REVISTA BIO CIENCIAS
http://revistabiociencias.uan.edu.mx
https://doi.org/10.15741/revbio.10.e1387

ISSN 2007-3380

Original Article/Artículo Original

Morphometric characterization and zoometric indices of the criollo mixteco cattle from Oaxaca, Mexico.

Caracterización morfométrica e índices zoométricos del bovino criollo mixteco de Oaxaca, México.

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Please cite this article as/Como citar este artículo: López Aguirre, R., Montiel Palacios, F., Carrasco García A. A., Ahuja-Aguirre, C., López de Buen, L., Severino Lendechy, V. H. (2023). Morphometric characterization and zoometric indices of the criollo mixteco cattle from Oaxaca, Mexico. Revista Bio Ciencias, 10 e1387. *Revista Bio Ciencias,* 10 e1387. https://doi.org/10.15741/revbio.10.e1387

Article Info/Información del artículo
Received/Recibido: June 07th 2022.
Accepted/Aceptado: November 14th 2022.
Available on line/Publicado: January 10th 2023.

ABSTRACT

The objective of the study was to characterize morphometrically and to estimate the zoometric indices of criollo Mixteco bulls from Oaxaca, Mexico. Thirty bulls (2.3 ± 0.8 years of age and 248.8 ± 27 kg of weight) were evaluated. Ten morphometric measurements were determined and from them 10 zoometric indices were calculated: cephalic, thoracic, corporal, lateral corporal, anamorphosis, pelvic, dactyl-thoracic, dactyl-costal, transverse pelvic, and longitudinal pelvic. The morphometric measurements showed a range of variation between 7.4 % (height at the withers) and 29.3 % (thoracic bicostal width), and the average coefficient of variation was 13 %. The general correlation coefficient indicated 66.6 % of phenotypic homogeneity. There was a positive correlation ($p < 0.05$) between the live weight and 90.9 % of morphometric variables, the thoracic perimeter being the variable with the highest correlation (r = 0.778). The indices obtained described the criollo Mixteco cattle as a dolichocephalic (cephalic index 48.5 ± 4.2) and brevilinear (corporal index 79.9 ± 7.8) biotype, with longilinear thoracic proportions (thoracic index 72.74 ± 22.12, anamorphosis index 2.1 ± 0.2), and with aptitude for the dual purpose but with tendency for meat production (lateral corporal index 94.4±9.0, dactyl-thoracic index 11.0 ± 0.5, dactyl-costal index 46.6 ± 12.8, transverse pelvic index 32.1 ± 1.6, longitudinal pelvic index 37.9 ± 2.4), and with body volume in harmony with skeleton development (pelvic index 84.8 ± 4.5, dactyl-thoracic index 11.0 ± 0.5, dactyl-costal index 46.6 ± 12.8). In conclusion, the criollo Mixteco bulls had a dolichocephalic, brevilinear biotype, longilinear thoracic proportions, with aptitude for the dual purpose but tendency for meat production, body volume in harmony with skeleton development, and morphostructural proportionality.

KEY WORDS: Animal genetic resource, Criollo cattle, Zoometry.

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RESUMEN

El objetivo del estudio fue caracterizar morfométricamente y estimar los índices zoométricos de toros criollo mixteco de Oaxaca, México. Se evaluaron 30 toros (2.3 ± 0.8 años de edad y 248.8 ± 27 kg de peso). Se determinaron 10 medidas morfométricas y con éstas se calcularon 10 índices zoométricos: cefálico, torácico, corporal, corporal lateral, de anamorfosis, pelviano, dáctilo-torácico, dáctilo-costal, pelviano transversal y pelviano longitudinal. Las medidas morfométricas mostraron rango de variación entre 7.4 % (altura a la cruz) y 29.3 % (anchura bicostal del tórax), y el coeficiente de variación promedio fue 13 %. El coeficiente de correlación general indicó 66.6 % de homogeneidad fenotípica. Hubo correlación positiva ($p < 0.05$) entre el peso vivo y 90.9 % de variables morfométricas, siendo el perímetro torácico la variable con mayor correlación (r = 0.778). Los índices obtenidos describieron a los toros criollo mixteco como un biotipo dolicocéfalo (índice cefálico 48.5 ± 4.2), de cuerpo brevilíneo (índice corporal 79.9 ± 7.8) y proporciones torácicas longilíneas (índice torácico 72.74 ± 22.12, índice de anamorfosis 2.1 ± 0.2), con aptitud para el doble propósito pero tendencia a producción de carne (índice corporal lateral 94.4 ± 9.0, índice dáctilo-torácico 11.0 ± 0.5, índice dáctilo-costal 46.6 ± 12.8, índice pelviano transversal 32.1 ± 1.6, índice pelviano longitudinal 37.9 ± 2.4), y con volumen corporal en armonía con el desarrollo óseo (índice pelviano 84.8 ± 4.5, índice dáctilo-torácico 11.0 ± 0.5, índice dáctilo-costal 46.6 ± 12.8). En conclusión, los toros criollo mixteco de Oaxaca presentaron un biotipo dolicocéfalo, de cuerpo brevilíneo y proporciones torácicas longilíneas, con aptitud para el doble propósito y tendencia a producción de carne, con volumen corporal en armonía con el desarrollo óseo y proporcionalidad morfoestructural.

