Applicability of an international linear appraisal system in Murciano-Granadina breed: fitting, zoometry correspondence inconsistencies, and improving strategies

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Abstract
Linear appraisal systems (LAS) are effective strategies to systematically collect zoometric information from animal populations. Traditionally applied LAS in goats was developed considering the variability and scales found in highly selected breeds. As a result, traditional LAS may no longer cover the different contexts of goat breeds widespread throughout the world, and departures from normality may be indicative of the different stages of selection at which a certain population can be found. The present study aimed to evaluate the distribution and symmetry properties of twenty-eight zoometric traits. After symmetry analysis was performed, the scale readjustment proposal suggested specific strategies should be implemented such as scale reduction of lower or upper levels, determination of a setup moment to evaluate and collect information from young (up to 2 years) and adult bucks (over 2 years), the addition of upper categories in males due to upper values in the scale being incorrectly clustered together. The particular analysis of each variable permits determining specific strategies for each trait and serve as a model for other breeds, either selected or in terms of selection.

Highlights
- Specific strategies must be approached for each particular zoometric trait.
- Scale levels for limb related traits must be readjusted.
- An extension of the scale in the stature of males is proposed.
- Males must be subdivided into two categories (below and over two years).
- Environment adaptability shapes progress for better dairy-linked zoometry.

Introduction
Morphology is a pivotal indicator of livestock health and value, whether it is for breeding, function or production (Guo et al. 2019). Selection for zoometrics not only defines the aesthetic nature or the adscription of individuals to a population but also their productive longevity, endurance, enhanced productive abilities (Bukar-Kolo et al. 2016) and in turn, the long-term profitability of these animals (Olechnowicz et al. 2016).

The morphological assessment considers a wide variety of zoometric traits and defines the degree of resemblance of a certain individual to the standard of the breed that it presumably belongs to (González-Velasco et al. 2011). This score is usually normalised to 100 points and is evaluated by highly qualified and experienced personnel, whose objective judgement derives from training sessions that focus on maintaining the breed’s standard.

The time and resource demands of such a detailed evaluation compromise its efficiency and profitability, thus the rationality of its application. This becomes evident when instead of working on populations under a conservation status, we start working with selected populations or for which breeding programs are being implemented (Fernández Álvarez et al. 2020). In these contexts, zoometry jumps from...
focussing on the determination and preservation of breed purity to the promotion of those traits which are linked to better performance for a specific commercial aptitude.

In such cases, linear appraisal systems (LAS) give a timely response to the time/resources demands previously addressed by traditionally zoometric assessments. In LAS, traits are generally, but not necessarily, scored on an ordinal scale that ranges between 1 and 10 points in a centralised manner, that is around and optimum.

With deep roots (Sánchez Rodríguez et al. 2012) in the American Dairy Goat Association (ADGA) and US Department of Agriculture’s (USDA) LAS, CAPRIGRAN LAS is relatively new, as its application only dates back to 2010.

As suggested by Goyache et al. (2001) and Alonso et al. (2007), this method is subject to a high subjectivity derived from raters’ personal appreciations. In these regards, a solid team of trained raters of the National Association of Breeders of Murciano-Granadina Goat Breed (CAPRIGRAN) performs the collection of zoometric data using “Escardillo” technical-economic management software. “Escardillo” is an application that is installed in PDA devices and directs raters in the collection of zoometric data, but also allows breeders to timely monitor production and morphological performance. Hence breeders can be informed about the particular evolution of their herds and assist them to make selection and management decisions more effectively (Fernández Álvarez et al. 2020; Murciano-Granadina 2020).

CAPRIGRAN routinely performs the numerical description of 17 zoometric linear traits. Once these measurements have been collected, CAPRIGRAN LAS is used to score them on a 1–9-point scale. Scale is reduced by one score (1–9 instead of 1–10) as odd scale levels enable having the same number of levels below and over the optimum. Afterwards, the global score is a weighted sum of the partial scores. The weights given to each particular area are determined by the characteristics of the breed and the aims to be reached with its control and selection (González-Velasco et al. 2011; Fernández Álvarez et al. 2020). Although in 2020, Fernández Álvarez et al. (2020) optimised and validated the conversion from zoometric assessment to CAPRIGRAN LAS, hence, the tool was deemed effective.

