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Morphofunctional characteristics of working mules in mountain areas of the Colombian Central Andes

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ABSTRACT. The application of morphofunctional measurements allows the selection of suitable animals to perform working activities and ensure that animal maximum capacities are not exceeded. Mules are commonly used by small farmers for agricultural work in mountain areas where the access is extremely difficult. We aimed to estimate the functionality indexes of working mules in mountain areas of the Colombian Central Andes. A total of 94 adult mules were evaluated for withers height, thoracic perimeter, body length, neck length, and body weight, which were used to determine the body index (BI), proportionality index (PI), and load carriage index (LCI). Descriptive statistics, analysis of correlations, and principal component analysis were performed. Males presented higher morphometric measurements than females. There was a negative correlation between BI with PI and LCI. The principal component analysis was able to merge characteristics in two components explaining 81.78% of the variance in the indexes. These results demonstrated that working mules in the studied area have morphometric characteristics that define them as mesolinear animals with a low frame and broad chest, and these characteristics can function as a guide to identify desirable conformation indices for working mules, determining values of adequate load, respecting animal welfare.

Keywords: biotype; *Equus caballus* x *Equus asinus*; load carriage index; morphological index.

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Introduction

Mules are produced by crossing a male donkey with a mare, aiming to obtain animals with better characteristics for working in mountain areas are obtained, thus making them efficient animals for this purpose. Some remarkable aspects of this cross-breeding are their small and oval hooves, which give them a more elastic thread, and their great endurance and strength for loading tasks (McLean, Wang, Heartfield, & Rodrigues, 2015). Additionally, they play an important role in the rural tropical communities in mountain areas by providing biomechanical power to perform agricultural operations (Greene, Hurson, & Wickler, 2006; Pineda & Florio-Luis, 2016). In these areas, it is necessary to ensure that mules have the ideal body conformations to perform their activities.

Morphometry evaluates the shapes of animals through their body measurements, thereby providing greater support to the evaluation of body conformation and establishment of concrete measures to estimate their productive capacity (McLean et al., 2015). Of these measurements, body weight (BW) and body condition score, for example, are used to monitor the nutritional status of animals over time, calculate the correct doses of drugs for a specific treatment, or determine their load carriage capacity (Carroll & Huntington, 1988; Jensen, Danielsen, & Tauson, 2016; Matsuura et al., 2013).

Functionality measurements (i.e., morphological ratios or morphometric index) can be established using ratios between body measurements, generating body index (BI), proportionality index (PI) and the load carriage capacity (García, García, Macarro, & Abascal, 1987). Some studies have suggested that body measurements that determine balance and body proportionality can be differently defined in mules and horses, according to animal's main purpose: working (traction and/or load) or riding animals (McLean et al., 2015).

In general terms, the unique muscular structure of mules, allows then to carry more weight than regular horses, presenting a higher proportion of fast-twitch fibers that resist fatigue, maximize energy production, and increase its power (D'angelis, Santos, Ferraz, Andrade, & Queiroz- Neto, 2014; Silva et al., 2018).

However, an equine that is not properly conditioned will not be able to efficiently carry the weight during a working day, thereby affecting its balance and transportation capacity (Powell, Bennett-Wimbush, Peeples, & Duthie, 2008; Souza et al., 2016; Souza et al., 2015). Therefore, the morphological and functional assessment of load carriage capacity in working equids is important using indices that improve their well-being and avoid health problems, economic losses, and, consequently, a decrease in productivity (Burn, Dennison, & Whay, 2010; Corrales-Hernández et al., 2018; McManus et al., 2005).

In this regard, the purpose of this study was to estimate morphofunctional indexes for working mules used in the raw cane sugar industry in mountain areas of western Cundinamarca (Colombian Andes) using morphometric measurements.

Materials and methods

A total of 94 working mules (39 males and 55 females) older than 5 years and located in five municipalities (Villeta, La Peña, Utica, Nimaima, and Vergara) of the northwestern area of the department of Cundinamarca, Colombia (central Andean area of Colombia), were evaluated. These municipalities are situated in the high mountain area at an altitude between 700 and 2000 m above sea level, with temperatures ranging from 18° to 24°C, where the sugarcane agriculture industry stands out. Each mule was weighed (BW), and a set of morphometric measurements was conducted.

To this purpose, each mule was placed on a horizontal plane, standing on all four legs, with its legs parallel to each other and perpendicular to the support plane, body length, thoracic perimeter, withers height and neck length were measured according to Figure 1.