PALABRAS CLAVE: Recurso zoogenético, Bovinos criollos, Zoometría.

Introduction

Criollo cattle breeds descend from the cattle (*Bos taurus*) that arrived in the Americas with the Spaniards from the Iberian Peninsula between 1493 and 1521 (De Alba, 2011). Throughout 500 years, these animals colonized the different agroecological regions of the Americas (Villalobos-Cortés *et al*., 2009), adapting to diverse ecosystems as a result of natural selection, and developing resistance to diseases and to variations in the amount and quality of forages (Landi & Quiroz, 2011). However, even though in the past this genetic resource was the basis of livestock activity, present these cattle are considered in risk of extinction because the cattle producers that preserve and use these breeds are only a few, most of them indigenous located in mountainous and wooded areas that are hard to access, thus limiting their training to improve the productive management of the animals and their selection for a specific zootechnical purpose (Perezgrovas-Garza & de la Torre-Sánchez, 2015).

In some regions of the states of Oaxaca, Guerrero, and Puebla there are still isolated nuclei of criollo cattle, mainly in mountainous and semidesertic areas, where one cattle breed known as Mixteco criollo has developed and is raised mostly by indigenous people under rustic systems of extensive silvopastoral production (Méndez *et al*., 2002). These cattle are commonly used to obtain weaned calves for fattening and meat production. Nonetheless, the productive system used by these cattle producers, which is extensive with no territorial restriction, has led to a decrease in the population of this animal genetic resource because it exposes the few criollo cattle individuals to indiscriminate and uncontrolled crosses with cattle of other *Bos taurus* and *Bos indicus* breeds, such as Brahman, Nelore, Angus, Beefmaster, Simmental and Simbrah, which roam loose in the same territory because they are owned by neighboring producers that also manage them extensively (Severino-Lendechy *et al*., 2021). This situation leads to the loss of genetic material and reduces the population of purebred Mixteco criollo cattle.

The conservation of animal genetic resources requires their characterization (Landi & Quiroz, 2011). The morphometric characterization establishes racial patterns from different body measurements, analyzes the relationships among individuals, and evaluates the harmony of the morphostructural model (Martínez-López *et al*., 2014; Parés i Casanova, 2009). Therefore, morphometric characterization is basic for the technical and scientific knowledge of new animal breeds and constitutes the first step toward conservation and protection (Contreras *et al*., 2012).

On the other hand, the body measurements used for the morphometric characterization are utilized to generate some zoometric indices, which are employed to determine a specific biotype or zootechnical purpose of the animal (meat, milk, or dual-purpose) that allows obtaining some productive profits (Contreras *et al*., 2011; Landi & Quiroz, 2011).

In the literature, there is only one study on the Mixteco criollo cattle that describes morphometric variables, but not their zoometric indices or their zootechnical purpose (Méndez *et al*., 2002). Therefore, the objective of this study was to determine the morphometric variables and the zoometric indices of Oaxaca Mixteco criollo bulls to know the degree of morphostructural harmony among the individuals, their ethnological characters, and their specific biotype.

Material and Methods

The Commission of Bioethics and Animal Welfare of the Facultad de Medicina Veterinaria y Zootecnia of the Universidad Veracruzana approved the experimental procedures that were used on the animals from this study, which comply with what is established in the NOM-062-ZOO-1999.