As suggested by Chadwick (2017), the basic aim of LAS-based tools is to capture the variability that can be found in populations. AGDA and USDA LAS were developed in the context of highly selected breeds, a trend which was followed by CAPRIGRAN LAS. However, the final designatory of CAPRIGRAN LAS application was the Murciano-Granadina breed, which should be framed at earlier stages prior to high selection. As a result, scale correspondence inconsistencies may appear, given scale correspondences derived from the valuation of highly selected breeds may not be able to represent the biological variability present in Murciano-Granadina bucks and does.

Selection, either natural or artificial, is well known to imply the reduction in variability for the target trait it intends to select for (Lynch et al. 1995). However, selection may also strongly condition the fitness of a population, with this being understood as the capacity for survival, adaptation and reproduction of populations.

In this context, selection using LAS-derived traits uses a particular way of interaction between fitness and productive traits, the so-called stabilising selection (García-Ballesteros et al. 2017). Stabilising selection occurs naturally, but in this case, it is replicated by artificial selection. Stabilising selection favours individuals with phenotypes close to an optimum value (i.e. if these phenotypes have higher fitness in the natural selection or if they are linked to desirable levels of expression of an economically important trait in artificial selection) and penalises those individuals which are far from it (Kingsolver et al. 2001; García-Dorado et al. 2007). In these regards, Johnson and Barton (2005) proved that stabilising selection may very likely lead to the reduction of genetic diversity for the trait being selected. As a result, the distribution of observations around the optimum statistically normalises.

According to Xiao (1995), the normal distribution of quantitative traits occurs as an intermediate consequence of the interaction between a group equal assortment of genes and a group unequal assortment of genes. This implies the reduction division and the assortment of genes are relatively equal (not completely equal). From the perspective of selection, the individual equal assortment of genes produces a centrifugal effect and the individual unequal assortment of genes produces a centripetal effect. Centrifugal effects counteract centripetal effects and one of the most visual consequences is the normalisation of the population. However, selection must not be regarded as a static process. For instance, the centrifugal effect of an individual equal assortment of genes leads to the result that the second filial generation is considerably more variable than the first filial generation. In turn, these interactions may eventually affect the stability of inheritance and variability patterns. For these
reasons, the normality of the trait values is usually assumed and violation of this assumption can have a detrimental effect on the power and type I error of such analyses (Peng et al. 2007). In this context, the analysis of normality and of the deviations from it may provide insights into the progress of the selection for specific traits, such as LAS-related traits and indirectly of zoometric traits selection.

Even if a normal distribution is presumed for these quantitative traits, in reality, this is often not observed and traits that depart the non-normal distribution are often found, especially in non-selected populations (Goh and Yap 2009). Many authors have ascribed this lack of normality to the fact that populations comprise individuals at a different life moment being evaluated altogether (Li et al. 2015), and that generates the presence of ‘biologically possible’ outliers. Contrarily, many examples have suggested life status may not correct for the broad variability that can exist among individuals of the same life background and status (lactational status, parturition moment, and age, among others) (Pizarro et al. 2020).

In light of the aforementioned, current selection practices for functional and biometric rely on trait normalisation around an optimum as their theoretical basis. In this regard, the opposition of the population distribution curve shape against the bilateral symmetry-based pose normalisation framework applied to livestock has been suggested to be an effective tool to evaluate selection efficiency (Guo et al. 2019).

Thus, the present study aimed at evaluating the distribution of the seventeen morphological characteristics comprised in the zoometric panel routinely measured in Murciano-Granadina does and bucks. The study of their distribution may help to understand the correspondence of those values on the CAPRIGRAN LAS scale. Symmetry analysis was used to determine the degree of selection that the Murciano-Granadina breed may have experienced in the scope of international dairy breeds, and to identify critical points on which to work, to promote the selection efficiency of LAS practices applied in the Murciano-Granadina breed population.

Material and methods

Animal sample and linear appraisal records

Murciano-Granadina complete pedigree comprised 279264 animals (266793 does and 12971 bucks) born from June 1966 to November 2019. The linear appraisal had been performed on 41418 individuals all year long. The records were measured in 73 farms in the South of Spain from 09/06/2010 to 18/12/2019. National and International Sanitary Certificates had been officially issued for all the farms considered in the study. Goats were clinically examined by an official veterinarian and those animals presenting signs of illness or disease conditions were officially declared and removed from the herds, hence, they were not considered in the analyses. All farms followed permanent stabling practices, with ad libitum water, forage and supplemental concentrate. A further description of the detailed and analytical composition of the diet provided to the animals in the study can be found in Table S1.