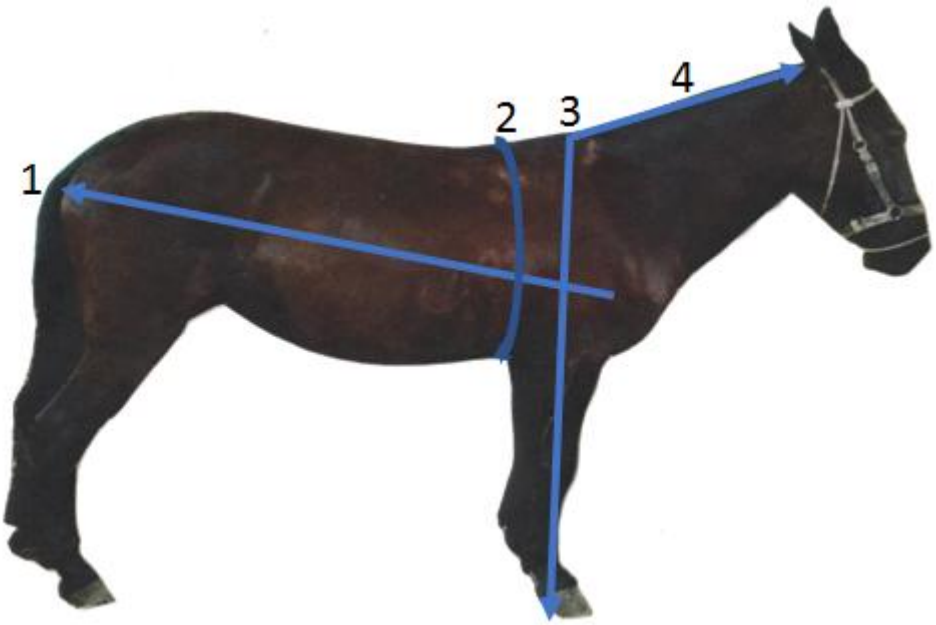

Figure 1. Morphometric measurements evaluated on mules in mountain areas of western Cundinamarca, Colombia. 1 = body length, 2 = thoracic perimeter, 3 = withers height, 4 = neck length.

The following morphofunctional indexes were obtained from ratios between the previous measures: *Body index (BI):* BI is the ratio of BL to TP multiplied by 100, and this index provides an estimate of an animal's body proportions (Mendoza et al., 2015), where animals with BI < 86 have a short or brevilinear body, those with BI between 86 and 88 have a medium or mesolinear body, and those with BI > 88 have a long or longilinear body (Rezende, Sousa, Mota, Oliveira, & Jardim, 2016). *Proportionality index (PI)*: This corresponds to the ratio of WH to BL multiplied by 100 (Solé, Gómez, Molina, Peña, & Valera, 2013). This index classifies animals into long (longer than tall, PI < 99); medium (PI: 99–101); and tall (taller than long, PI > 101). *Load carriage index (LCI)*: This corresponds to the squared TP divided by height and multiplied by 0.95 for working equids (McManus et al., 2005). The load on the back directly affects the center of gravity of working equids, which must be supported by all four limbs, and particularly by the front limbs. This index indicates the weight (kilograms) that the animal can hold on its back while walking.

Descriptive analyses were conducted, in addition to the Pearson correlation and principal component analyses to determine the relationship between variables analyzed and each index under study. To evaluate possible effects of sex (female and male) and municipality on morphometric measurements, analysis of variance was conducted for each characteristic under study. The LS-means test was used in the R-studio program (3.3.1) to compare means between sexes.

Results and discussion

Body measurements and morphofunctional indexes are presented in Table 1. Males presented higher ($P < 0.05$) morphometric measurements, characterized as having a taller and longer body, increased weight, a larger TP and a longer neck. However, the morphofunctional indexes were similar between sexes, which indicate that these working animals, regardless of sex, maintain their body proportion. The origin location of the mules did not show significant differences, indicating that morphometric characteristics of the working animals in these areas are quite similar.

Table 1. Morphometric characteristics and morphofunctional indexes (mean ± standard error) in male and female mules in mountain areas of western Cundinamarca, Colombia.

	Females	Males
WH, cm ***	130.40 ± 0.79	135.28 ± 1.05
BL, cm ***	129.08 ± 0.75	135.14 ± 0.99
BW, kg *	275.36 ± 5.59	298.88 ± 7.37
TP, cm *	147.85 ± 1.10	152.58 ± 1.45
NL, cm *	67.36 ± 1.16	71.94 ± 1.52
BI	87.51 ± 0.61	88.69 ± 0.81
PI	101.1 ± 0.52	100.12 ± 0.69
LCI, Kg	159.57 ± 2.01	163.85 ± 2.65

*$p < 0.05$; ***$p < 0.001$. WH = withers height, BL = body length, BW = body weight, TP = thoracic perimeter, NL = neck length, BI = body index, PI = proportionality index, LCI = load carriage index.