Geographical location of the study site

The study was conducted in 10 cattle production units (UP) located in the municipality of Huajuapan de León (Lat. 17°48’14’’ North and Long. 97°46’33’’ West), in the state of Oaxaca, Mexico, at altitude 1641 masl, with semi-warm humid climate with summer rainfall, mean annual temperature of 20 °C, and annual rainfall of 736 mm (INEGI, 2022).

Characteristics of the animals

Thirty bulls that fitted the racial pattern of the Mexican criollo cattle (Espinoza-Villavicencio *et al*., 2009; Méndez *et al*., 2002) were selected from 10 UP of the municipality of Huajuapan de León, Oaxaca, through a convenience sampling. The average age and weight of the bulls were 2.3 ± 0.8 years and 248.8 ± 27 kg. The bulls were visually examined to confirm that they were free from pathologies or physical defects that could alter the morphometric measurements. They were kept under the usual management of the UP regarding sanitary measures and feeding, the latter being continuous extensive grazing.

Morphometric characterization

Ten morphometric variables were measured (in centimeters) in each bull using the morphometric standard for the Mixteco criollo cattle proposed by Méndez *et al*. (2002). The variables measured were: head width (ACa), head length (LCa), corporal length (LCo), height at the withers (ACr), thoracic perimeter (PTx), dorsal-sternal height (ADE), thoracic bicostal width (ABTx), rump length (LGr), rump width (AGr), and the metacarpus perimeter (PC) (Aguirre-Riofrio *et al*., 2019; Méndez *et al*., 2002). To obtain the measurements of length, width, height, and perimeter, a measuring tape and zoometric sticks were used. To facilitate obtaining the measurements, the bulls were immobilized in a chute. The live weight of the animals was determined using a portable scale with a maximum capacity of 500 kg (FSK-Basic, A and A Scales, EUA), and their age was calculated through dental chronology (Casas *et al*., 2001).

Zoometric indices

The zoometric indices indicate relationships among quantitative morphological variables, and they have been established as patterns to define the different types or breeds in which animals and their zootechnical purposes (milk, meat, or dual-purpose) can be classified (Contreras *et al*., 2011; Parés i Casanova, 2007, 2009; Salamanca & Crosby, 2013a). The zoometric indices are calculated from the morphometric variables. The most commonly used are (Aguirre-Riofrio *et al*., 2019; Contreras *et al*., 2011; 2012; Fernández *et al*., 2007; Casanova, 2007; 2009; Rodríguez *et al*., 2001; Salamanca & Crosby, 2013a,b):

1) Cephalic index (ICEF): it measures the proportionality of the head of the animal. It classifies the animals as dolichocephalic (index <75.9; long and slim head), brachycephalic (index >81; short and wide head), and mesocephalic (index between 76 and 81; facial proportion apparently symmetrical, namely, the facial proportion of the head is apparently the same as its width).

2) Thoracic index (IT): it reflects the variations in the shape of the thorax; higher values (more circular) correspond to beef cattle and lower values (more elliptical) to dairy cattle. The mediolinear breeds have an IT between 86 and 88, the brevilinear breeds ≥89, and the longilinear breeds ≤85.

3) Corporal index (ICO): it classifies the animals as brevilinear (≤85), mesolinear (86-88), or longilinear (≥90).

4) Lateral corporal index (ICL): it indicates whether an animal is tall rather than long, or vice versa; a lower value indicates that the shape of the animals is close to a rectangle, which is the predominant shape of beef cattle.

5) Anamorphosis index (IA): it relates the thoracic perimeter with the height at the withers, and provides indications of the aptitude for meat production of the animal; as the index decreases it indicates that the animal has long legs and is lighter, suggesting a tendency to the production of lean meat, whereas as the index increases it indicates that the animal has the tendency to produce fat. It is, if in cattle this value is high (4.0 and 5.0) it corresponds to an animal with a tendency to produce meat, and if the index is low (2.5 and 3.0) it corresponds to an animal with a tendency to produce more milk than meat.

6) Pelvic index (IP): it indicates the relationship between the width and length of the pelvis, reflecting a pelvis that is proportionally wider than long, or vice versa. A higher value indicates a pelvis which is wider than long, which is observed in an animal with a tendency to produce meat rather than milk.

