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ORIGINAL RESEARCH

Phenotypic characterization of the population of creole wool ewes in the highlands of Puebla State, Mexico

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Abstract This study characterized the population of wool ewes in the highlands of the State of Puebla, Mexico, considering traits such as fleece color, weight, and body measurements. In this region, dominated by a temperate climate, sheep are a traditional animal species for farming systems. To carry out the work, 2,082 ewes were randomly selected from 14 communities and 124 flocks belonging to the six municipalities that have the largest inventory of sheep in the state. For each ewe, live weight, breed, fleece color pattern, and 18 other body measurements were recorded. Descriptive statistics were estimated for weight and body traits and the morphotype was classified by multivariate analysis. Factor analysis identified the bulk, size, and breed standard as the attributes that best describe the population of ewes. These elements varied in importance among the groups ($p<0.05$). Cluster analysis helped to classify the population into small black-faced ewes (28.5 %), small white ewes (11.9 %), black-faced medium-sized ewes (24.1 %), large ewes (12.3 %), and white medium-sized ewes (23.2 %). The groups identified were similar to creole sheep present in rural communities in other environments, but have lower morphostructural values than specialized breeds.

Keywords Live body weight · Morphotypes · Multivariate analysis · Zoometric measures

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Introduction

Most sheep production systems are extensive worldwide, and in some places, the use of native animals is predominant because they have shown a capacity to adapt to the environment and manage conditions where the use of external inputs is rare (Kunene et al. 2009a; Carneiro et al. 2010; Parsons et al. 2011). These sheep production systems in developing countries consist of small-sized herds whose production is marketed locally and are engaged in a peasant economy system with a diversified income source, combining agriculture, sale of labor, production of other animal species, and government support (Arriaga-Jordán et al. 2005; Quiroz et al. 2008; Gizaw et al. 2009).

As a policy to address the challenges of the global sheep industry, there is a trend to introduce pure breeds and technologies from developed countries into developing countries through government social programs. Nonetheless, these actions have resulted in a failure of the implemented programs because the introduced animals do not have the ability to produce under the harsh conditions of the smallholders (Parsons et al. 2011). Additionally, there is a big risk from a replacement of the genes of creole sheep population, which can lead to a gradual loss of important genotypes. To address this problem, a study of production systems under the conditions typical for local producers has begun and it is expected to advance the definition of local production systems and highlight the potential for creole animals as some authors have mentioned (Traoré et al. 2008; Kunene et al. 2009a).

In the characterization of native sheep populations, studies have focused on the definition of racial pattern (Nsoso et al. 2004; Traoré et al. 2008), the analysis of the relationships among morphostructural characteristics, and genetic diversity (Kunene et al. 2009a; Robinson et al. 2009). For the characterization of sheep populations, live weight and body traits, such as withers height, height to the ilium, chest girth, diameter bicostal, width at shoulder, and body length, are used (Kunene et al. 2009a; Riva et al. 2004).

In Mexico, sheep production industry is not well-established, the sheep meat market is dependent on imports (Pérez et al. 2011); production takes place mostly in subsistence regions (Vázquez et al. 2009; Galaviz-Rodríguez et al. 2011), especially in the Puebla State which is the third largest sheep producer with a population of 504,660 heads (INEGI 2007). In this state, sheep production is mainly carried out under agropastoral system (Vázquez et al. 2009). At present, due to the high demand for sheep meat and the high sale price of live animals and processed products, there is a great opportunity to guide the production of sheep to market. This is accomplished with the use of new forms of sustainable sheep production based on the rescue and use of local genotypes (Borg et al. 2009; Taye et al. 2010). This study aimed to characterize the population of ewes in the temperate farming systems in the highlands of Puebla State and to define the existing racial pattern based on the live weight, body traits, and qualitative characters.