95 individuals with missing or incomplete zoometric and linear appraisal records were discarded. As a result, 41323 records, belonging to 22727 herdbooks registered primiparous does, 17111 multiparous does and 1485 bucks were retained in the analysis. The average age ranges for primiparous, multiparous does and bucks in the sample were 1.61 ± 0.35 years, 3.96 ± 1.74 years, and 2.43 ± 1.49 years (μ ± SD), respectively.

Murciano-Granadina linear appraisal system (LAS)

Each registry comprises raters’ scores for each animal for the following four major categories for primiparous and multiparous does (three for bucks, young males and goats that have not given birth yet); structure and capacity, dairy structure, mammary system (not in males) and legs and aplomb. In the case of primiparous and multiparous does, each record comprised information on 17 linear traits rated on a 9-points scale. As bucks were not scored for the traits in the mammary system major category, only 10 traits were scored for them following the same 9-points scale. Body depth from the structure and capacity major category and the major categories of dairy structure and legs and feet followed the same criteria for males and females.

Afterward, the final score represents how close the overall animal comes to the optimal dairy standard. Murciano-Granadina LAS establishes that each major category contributes to the final score based on 25% for structure and capacity, 15% for dairy structure, 20% for legs and feet, and 40% for the mammary system for primiparous and multiparous does (any doe which has ever begun producing milk). In the case of bucks and young males, these percentages change to 50% for structure and capacity, 20% for dairy structure, and 30% for legs and feet.
Rater’s scores are assigned one of the six category qualifications considered by CAPRIGRAN as follows; insufficient (IN) for animals that display less than 69% of the optimal standard for Murciano-Granadina dairy goats, which translates into a final score of 69 points or less, mediocre (R), 70–74% of optimal standard, which translates into a final score between 70 and 74 points, good (G) from 75 to 79% of optimal standard, which translates into a final score from 75 to 79 points, quite good (BB) from 80 to 84% of optimal standard, which translates into a final score from 80 to 84 points, very good (MB) from 85 to 89% of optimal standard, which translates into a final score from 85 to 89 points, or excellent (E) when at least 90% of the optimal standard is displayed, which translates into a higher than 90 points final score. A detailed description of the scales and the translation process from zoometric traits can be found in Sánchez Rodríguez et al. (2012), Table 1, and Figures S1–S27.

Age components such as the age of the doe or lactation stage have been reported to condition dairy linear or type appraisal-related traits (Manfredi et al. 2001). Hence, these age components, often recorded for does at appraisal, are considered as elements that permit to adjust models for the outputs of linear or type appraisal records (Wiggans and Hubbard 2001).

Pearson product-moment correlation coefficient between lactation order and age in years was 0.705 ($P < 0.01$). Such a correlation very likely stems from the fact that the older the doe becomes, the higher the number of lactations that it goes through is as well, and the further the order of these lactations reaches as well, hence a certain redundancy could be presumed for the outputs of linear or type appraisal in case both age components were considered simultaneously. For this reason, the lactation order was considered and results for primiparous and multiparous goats were broken down in the present study.

**Symmetry analysis: normality, skewness and kurtosis**

Murciano-Granadina goat breed zoometric historical records collected until December 2019 were tested for common parametric assumptions. Kolmogórov-Smirnov and Levene tests were used to evaluate normality and homoscedasticity, respectively using SPSS Statistics for Windows statistical software, Version 25.0.

Skewness and Kurtosis evaluation has been suggested as an efficient method to model the asymmetry and tail-fatness of population distribution curves.

As reported by Pizarro et al. (2020), data that are skewed to the right have a long tail that extends to the right, which is a positive skewness statistic value. In this situation, the mean and the median are both greater than the mode. As a general rule, most of the time for data skewed to the right, the mean will be greater than the median. The situation reverses itself when we deal with data skewed to the left. Data that are skewed to the left have a long tail that extends to the left, which is negatively skewed. In this situation, the mean and the median are both less than the mode. As a general rule, most of the time for data skewed to the left, the mean will be less than the median.

