.org/10.1046/j.1365-2052.2000.00558.x

Brooks SA, Makvandi-Nejad S, Chu E, Allen JJ, Streeter C, Gu E, McCleery B, Murphy BA, Bellone R, Sutter NB, 2010. Morphological variation in the horse: defining complex traits of body size and shape. Anim Gen 41: 159-165. https://doi.org/10.1111/j.1365-2052.2010.02127.x

Cano MR, Vivo J, Miro F, Morales JL, Galisteo AM, 2001. Kinematic characteristics of Andalusian, Arabian and Anglo-Arabian horses: a comparative study. Res Vet Sci 71: 147-153. https://doi.org/10.1053/rvsc.2001.0504

Cervantes I, Baumung R, Molina A, Druml T, Gutiérrez JP, Sölkner J, Valera M, 2009. Size and shape analysis of morphofunctional traits in the Spanish Arab horse. Livest Sci 125: 43-49. https://doi.org/10.1016/j.livsci.2009.03.006

Cieslak J, Borowska A, Wodas L, Mackowski M, 2017. Interbreed distribution of the myostatin (MSTN) gene 5'-flanking variants and their relationship with horse biometric traits. J Eq Vet Sci 60: 83-89. https://doi.org/10.1016/j.jevs.2017.08.002

Coelho CS, Lopes PFR, Pissinati GL, Ramalho LO, Souza VRC, 2011. Influence of physical exercise on serum electrolytes in Quarter horses submitted to team roping. Rev Bras Cienc Vet 18: 32-35. https://doi.org/10.4322/rbcv.2014.117

Dias IMG, Bergmann JAG, Rezende ACC, Castro GHF, 2000. Formation and population structure of the Brasileiro de Hipismo horse breed. Arq Bras Med Vet Zootec 52: 647-654. https://doi.org/10.1590/S0102-09352000000600016

Edwards EH, 1992. El gran libro del caballo, 1st ed. El Pais/Aguilar. 9 pp.

Figueiredo GC, Rezende MPG, Figueiredo MP, Bozzi R, Junior AAOS, Carneiro PLS, Malhado CHM, 2019. Morphofunctional characteristics of Dorper sheep crossed with Brazilian native breeds. Small Rumin Res 170:143-148. https://doi.org/10.1016/j.smallrumres.2018.11.024

Franci O, Giogetti A, Gremoli G, 1989. Evoluzi one delle caractteristic hemorphologi quenel cavalo avelignese in accrescimento. Zootec Nutr Anim 15: 373-380.

Głażewska I, 2010. Speculations on the origin of the Arabian horse breed. Livest Sci 129: 49-55. https://doi.org/10.1016/j.livsci.2009.12.009

Głażewska I, Wysocka A, Gralak B, Prus R, Sell J, 2007. A new view on dam lines in Polish Arabian horses based on mtDNA analysis. Genet Select Evol 39: 609-619. https://doi.org/10.1186/1297-9686-39-5-609

Gonçalves RW, Costa MD, Roch Junior VR, Costa MR, Silva ESP, Ribeiro AM, 2011. Inbreeding effect on reproductive traits in a herd of Mangalarga Marchador

Brazilian horses. Rev Bras Saúd Prod Anim 12: 641-649.

Hammer Q, Harper DAT, Ryan PD, 2001. PAST. Palaeontologia statistics software package for education and data analysis. Palaent Eletr 4: 1-9.

Inglês FPLD, Vianna SAB, 2004. Campolina Horse commented racial pattern [Technical Bulletin]. Belo Horizonte, MG: Brazilian Campolina Horse Breeders Association.

Jones WE, 1987. Genetics and breeding of horses. São Paulo: Roca. 666 pp.

Kane AJ, Stover SM, Gardner IA, Case JT, Johnson BJ, Read DH, Ardans AA, 1996. Horseshoe characteristics as possible risk factors for fatal musculoskeletal injury of thoroughbred breed horses. Am J Vet Res 157: 1147-1152.

Martin-Rosset W, 1983. Particularités de la croissance et du development du cheval. Revue bibliographique. Ann Zootec 32: 373-380. https://doi.org/10.1051/animres:19830108

McManus C, Falcão RA, Spritze A, Costa D, Louvadini H, Dias LT, Teixeira RA, Rezende MJM, Garcia JAS, 2005. Morphological characterization of the Campeiro horse breed. R Bras Zootec 34: 1553-1562. https://doi.org/10.1590/S1516-35982005000500015

Meira CT, Pereira IG, Farah MM, Pires AV, Garcia DA, Cruz VAR, 2013. Identification of morphofunctional traits in Mangalarga Marchador horse using principal component analysis. Arq Bras Med Vet Zootec 65: 1843-1848. https://doi.org/10.1590/S0102-09352013000600036

Mello FA, Schmidt V, 2008. Biometric characterization of Anglo-Nubian goats in Brazil, born from 1993 to 2001. Arch Zootec 57: 525-535.