7) Dactyl-thoracic index (IDT) and 8) Dactyl-costal index (IDC): they give an idea of the degree of refinement of the skeleton, being their value higher in animals with a tendency to produce meat rather than milk.

9) Transverse pelvic index (IPT): it relates the development of the rump with the body size; as it exceeds 33, the animal is considered with a tendency to meat production.

10) Longitudinal pelvic index (IPL): it relates the length of the rump with the height at the withers, indicating that as the value increases, the animal is larger; a value above 37 indicates an animal for meat production.

In this study, based on the morphometric variables 10 zoometric indices were determined, which provided information on the ethnological characteristics and the productive aptitude (milk and meat) of the animals. To achieve this, the formulas described by Parés i Casanova (2009) and Aguirre-Riofrio *et al*. (2019) were used (Table 1).

Statistical analysis

The morphometric variables and zoometric indices were analyzed using descriptive statistics including mean, standard deviation (SD), minimum value (Min), maximum value (Max), and coefficient of variation (CV). The morphometric measurements were correlated using simple linear correlation (r) to determine the degree of association between variables. All the analyses were conducted using the software Statistical Package for Social Sciences version 19 (SPSS V.19).

Table 1. Formulas used to calculate the zoometric indices of cattle and type of information they provide.

Information	Index	Formula
Ethnological characters	Cephalic (ICE)	ICE = (head width/head length) x 100
	Thoracic (ITO)	ITO = (bicostal width/dorsal-sternal height) x 100
	Corporal (ICO)	ICO = (body length/thoracic perimeter) x 100
	Lateral corporal (ICL)	ICL = (height at the withers/body length) x 100
	Anamorphosis (IAN)	IAN = thoracic perimeter^2/(height at the withers x 100)
	Pelvic (IPE)	IPE = (rump width/rump length) x 100
Milk producing aptitude	Dactyl-thoracic (IDT)	IDT = (metacarpus perimeter/thoracic perimeter) x 100
	Dactyl-costal (IDC)	IDC = (metacarpus perimeter/thoracic bicostal width) x 100
Meat producing aptitude	Transversal pelvic (IPT)	IPT = (rump width/height at the withers) x 100
	Longitudinal pelvic (IPL)	IPL = (rump length/height at the withers) x 100

Sources: Parés i Casanova (2009) and Aguirre-Riofrio *et al*. (2019).

Results and Discussion

Morphometric measurements

The morphometric measurements obtained in the Oaxaca Mixteco criollo bulls (Table 2) provided a general approximation of the physical characteristics of the animals, showing a range of variation between 7.4 % (ACr) and 29.3 % (ABTx) (Table 2), with an average CV of 13 %. This differs from the information reported in limonero criollo in Venezuela, in which the measurements that were evaluated showed low variability, being 3.3 % for height at the withers and 10.8 % for hip perimeter, with average CV of 6.6 % (Contreras *et al*., 2012). In Argentinian criollo cattle, the range of variability was 3.7 % for height at the rump and 13.4 % for head width, with an average CV of 7.7 % (Martínez *et al*., 2007). These differences in the range of variability and CV can be attributed to the low genetic selection of the Oaxaca Mixteco criollo bulls. Nonetheless, according to the weight and size, it was determined that this breed is eumetric (medium weight and small to medium size), and according to its regional morphology (head, torso, rump, and extremities) this breed has mediolinear proportions.

The morphometric measurements ACa and LCa in the Oaxaca mixteco criollo were similar to those reported in lojano criollo (ACa 21 ± 0.3, LCa 46 ± 0.6; Aguirre-Riofrio *et al*., 2019), but different to those obtained in limonero criollo (ACa 26.7, LCa 49.08; Contreras *et al*., 2012) and blanco orejinegro (ACa 49.0 ± 1.3, LCa 50 ± 2.4; Rojas-Jiménez *et al*., 2014). This body region is important because it allows to establish differences in the comparative studies by sex within and between breeds (Contreras *et al*., 2012). In addition, the ethnological characteristics contributed by the head are very useful because they are not influenced by environmental and managemental factors, allowing to establishment particular characteristics for each breed (Parés i Casanova, 2009).

Table 2. Morphometric variables in Mixteco criollo bulls.