Materials and methods

Site and livestock management

The study area included the municipalities of Atempan (19°48′04″ N, 97°26′23″ W), Cuyoaco (19°35′44″ N, 97°510″ W), Libres (19°28′06″ N, 97°40′35″ W), Saltillo La Fragua (19°16′49″ N, 97°17′28″ W), Acajete (19°06′07″ N, 97°56′53″ W), and Santa Rita Tlahuapan (19°16′49″ N, 98°35′16″ W), located in the highland valley region, State of Puebla, Mexico. The climate in the study area has a wide variability, ranging from temperate humid in the municipalities of Atempan, Acajete, and Santa Rita Tlahuapan (with more than 950 mm of annual rainfall) to the temperate subhumid (850 mm of precipitation) in the municipalities of Cuyoaco, Libres, and Saltillo La Fragua. The average annual temperature is 17°C, the maximum ranges between 26 and 28°C, and the minimum drops to 3 and 4°C below zero in winter. In this region, the soil types are Andosol, Litosol, and Regosol (INEGI 2006). The vegetation is composed of areas of pine–oak and fir forests on the mountain sides; in the valley, the main vegetation is halophyte grassland and induced grassland along the forest edge.

Agricultural activity is characterized by the production of grains such as beans, maize, fababeans, barley, and wheat (INEGI 2007). Livestock production is carried out in common use lands and the stubble left over from agricultural crops, grazed by mixed herds of sheep and goats, cattle, and equines, which are confined in pens at night. In sheep production, creole genotypes and/or crosses (46.4 %), crosses of Suffolk (45.8 %), and crosses of Columbia (6.8 %) and Pelibuey (0.9 %) (Vargas et al. 2004) are used.

Table 1 Live weight and zoometric characteristics of wool ewes in the highland valleys of the State of Puebla

Variable	Mean ± SEM	Coefficient of variation
Live weight (kg)	40.31±0.21	24.26
Head length (cm)	22.54±0.04	8.82
Head width (cm)	12.03±0.02	7.45
Face length (cm)	12.88±0.03	11.73
Face width (cm)	5.81±0.01	11.06
Ear length (cm)	10.88±0.04	14.90
Ear width (cm)	6.78±0.02	12.08
Neck length (cm)	27.65±0.06	10.05
Body line distance (cm)	71.93±0.14	8.66
Withers height (cm)	62.74±0.11	8.30
Height at the ilium (cm)	64.35±0.11	7.85
Height at the ischium (cm)	52.04±0.10	9.02
Chest girth (cm)	83.84±0.18	9.92
Body length (cm)	71.96±0.15	9.41
Chest depth (cm)	18.89±0.06	13.79
Thorax depth (cm)	28.20±0.06	9.86
Rump width (cm)	17.63±0.05	12.61
Rump length (cm)	21.59±0.04	9.08
Width at shoulders (cm)	19.47±0.06	13.42
Shin circumference (cm)	8.10±0.02	10.44

n=2,082 ewes

SEM standard error of the mean

Table 2 Color pattern of wool and the nose of the sheep population in the highlands of Puebla

Variable	Frequency	Percentage
Wool body color pattern		
White	1,961	94.19
Brown	13	0.62
Black	91	4.37
White with others	17	0.82
Wool color face		
White	695	33.38
Brown	90	4.32
Black	1,163	55.86
White with others	134	6.44
Nose color		
Pink	310	14.89
Brown	255	12.25
Gray	12	0.58
Black	1,292	62.06
Black with others	213	10.23

Table 3 Eigenvalues for each factor and the relative proportion of variance explained

Factor	Eigenvalue	Variation proportion	Cumulative percentage variation
1	115.12	0.86	0.86
2	12.00	0.09	0.95
3	2.64	0.02	0.97
4	2.00	0.01	0.98
5	1.21	0.01	0.99
6	0.76	0.01	1.00