Oom MM, Ferreira JC, 1987. Biometric study of the Alter horse. Rev Port Cienc Vet 83: 101-148.

Parés-Casanova P, 2010. Relationships between morphometric values in "Cavall pirinenc català" equine breed carcasses. Rev Electr Vet 11: 1-6.

Peres-Neto PR, 1995. Introduction to morphometric analysis. Oecol Bras 2: 57-89. https://doi.org/10.4257/oeco.1995.0201.03

Pimentel MML, Pinheiro M, Maria Filho H, Sakamoto SM, Nobre FV, Dias RVC, 2014. Biometric parameters of asinines (Equus asinus) used in evidence of race in the state of Rio Grande do Norte. Acta Vet Bras 8: 136-143. https://doi.org/10.21708/avb.2014.8.2.3579

Pinto LFB, Almeida FQ, Quirino CR, 2005. Multivariate analysis of body measures in Mangalarga Marchador foals: discriminant analysis. Rev Bras Zootec 34: 600-612. https://doi.org/10.1590/S1516-35982005000200030

R Development Core Team, 2018. R: A language and environment for statistical computing.

Rezende MPG, Souza JC, Mota MF, Jardim RJD, Ramires GG, Silva RM, Souza CF, 2014. Morphometry body of equines used in work, sport and leisure in three cities of Mato Grosso do Sul. Vet Zootec 21: 569-583.

Rezende MPG, Abreu UGP, Santos SA, Souza JC, Sitorsky LG, 2015. Body morphology of purebred and crossbred Quarter Horses used in Lasso competitions in Mato Grosso do Sul. Arch Zootec 64: 183-186. https://doi.org/10.21071/az.v64i246.395

Rezende MPG, Souza JC, Mota MF, Oliveira NM, Jardim RJD, 2016. Conformation index of horses of different genetic groups. Cienc Anim Bras 17: 316-326. https://doi.org/10.1590/1089-6891v17i321194

Rezende MPG, Ferraz PC, Carneiro PLS, Malhado CHM, 2017. Phenotypic diversity in buffalo cows of the Jafarabadi, Murrah, and Mediterranean breeds. Pesq Agropec Bras 52: 663-669. https://doi.org/10.1590/s0100-204x2017000800012

Rezende MPG, Souza JC, Carneiro PLS, Bozzi R, Jardim RJD, Malhado CHM, 2018. Morphofunctional diversity of equine of varied genetic compositions raised in the Pantanal biome of Brazil. Trop Anim Health Prod 45: 1-10.

Sadek MH, Al-Aboud AZ, Ashmawy AA, 2006. Factor analysis of body measurements in Arabian horses. J Anim Breed Genet 123: 369-377. https://doi.org/10.1111/j.1439-0388.2006.00618.x

Santos MR, Freiberger G, Bottin F, Chiocca M, Zampar A, Cucco DC, 2017. Evaluation of methodologies for equine biometry. Livest Sci 206: 24-27. https://doi.org/10.1016/j.livsci.2017.10.009

SAS Institute, 2017. Statistical analysis system: user's guide. Cary, NC, USA.

Stashak TS, Hill C, 2006. Conformation and movement. In: Lameness in horses; Adams OR & Stashak TS (eds.). pp: 55-77. Editora Roca, São Paulo.

Thomas HS, 2005: The horse conformation. Storey Publishing, North Adams, MA, USA. 387 pp.

Torres ADP, Jardim WR, 1992: Rearing of horse and other horses. Nobel, São Paulo. 654 pp.

Yilmaz O, Ertugrul M, 2012. Some morphological traits of Thouroughbred horses in Turkey. AgroLife Sci J 1: 157-164.

Zamborlini LC, Bergmann JAG, Pereira CS, Fonseca CG, Carneiro ASR, 1996. Genetic-quantitative study of body measurements of Mangalarga Marchador horse bred in Brazil-I. Estimates of genetic and environmental effects. Rev Bras Cienc Vet 3: 33-37. https://doi.org/10.4322/rbcv.2015.041