Variable (cm)	Mean ± SD	Min	Max	CV (%)
Head width (ACa)	21.9 ± 5.1	17	45	23.3
Head length (LCa)	45.2 ± 3.4	17	45	7.6
Corporal length (LCo)	123.6 ± 15.1	95	153	12.2
Height at the withers (ACr)	115.7 ± 8.6	101	130	7.4
Thoracic perimeter (PTx)	154.8 ± 14.8	130	183	9.6
Dorsal-sternal height (ADE)	56.1 ± 8.4	39	70	14.9
Thoracic bicostal width (ABTx)	38.9 ± 11.4	24	59	29.3
Rump length (LGr)	43.8 ± 3.4	38	51	7.8
Rump width (AGr)	37.2 ± 5.9	30	56	15.8
Metacarpus perimeter (PC)	17.1 ± 1.5	15	21	9.1

SD = standard deviation. CV = coefficient of variation.

The Oaxaca mixteco criollo bulls showed short LCo, smaller than other criollo breeds such as the limonero in Venezuela (LCo 132.04; Contreras *et al*., 2012), chinampo in Mexico (LCo 128; Espinoza-Villavicencio *et al*., 2009), and lojano in Ecuador (LCo 179; Aguirre-Riofrio *et al*., 2019). Additionally, due to its ACr the Oaxaca mixteco criollo is considered a small size breed, similar to the Suriname (ACr 112.70; Tjon A San & Molina-Flores, 2016) and the lojano (ACr 111; Aguirre-Riofrio *et al*., 2019), but smaller than other criollo breeds such as the blanco orejinegro (ACr 122; Rojas-Jiménez *et al*., 2014), limonero (ACr 126.65; Contreras *et al*., 2012), and the Manabi in Ecuador (ACr 131.90; Cevallos-Falquez *et al*., 2016).

The PTx of the Oaxaca mixteco criollo was similar to those reported in lojano (PTx 151; Aguirre-Riofrio *et al*., 2019) and Casanare (PTx 156; Salamanca & Crosby, 2013b) criollos, but wider than the PTx of the criollos chinampo (PTx 137; Espinoza-Villavicencio *et al*., 2009) and

Suriname (PTx 142; Tjon A San & Molina-Flores, 2016). The ADE and ABTx were similar to those obtained in lojano criollo (ADE 59, ABTx 35; Aguirre-Riofrio *et al*., 2019), and smaller than those of the Puno (ADE 67, ABTx 53; Rojas-Espinoza & Gómez-Urviola, 2005) and the Santa Elena (ADE 62.5 y ABTx 42.2; Cabezas-Congo *et al*., 2019) criollos. The LGr and AGr were similar to those recorded in the lojano (LGr 43, AGr 39; Aguirre-Riofrio *et al*., 2019), Santa Elena (LGr 43, AGr 39.1; Cabezas-Congo *et al*., 2019), and Puno (LGr 47, AGr 39.1; Rojas-Espinoza & Gómez-Urviola, 2005) criollos. The PC was similar to the one reported in lojano criollo (16 ± 0.3; Aguirre-Riofrio *et al*., 2019) and narrower than in the Santa Elena criollo (19.29 ± 3.70; Cabezas-Congo *et al*., 2019).

The differences found between morphometric variables can be attributed to environmental and managemental factors that can influence the size, growth, and physical conformation of the animal (Contreras *et al*., 2011; Espinoza-Villavicencio *et al*., 2009), which is related to the zootechnical purpose of each breed (milk, meat, or dual-purpose) (Contreras *et al*., 2011; Espinoza-Villavicencio *et al*., 2009; González-Stagnaro & De la Fuente-Martínez, 2012; González-Stagnaro *et al*., 2006). However, the morphometry of the Mixteco criollo bulls indicated that these animals are well adapted to their environment, where adverse climatic, orographic, and feeding conditions exist.

Harmony of the morphometric model

The morphometric variables obtained in this study provided an approximation of the phenotypic characteristics of the Oaxaca Mixteco criollo cattle. However, to generate a harmonious morphometric model of the breed it was necessary to subject such variables to simple linear correlation analysis to determine the degree of association between the morphometric measurements. When in a group of animals or breeds more than 50 % of the variables are correlated, it corresponds to a harmonious morphometric model; when 25 to 50 % of the variables are correlated, it is defined as a moderately harmonious model; when less than 25 % of the variables are correlated, it corresponds to a little harmonious model (Contreras *et al*., 2011; Rojas-Jiménez *et al*., 2014).