Data collection

To carry out the work, 2,082 ewes were measured. In order to select the animals, firstly, six municipalities which have sheep inventories in the State of Puebla were chosen (INEGI 2007). Within each municipality, a random community selection was made in order to gather a sample of 350 to 500 ewes; if the chosen community did not cover the number of ewes required, then the nearest neighboring community supplied the rest of the animals. The final sample selected consisted of 14 communities and 124 flocks. For each ewe, several measurements were recorded including live body weight, age, qualitative characteristics, and zoometric body measurements. Weight was recorded with a digital balance after ewes had been fasted for 12 h. The age of animals was estimated by counting permanent incisors (Kunene et al. 2009b) and records from the animal owners. Qualitative characteristics such as body and face wool color and nose color were recorded. Zoometric measures were determined with the methodology proposed by Riva et al. (2004), Carneiro et al. (2010), and López-Carlos et al. (2010). The traits measured were height at withers, height at the ilium, the ischium height, width at shoulders, rump width, head length, head width, face length, chest girth, thorax depth, neck length, body line distance, and shin circumference. These measurements were done using a flex meter of 1.5 m in length, an outside caliper, and a digital caliper.

Statistical analysis

Data on live weight, qualitative characteristics, and body measurements of the ewes were coded into spreadsheets in order to generate indicators. Analyses were performed with Statistical Analysis System program (SAS Institute Inc. 2003). Descriptive statistics were determined for quantitative traits and frequencies for qualitative traits. The database of weight and body traits was analyzed using multivariate techniques as described by Khattree and Dayanand (2000) to cluster and describe the groups of ewes.

Descriptive statistics included mean, standard error, and coefficient of variation for each of the measured traits. A correlation analysis was performed, and when a set of variables had a high correlation only, one was left and the others were discarded from the database in order to perform the multivariate analysis. Thus, uncorrelated variables were selected and related to physical attributes of the ewes. A factor analysis was then performed, which allowed data to be grouped into subsets or groups of a few explanatory variables describing the highest proportion of the variance in the data. With the variables of greatest contribution for each of the factors described, subsets of variables were formed and each subset was labeled. With variables that showed high contribution on the factors, a cluster analysis using the procedure FASTCLUS of SAS was performed (Usai et al. 2006). The purpose of this analysis was to group

Table 4 Factorial structure of ewe groups in the highlands of the State of Puebla

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Chest depth (cm)	0.81	0.17	0.15	0.12	0.12
Width at shoulders (cm)	0.73	0.22	0.14	0.15	0.08
Chest girth (cm)	0.68	0.35	0.27	0.16	0.14
Shin circumference (cm)	0.44	0.30	0.35	0.16	0.21
Thorax depth (cm)	0.42	0.39	0.23	0.18	0.12
Withers height (cm)	0.28	0.79	0.31	0.14	0.10
Height at the ilium (cm)	0.34	0.58	0.29	0.15	0.12
Ear length (cm)	0.08	0.18	0.54	0.15	0.04
Head width (cm)	0.28	0.22	0.53	0.06	0.19
Rump length (cm)	0.33	0.48	0.52	0.13	0.10
Head length (cm)	0.24	0.32	0.43	0.33	0.12
Face length (cm)	0.25	0.19	0.24	0.89	0.13
Face width (cm)	0.16	0.11	0.13	0.10	0.80
Age (years)	0.06	0.03	−0.01	0.07	0.04

Table 5 Main statistical morphotypes of the population of wool ewes in the highlands of the State of Puebla

Cluster	Ewe number	Root mean square of standard deviations	Max distance seed-observation	Distance between cluster centroids
1	594	2.292	30.4061	11.8404
2	247	2.4125	34.9429	13.0159
3	502	2.2983	34.784	12.1695
4	256	2.6061	27.8345	14.4351
5	483	2.2622	26.8948	11.8404

ewes based on the individual homogeneity and heterogeneity among groups. As a linkage measurement, the squared Euclidean distance and the Ward method were used.