Averages for morphometric measurements, except for NL, were lower than those reported in mules by other studies conducted in different countries (Pineda & Florio-Luis, 2016). These results indicate that smaller mules are used in mountain areas where raw cane sugar is produced, facilitating movement on irregular topography.

Averages of WH, BL, and TP in mules were similar to those reported for mules in Turkey (WH: 130.6 cm; BL: 133.9 cm; TP: 149.6 cm) (Yilmaz, Coskun, & Ertugrul, 2012, 2013). Measurements of WH and BW in the present study were lower than those reported for mules in Cuba (BW: 345 kg) (Ramajo et al., 2000) and Venezuela (WH: 148 cm and BW: 275 kg) (Pineda & Florio-Luis, 2016). These differences can be explained by the effect the parental genetic group (Rezende et al., 2018), which could be reflected on mules body measurements.

When comparing certain body measurements, in general, there was a 1:1 relationship of proportionality between the measures of WH and BL, indicating the importance of these two measurements for body balance in working and riding animals, as reported (Souza et al., 2015). The weight corresponded to 2.2 times the length and 1.9 times the height. The thoracic height and TP were 1.9 and 2.1 times the NL of the animal, being an important measure for the animal's body balance, as some studies have suggested that mules bear 55% of the total load weight on their front legs (Powell et al., 2008).

The average BI indicates that, on average, the mules were mesolinear and longilinear, respectively. This demonstrates the need for shorter mares to obtain short-bodied or brevilinear mules that have a greater load carriage capacity. Regarding PI, both females and males had an average proportionality and adequate balance, which indicates a balance between the animal's WH and BL, maintaining its center of gravity.

The average load carriage capacity in females and males was 159.57 ± 2.01 and 163.85 ± 2.65 kg, respectively, which is equivalent to 57% and 54% of BW for females and males. As reported by the owners, the mules carried approximately 13 sacks (162.5 kg) in 8- to 9-h working days with a break of between 1 and 2 weeks during the month, depending on the activity in the sugar mill. Some authors have recommended that working equids with optimal body conditions can support loads on their back between 33% and 50% of their BW (Powell et al., 2008). These loading values of >50% of BW on the back exceed the percentages of weight recommended for horses of the same weight. Different studies (Matsuura et al., 2013; Powell et al., 2008) have argued that despite the greater strength of a mule than that of a horse of the same weight,

subjecting working horses to loads on their backs of >30% of their weight for long working days can cause stress to the animal and have consequences in the joints, leading to injuries in the dorsal region. Although the maximum load carriage capacity that a horse or mule can carry on its back depends on several variables, it is essential to determine whether the animal has the appropriate load weight based on its movements.

Exploratory studies in the subtropics and tropics, such as those in Chile (Tadich & Stuardo, 2014), Cuba (Ramajo et al., 2000) and Venezuela (Pineda & Florio-Luis, 2016) have determined that mules in mountain areas have BWs ranging from 200 to 345 kg and that they carry work loads of 100 kg in daily shifts from 9 to 10 h. In the study conducted by (Pineda & Florio-Luis, 2016), they recommend not exceeding 100 kg because of the difficulty of transportation in areas with steep slopes and fatigue that is caused in animals because of the complexity of the mountain topography. Further, mules working with moderate loads would have better animal welfare and a higher life expectancy (Ramajo et al., 2000).

The coefficients of correlation between morphometric characteristics of working mules are presented in Table 2. The highest and positive correlations ($r > 0.5$) were obtained in WH–BL, WH–BW, WH–TP, NL–BW, TP–BW, BW–LCI, and TP–LCI and high but negative correlations ($r < -0.5$) were obtained in TP–BI, BI–PI, and BI–LCI. These results are similar to those reported in studies conducted in tropical countries (Yilmaz et al., 2012, 2013) where it is important to highlight that for working equids, based on the carriage capacity, it is necessary to search for phenotypically short-bodied or brevity individuals with a larger TP.

The principal component analysis demonstrated that the first two components explain 81.78% of the variance in relationships presented by morphometric variables and body indices. Figure 2 shows a positive relationship in component 1 (X-axis) between variables BL, WH, LW, TP, and LCI, and these, in turn, has a negative relationship with BI. A positive relationship was observed between NL and BI in component two (Y-axis).

Table 2. Phenotypic correlations between morphometric measurements and functionality indexes of working mule in mountain areas of western Cundinamarca, Colombia.