To analyze the morphometric variables obtained in this study the methodology proposed by Herrera *et al*. (1996) and Rojas-Jiménez *et al*. (2014) was used, conducting a simple correlation analysis between the studied variables (Table 3). In 66.6 % of the cases, a correlation was observed between the different morphometric variables ($p < 0.05$); this result was superior to that obtained in Santa Elena criollo (55.2 %; Cabezas-Congo *et al*., 2019), similar to the one in limonero criollo in Venezuela (61.5 %; Contreras *et al*., 2011), but inferior to the results in other criollo breeds such as the pampa chaqueño (75.7 %; Martínez-López *et al*., 2014) and blanco orejinegro (88.2 %; Rojas-Jiménez *et al*., 2014). The percentage of correlations within each population, as well as the differences or similarities of correlation between the variables analyzed, are indicators of the underlying variability among populations, which could be expected in this type of populations that historically have been genetically managed by producers that use different criteria, which can or cannot include adequate genetic improvement and/or reproductive programs, as well as criteria for the selection of breed traits, besides the use of bulls of other breeds (Cabezas-Congo

et al., 2019; Severino-Lendechy *et al*., 2021). Nonetheless, independently of the differences or similarities, the Oaxaca Mixteco criollo bulls showed harmony and proportionality in their morphostructural model.

In this study there was a positive correlation ($p < 0.05$) between live weight and 90.9 % of the morphological characteristics (Table 3), being PTx the variable with the highest correlation (r = 0.778) with weight. However, the values obtained were lower than those reported in limonero criollo (r = 0.93; Contreras *et al*., 2012), Lucerna (r = 0.94; Mahecha *et al*., 2002), and crossbred cattle (r = 0.94; Khalil & Vaccaro, 2002). According to Mahecha *et al*. (2002), although most of the variations in body weight modify the morphometric profile of the animal, which is reflected in the change in PTx, the live weight can be estimated almost exactly from this morphometric measurement, which itself is an indicator of growth, adaptability, and feed efficiency in cattle.

The results of the present study indicate that the percentages of correlation between these morphological variables can be modified by the genetic management of the herds leading to conserve or loss the characteristics of a specific breed and that the body measurement of PTx could be used to estimate the live weight of the animals.

Zoometric indices

The studied indices in general showed a range of variation between 4.4 % (IDT) and 41.2 % (IT) (Table 4), being the thoracic index the less homogeneous. Nonetheless, the average CV was 12.8 %. Therefore, these data allowed to define the Oaxaca Mixteco criollo bulls as a dolichocephalic biotype (ICEF 48.5 ± 4.2) with brevilinear body (ICO 79.9 ± 7.8), with aptitude for the dual-purpose but with tendency to produce meat (ICL 94.4 ± 9.0, IDT 11.0 ±0.5, IDC 46.6 ± 12.8, IPT 32.1 ± 1.6, IPL 37.9 ± 2.4), with longilinear thoracic proportions (IT 72.7 ± 22.1, IA 2.1 ± 0.2), and with corporal volume in harmony with the skeletal development (IP 84.8 ± 4.5, IDT 11.0 ± 0.5, IDC 46.6 ± 12.8) (Table 4, Photographs 1 and 2).

The ICEF (48.5 ± 4.2) of the Oaxaca Mixteco criollo bulls is an indicator of an animal with narrow head, similar to the Casanare criollo (40.0 ± 4.8; Salamanca & Crosby, 2013a), but this index was lower to the one reported in limonero criollo (54.5 ± 4.2; Contreras *et al*., 2012). However, they enter in the classification of dolichocephalic animals, as the length of the head prevailed over the width of the head.

The IT of the bulls from this study (72.7 ± 22.1) was similar to that recorded in Santa Elena criollo (74.3; Cabezas-Congo *et al*., 2019), higher to the IT of Holstein cattle (62.0; Rodríguez *et al*., 2001), Barroso-Salmeco criollo (61.6; Jáuregui *et al*., 2014) and lojano criollo (59.6; Aguirre-Riofrio *et al*., 2019), and lower than that of Hereford cattle (93.0; Rodríguez *et al*., 2001). This index reflects the variations in the shape of the thorax; a higher value (more circular) indicates that the animal has aptitude for meat production, while a lower value (more elliptical) indicates that the animal has aptitude for milk production. Therefore, according to this index the Mixteco criollo cattle could be considered as a meat producing animal, with longilinear thoracic conformation and lightly elliptical.