In order to perform an analysis of variance, the identified groups were labeled with a number then each ewe belonging to a group received the number of that group. The model for the analysis of variance of zoometric variables was the following:

$$Y_{ij} = \mu + C_i + \varepsilon_{ij}$$

where Y is the value of live weight and morphostructural traits determined by the population mean (μ), the group determined with cluster analysis (C), and the random error (ε).

Results

The ewe population had an average live body weight of 40.3 kg and an age of 3.2 years. The length (22.5 cm) and head width (3.12 cm) had a rectangular projection and an almost symmetrical proportion of 1.8:1 (Table 1). The body line distance (71.96 cm) and withers height (62.74 cm) were of average proportion. Chest depth was 18.9 cm and chest girth was 83.84 cm. The region of the rump had measures of 64.35 cm in height, 21.59 cm in length, and 17.63 cm in width, and the shin circumference was 8.1 cm.

The dominant body color was white, while the predominant colors for the face were black and white (Table 2). The nose colors were black and pink.

Table 6 Means obtained by the method of least squares for the variables of the groups of the population of ewes in the highlands of Puebla

Variable	Black face		White		Large size
	Small size	Medium size	Small size	Medium size	
Live weight (kg)	39.4c	47.0b	26.4e	32.8d	57.0a
Wool length (cm)	2.9ns	3.1ns	2.8ns	2.9ns	3.2ns
Ear length (cm)	10.8c	11.4b	9.8e	10.4d	11.8a
Ear width (cm)	6.8c	7.2b	6.1e	6.4d	7.5a
Neck length (cm)	27.6c	28.4b	25.7e	27.1d	29.3a
Body line distance (cm)	72.2c	75.2b	64.3e	68.4d	79.0a
Head length (cm)	22.5c	23.4b	20.4e	21.6d	24.6a
Head width (cm)	12.0c	12.4b	11.2e	11.6d	12.9a
Face length (cm)	12.9c	13.6b	11.5e	12.2d	14.2a
Face width (cm)	5.8c	6.0b	5.5e	5.6d	6.2a
Withers height (cm)	63.1c	65.6b	55.5e	59.4d	69.5a
Height at the ilium (cm)	64.6c	67.2b	57.4e	61.1d	71.1a
Height at the ischium (cm)	52.1c	54.6b	46.5e	49.4d	57.4a
Chest girth (cm)	83.4c	89.9b	71.2e	78.4d	95.6a
Body length (cm)	72.3c	76.4b	62.1e	67.1d	81.4a
Chest depth (cm)	18.8c	20.3b	15.8e	17.5d	21.9[a]
Thorax depth (cm)	28.1c	29.8b	25.0e	26.5d	31.5a
Rump width (cm)	17.6c	18.9b	14.8e	16.4d	20.2a
Rump length (cm)	21.6c	22.7b	19.0e	20.4d	24.1a
Width at shoulders (cm)	19.4c	20.7b	16.6e	18.2d	22.4a
Shin circumference (cm)	8.1c	8.5b	7.2e	7.7d	9.0a

Values in the same row followed by different letters differ ($p<0.05$) according to Tukey-Kramer test

Morphotype factors of wool ewes

In the analysis of factors, it was determined that five factors explained the total data variance (Table 3). A total of five linear combinations had eigenvalues greater than 1; therefore, they were used for cluster analysis. They had eigenvalues of 1.21 to 115.12 and together they accounted for 99 % of the total variance. The factor structure and the load of the identified five factors are presented in (Table 4).

Factor I explained 85.84 % of the total variance. The traits that contributed in high proportion to this factor were chest depth (81 %), the width at shoulders (73 %), and the shin circumference (44 %). Such traits are related to the bulk of the meat-type sheep (Table 4).