Characteristic	WH	BL	NL	BW	TP	BI	PI
BL	0.65 ***						
NL	0.20 *	0.31 **					
BW	0.72 ***	0.53 ***	0.05 ^{NS}				
TP	0.64 **	0.48 **	0.04 ^{NS}	0.87 ***			
BI	-0.13 ^{NS}	0.36 ***	0.21 *	-0.48 ***	-0.64 ***		
PI	0.42 ***	-0.41 ***	-0.13 ^{NS}	0.24 *	0.20 *	-0.59 ***	
LCI	0.28 **	0.28 **	-0.06 ^{NS}	0.70 ***	0.91 ***	-0.73 ***	0.03 ^{NS}

NS: not significant, *p < 0.05, **p < 0.01, ***p < 0.001. WH = withers height, BL = body length, NL = neck length, BW = body weight, TP = thoracic perimeter, BI = body index, PI = proportionality index, LCI = load carriage index.

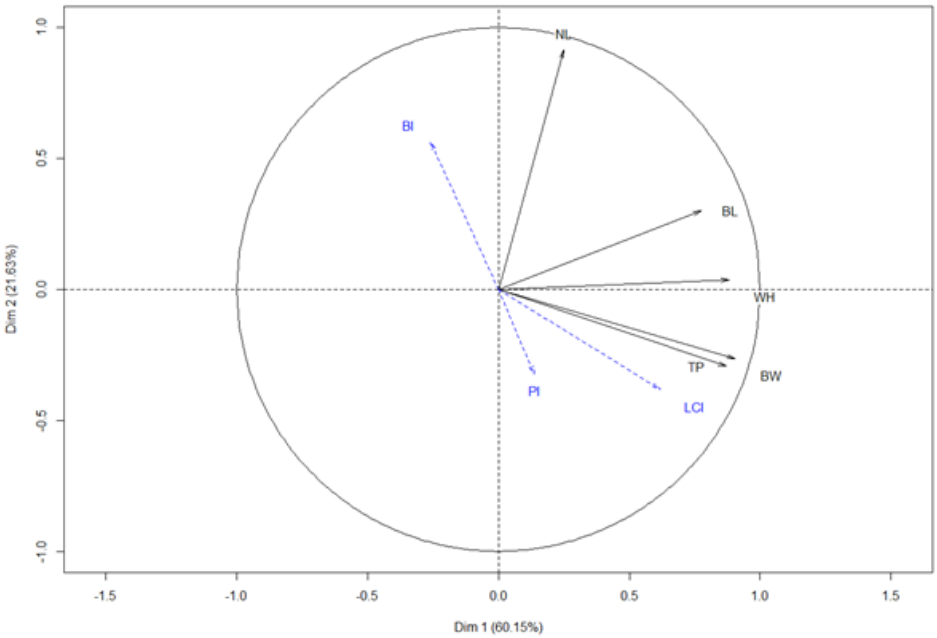

Figure 2. Relationship between morphometric variables in components 1 and 2.

Component 1 was associated with the animal's volume and strength measurements, and component 2 was associated with body balance measurements. A possible interpretation of these relationships is the conformation inherited by the mule's progenitors. Smith and Burden (2013) have indicated that although mules have characteristics of both parents, the mule phenotype usually resembles the shape of a horse in its hind legs, whereas the sections of the middle and neck resemble those of a donkey's. NL is important for the balance of the hind legs. Thus, the head, together with the neck, forms a flexible lever support system, which allows useful movements of the center of gravity and all the required attitudes in adverse conditions of locomotion, such as movement in mountainous areas.

The principal component analysis, besides corroborate with the negative relation between BI with LCI and PI, also show a close positive relation with BW and TP with higher LCI, therefore indicated the necessity of an adequate nutrition in order to ensure animal strength and welfare. When analyzing PI, it's noteworthy its behavior as a more independent variable. Other possibilities of multivariate analysis have been reported in horses, in order to evaluate the morphofunctional diversity of animals from different genetic composition, aiming to identify a better biotype for the Pantanal region of Brazil (Rezende et al., 2018).

Conclusion

Morphometric measurements were different between sex, presenting higher values for the males. However, morphofuntional indexes were similar between sex. Mules from the central Andean mountainous area of Colombia can be classified as small- to medium-sized animals, with adequate body proportions and balance. Load carriage index indicated that mules can carry around 50% for their body weight, and animals with a brevilinear body are related with higher load carriage capacity. These findings allow animal selection with desirable conformation for work and, thereby, determine values of adequate load for work and animal welfare.

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