Table 3. Phenotypic correlations (r) between weight and the morphometric variables of Oaxaca Mixteco criollo bulls, with *p*-values.

	LCa	ACa	LCo	ACr	ABTx	PTx	ADE	LGr	AGr	PC
Peso	0.456(*)	0.299*	0.403(*)	0.418(*)	.0580(**)	0.778**	0.083	0.459**	0.470**	0.491**
p	0.022	0.030	0.046	0.038	0.002	0.000	0.694	0.001	0.001	0.000
LCa	1	0.207	0.311	0.239	0.210	0.332	0.337	-0.004	0.306	0.286
p		0.321	0.131	0.249	0.314	0.104	0.099	0.984	0.137	0.166
ACa		1	0.225	0.371	0.059	0.357	0.333	0.224	0.081	0.161
p			0.279	0.068	0.778	0.080	0.103	0.282	0.699	0.441
LCo			1	0.604(**)	0.429(*)	0.618(**)	0.441(*)	0.552(**)	0.711(**)	0.586(**)
p				0.001	0.033	0.001	0.027	0.004	0.000	0.002
ACr				1	0.750(**)	0.845(**)	0.633(**)	0.633(**)	0.570(**)	0.692(**)
P					0.000	0.000	0.001	0.001	0.003	0.000
ABTx					1	0.426(*)	-0.480(*)	0.610(**)	0.557(**)	0.433(*)
p						0.034	0.015	0.001	0.004	0.031
PTx						1	0.525(**)	0.628(**)	0.687(**)	0.720(**)
p							0.007	0.001	0.000	0.000
ADE							1	0.169	0.425(*)	0.641(**)
p								0.421	0.034	0.001
LGr								1	0.638(**)	0.748(**)
p									0.001	0.000
AGr									1	0.653(**)
p										0.000
PC										1

p < 0.05* and *p* < 0.01** Statistical difference. Variables: Head length (LCa), Head width (ACa), Corporal length (LCo), Height at the withers (ACr), Thoracic bicostal width (ABTx), Thoracic perimeter (PTx), Dorsal-sternal height (ADE), Rump length (LGr), Rump width (AGr), and Metacarpus perimeter (PC).

Table 4. Zoometric indices of Oaxaca Mixteco criollo bulls.

Indices	Variables	Mean ± SD	Min	Max	CV (%)
Ethnological	Cephalic	48.5 ± 4.2	36.2	52.4	8.6
	Thoracic	72.7 ± 22.1	40.0	141.7	41.2
	Corporal	79.9 ± 7.8	66.7	91.2	9.7
	Lateral corporal	94.4 ± 9.0	82.8	110.7	9.6
	Anamorphosis	2.1 ± 0.2	1.6	2.5	11.0
	Pelvic	84.8 ± 4.5	75.0	90.2	5.3
Milk producing aptitude	Dactyl-thoracic	11.0 ± 0.5	10.2	11.7	4.4
	Dactyl-costal	46.6 ± 12.8	28.6	62.5	27.4
Meat producing aptitude	Transverse pelvic	32.1 ± 1.6	28.3	33.7	4.9
	Longitudinal pelvic	37.9 ± 2.4	35.0	43.2	6.4

SD = standard deviation. CV = coefficient of variation.

Picture 1. Black-roan Oaxaca Mixteco criollo bull.

Source: V. H. Severino-Lendechy.

The ICO of the Oaxaca Mixteco criollo (79.9 ± 7.8) was lower than that of the Casanare criollo (82.7; Salamanca & Crosby, 2013a), and higher than the ICO of the limonero criollo (76.2 ± 2.8; Contreras *et al*., 2012). These breeds, according to this index and the authors reporting on them, are classified as brevilinear, the same as the Mixteco criollo.

The ICL (94.4 ± 9.0) in the Oaxaca Mixteco criollo bulls was higher than in the Uruguayan criollo and in Hereford cattle (86.4 y 78.2, respectively; Rodríguez *et al*., 2001). In the first case, the authors could not determine whether the animals had an aptitude for milk or meat production, indicating that this situation could be clarified with a study on their productive and reproductive characteristics, whereas the Hereford breed is already known that is specialized in meat production. Therefore, according to the results obtained and considering that this index indicates that the lesser the value the more approximation of the animal to a rectangle shape, which is the predominant shape in the animals with aptitude for meat production (Parés i Casanova, 2009), the Oaxaca Mixteco criollo could be classified as an animal with tendency to the dual-purpose.