Factor II explained 8.94 % of the variance in the data. The contributing traits were the height at withers (79 %), the ilium height (58 %), and rump length (48 %)—characteristics related to ewe body size. Collectively, factors III, IV, and V explained only 4.36 % of total variance and the contributing traits were the length of ear (54 %), face length (89 %), and face width (80 %).

Morphotype groups of ewes

The number of ewes per group ranged from 247 to 594. The degree of dispersion of clusters given by the root mean square of standard deviations ranged from 2.3 to 2.6. The maximum distance of seed and an observation within each cluster indicated that each cluster was enough separated (Table 5).

The identified groups of sheep were named as: (a) small black-faced ewes, (b) small white ewes, (c) black-faced medium-sized ewes, (c) large ewes, and (d) white medium-sized ewes (Table 6). The criteria used to define the groups were frequency of body coat and face color, weight, withers height, body length, and length and height to the ilium.

Cluster 1 Small black-faced ewes: This group comprised 28.5 % of the sampled ewes. The average live weight of these ewes was 39.4 kg, with a range from 21.2 to 50 kg, representing 69.1 % of the large-sized group of ewes. The values of zoometric measurements showed significant differences with other groups and were 10 % lower than the large ewes group.

Cluster 2 Small white ewes: This group included 11.9 % of the ewes studied. The live weight range was 17 to 40 kg. The weight represented 46.3 % of the group of the large ewes and 80.6 % of the white medium-sized ewes. Zoometric traits were 93.5 and 94.7 % of the white medium-sized and large ewes, respectively.

Cluster 3 Black-faced medium-sized ewes: This group included 24.1 % of the population of ewes. The average live weight was 47.0 kg and ranged from 34.9 to 57.0 kg; this was the second heaviest group within the sample of ewes studied. This group had 83 % of live weight and 95 % of zoometric traits of the large ewes group.

Cluster 4 Large ewes: This group had the highest values ($p \leq 0.05$) in live weight and body traits compared to other groups and only 12.3 % of the sampled ewes belonged to this group. The average live weight was 57 kg with a range of 43.66 to 75.8 kg.

Cluster 5 White medium-sized ewes: This group included 23.2 % of the population of ewes. The average weight was 32.8 kg, which ranged from 23.5 to 44.32 kg. Zoometric measures in this group were 15 % below the large ewes group.

The five groups of ewes were identified by two-dimensional diagram in Fig. 1. Attributes evaluated by the five groups were well defined in the canonical two-dimensional space. Large ewes and black-faced were situated to the right of the chart, while white ewes were located on the left side.

