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

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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-functional 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).

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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 mor-
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 centers 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).](image-url)
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.
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.

| 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 | 3.33 | 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.
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 \((g_i, g_j)\), \(i = 1, \ldots, n\), and each column a vector starts at the origin to the point \(H_m\) with a coordinate \((h_j, h_j)\), \(j = 1, \ldots, p\), 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.
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 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 dolichomorphic 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 & Viana, 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 dolichomorphic 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 dolichomorphic 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 dolichomorphic 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 (Glazewska, 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 & Ertegrul, 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.

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