The IA obtained in these bulls (2.1 ± 0.2) was lower than the one reported in Santa Elena criollo (2.2; Cabezas-Congo *et al*., 2019), Hereford (2.3) and Holstein (2.8) (Rodríguez *et al*., 2001), and limonero criollo (2.38 ± 0.21; Contreras *et al*., 2012). According to Contreras *et al*. (2012), the IA determines the conformation of the individual because if its value is high (4.0 and 5.0) it makes

reference to an animal for meat production and if it is low (2.5 and 3.0) to an animal with tendency to produce more milk than meat; nonetheless, according to the IA obtained in limonero criollo they determined that this breed has a biotype for the dual-purpose. Therefore, it could be considered that the Oaxaca Mixteco criollo fits this classification.

Picture 2. Black-roan Oaxaca Mixteco criollo bull.

Source: V. H. Severino-Lendechy.

The IP of the Oaxaca Mixteco criollo (84.8 ± 4.5) was similar to the one reported in barroso-Salmeco criollo (84.7; Jáuregui *et al*., 2014), but lower than that in the lojano (92.9; Aguirre-Riofrio *et al*., 2019) and Uruguayan (130.1; Rodríguez *et al*., 2001) criollos. This index denotes the relationship between the width and length of the pelvis, indicating a pelvis that is proportionally wider rather than large or vice versa. A higher value is an indicator of a pelvis that is rather wide instead of long, which is observed in an animal with aptitude for the production of meat but not milk. The Mixteco criollo bulls had a pelvis which has wide rather than long, which suggests an aptitude for the dual purpose.

The IDT (11.0 ± 0.5), IDC (46.6 ± 12.8), IPT (32.1 ± 1.6), and IPL (37.9 ± 2.4) indices, which are used as indicators of the ability to produce milk or meat, were similar to those reported by Aguirre-Riofrio *et al*. (2019) in four biotypes of criollo cattle in the south of Ecuador: black (IDT

9.9, IDC 44.1, IPT 36.0, IPL 38.7), encerado (IDT 10.1, IDC 44.1, IPT 36.7, IPL 38.5), red (IDT 10.1, IDC 45.5, IPT 35.5, IPL 39.3), and Cajamarca (IDT 10.0, IDC 44.1, IPT 36.0, IPL 38.7). According to these indices, these authors classified the biotypes black, encerado, and Cajamarca as dual-purpose with a tendency for milk production, and the red biotype as dual-purpose with a tendency to meat production. Particularly, IPT and IPL indicate the meat-producing ability through the relationship between the width and length of the pelvis, which in turn is related to the height or corpulence of the animal, therefore, the Mixteco criollo showed an intermediate predisposition for the development of muscle tissue in this area that produces the most valuable meat cuts. Therefore, the Oaxaca Mixteco criollo cattle could be classified as a biotype for dual-purpose with a tendency to meat production.

Conclusions

The Oaxaca Mixteco criollo bulls showed a dolichocephalic, brevilinear biotype, longilinear thoracic proportions, with an aptitude for the dual purpose but a tendency for meat production, body volume in harmony with skeleton development, and morphostructural proportionality.

Contribution of the authors

“Conceptualization of work, V.H.S.L., F.M.P., R.L.A.; methodology development, V.H.S.L., F.M.P., R.L.A.; experimental validation, V.H.S.L., F.M.P. A.A.C.G., L.L.B.; analysis of results, V.H.S.L., F.M.P., C.A.A., R.L.A.; Data management, V.H.S.L., F.M.P., C.A.A., R.L.A.; writing and preparation of the manuscript, V.H.S.L., F.M.P., C.A.A., R.L.A.; writing, revision and edition, V.H.S.L., F.M.P., C.A.A., R.L.A. “All authors of this manuscript have read and accepted the published version of it.”

Acknowledgements

To the cattle producers of Huajuapan de León, Oaxaca, for their disposition, collaboration, and support showed for the development of the study, and particularly to MVZ. Víctor Hernández Núñez for his attentions and unconditional support.

Conflict of interest

The authors declare having no conflict of interest.

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