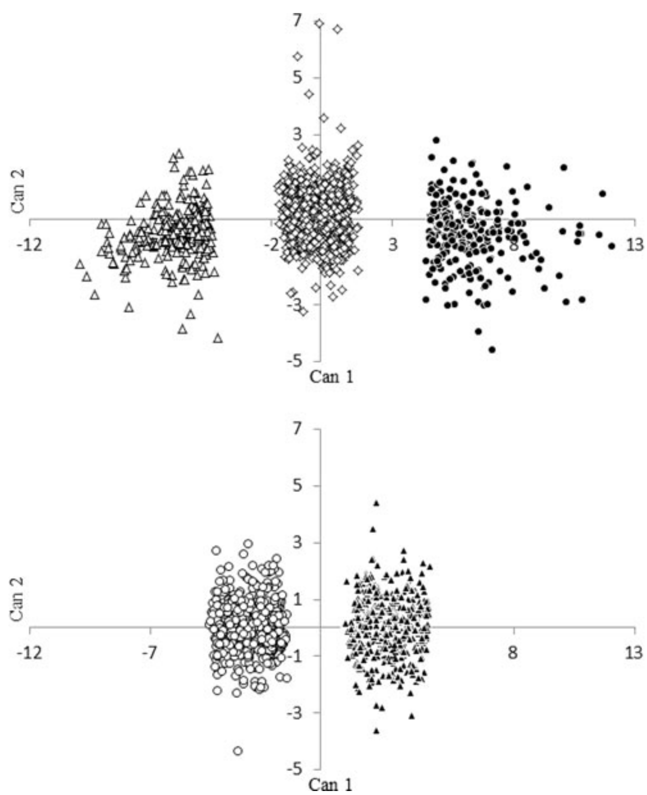

Fig. 1 Distribution of groups of ewes (*empty triangle* small white ewes, *empty circle* white medium-sized ewes, *diamond* small black-faced ewes, *filled triangle* black-faced medium-sized ewes, *filled circle* large ewes) in the temperate highlands of Puebla in the two-dimensional canonical space

Discussion

The introduction of exotic sheep in rural communities of the highlands of Puebla has been seen as the main means of improving the productivity of flocks, similarly to other regions of Mexico (Arriaga-Jordán et al. 2005), where this constitutes part of informal breeding goals and strategies of smallholder farmers in low input systems (Gizaw et al. 2009). However, studies of morphological characterization towards selection of wool sheep in Mexico are scarce.

The ewe population studied showed low coefficients of variation for all zoometric traits (less than 15 %), except for live weight, indicating that they belong to a homogenous population. In relation to live weight, the values assessed in this study were similar to the Criolla sheep from Brazil, Uruguay, and Colombia studied by Carneiro et al. (2010), which had a lower adult weight than Suffolk, Texel, Ile de France, and Merino. Other traits such as height at withers, chest girth, and body length were similar to the results found by Traoré et al. (2008) and Carneiro et al. (2010) for creole sheep in South America and Africa, respectively. Exotic breeds generally have higher values in most traits than creole sheep according to Carneiro et al. (2010). On the other hand, there are traditional breeds that have high live weight and morphological traits like the Bergamasca sheep studied by Riva et al. (2004) in Italy.

Factor analysis results showed five factors as the most important in the description of the ewe population studied. These factors were associated to chest depth, chest girth, height at withers, width at shoulder, and traits related to bulk, size, and racial pattern. Due to the fact that the factors are not correlated by definition, the data suggest that bulk and size (Kunene et al. 2009b; López-Carlos et al. 2010) are attributes that producers pay most attention to when selecting the breeding stock.

Cluster analysis allowed for the detection of significant differences among groups into the ewe population in the State of Puebla. This indicated different scenarios for herd management and producers' preferences (Usai et al. 2006). The results of the cluster analysis identified five groups of ewes, which were small black-faced, small white, black-faced medium-sized, large, and white medium-sized ewes. Some groups comprised black-faced ewes, possible cross-bred with Suffolk at some point in the past. Characteristics of coat pigmentation can define breeds as Kijas et al. (2012) suggest. Nonetheless, other body measures found do not match the racial description of this breed because the studied ewes have lower body measurements than Suffolk. In this regard, Quiroz et al. (2008) stated that the poor differentiation at a breed level may be due to a continuous crossbreeding among different populations.

The canonical analysis for weight and body traits showed a wide dispersion within the ewe population, dominated by small- and medium-sized ewes, comprising 87.7 % of the whole population. The black-faced ewes were better placed in the canonical two-dimensional space than the groups dominated by white coat ewes. The smallest proportion was the large ewes, possibly due to the fact that there is a positive relationship between increased live body weight and food demand, which in traditional systems is difficult to cover (Arriaga-Jordán et al. 2005).

The high differentiation assessed among clustered groups enhances the need for selection due to the wide variation in live weight and coat color, taking advantage of the adaptation to the environment and the rusticity that this kind of animals show (Quiroz et al. 2008). According to Kunene et al. (2009a), native sheep genotypes are becoming extinct due in part to crossbreeding with exotic breeds, induced for sociopolitical reasons; therefore, there is a need for enhancing selection and breeding of native animals. This represents an opportunity to design plans for genetic selection, due to the existence in the same region of a broad mosaic of sheep, which can serve as the core basis for a breeding program.

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