With respect to Skewness, if skewness is less than $-1$ or greater than $+1$, the distribution is highly skewed. If skewness is between $-1$ and $-1/2$ or between $+1/2$ and $+1$, the distribution is moderately skewed. If skewness is between $-1/2$ and $+1/2$, the distribution is approximately symmetric.

Parallelly, a normal distribution has kurtosis exactly 3 (excess kurtosis exactly 0). Any distribution with kurtosis $\approx 3$ (excess $\approx 0$) is called mesokurtic. A distribution with kurtosis $< 3$ (excess kurtosis $< 0$) is called platykurtic. A distribution with kurtosis $> 3$ (excess kurtosis $> 0$) is called leptokurtic.

**Results and discussion**

**Symmetry analysis: normality, skewness and kurtosis**

The values for skewness statistics ranged from $-1/2$ to $1/2$, which evidenced the symmetry of the profile of the curve described by the distribution of the data for all the variables evaluated (Table 2). According to the evaluation of kurtosis, the variable of movements or motility was the only one approaching a normal distribution naturally and describing a mesokurtic profile (kurtosis $\approx 3$ (excess $\approx 0$)). Most of the variables presented a distribution with kurtosis $< 3$ (excess kurtosis $< 0$) or platykurtic with low and broad central peaks and short thin tails. Exceptionally, a distribution with kurtosis $> 3$ (excess kurtosis $> 0$) or leptokurtic was reported for motility of movements in bucks. Compared to a normal distribution, the central peak of the curve profile is higher and sharper, and its tails are longer and fatter (Table 2).

**Structure and capacity**

Age plays a major role in animals’ stature (or height at withers) (Ariff et al. 2010). Stature strongly depends on
Table 1. A detailed description of the scales used and the translation process from zoometric traits to Linear appraisal system (LAS) scores in Murciano-Granadina does and bucks.

| Gender/Status       | Major area       | Linear trait                  | Zoometric scale/ categorical scale | Zoometric optimum scoring | Reference/ Middle point | LAS extrapolation | LAS optimum scoring |
|---------------------|------------------|-------------------------------|------------------------------------|---------------------------|-------------------------|---------------------|---------------------|
| Primiparous/        | Structure and    | Stature (height to withers)   | 62–78 cm                           | 72 cm (primiparous) and 74 cm (multiparous) | 5 (70 cm)              | 1–9 points          | 6 (primiparous) and 7 (multiparous) |
| Multiparous does    | capacity         | Chest width                   | 15–23 cm                           | 20 cm (primiparous) and 21 cm (multiparous) | 5 (19 cm)              | 1–9 points          | 6 (primiparous) and 7 (multiparous) |
|                     |                  | Body depth                    | Shallow-Extremely deep             | Intermediate              | 5 (elbow end matches rib depth) | 1–9 points          | 7 (primiparous and multiparous) |
| Dairy structure     |                  | Rump width                    | 13–21 cm                           | 18 cm (primiparous) and 19 cm (multiparous) | 5 (17 cm)              | 1–9 points          | 6 (primiparous) and 7 (multiparous) |
| Mammary system      |                  | Rump angle                    | 55°–31°                            | 31°                        | 5 (43°)                 | 1–9 points          | 9                   |
| Leg aplomb          |                  | Angulosity                    | Angulous extremity                 | Angulous extremity         | 5 (intermediate)        | 1–9 points          | 9                   |
|                     |                  | Bone quality                  | Round and rough bones-flat         | Flat and neat bones        | 5 (intermediate)        | 1–9 points          | 9                   |
|                     |                  | Anterior insertion            | Weak-Strong                        | 120°                       | 5 (90°)                | 1–9 points          | 9                   |
|                     |                  | Rear insertion height         | 11–3 cm                            | 3 cm                       | 5 (7 cm)               | 1–9 points          | 9                   |
|                     |                  | Median suspensor ligament     | 1–9 cm                             | 5 cm                       | 5 (5 cm)               | 1–9 points          | 5                   |
|                     |                  | Udder width                   | 3–11 cm                            | 11 cm                      | 5 (7 cm)               | 1–9 points          | 9                   |
|                     |                  | Udder depth                   | –10–10 cm                          | –5 cm (5 cm over hock level) and 0 cm (udder bottom at hock level) | 5 (7 cm)               | 1–9 points          | 9                   |
|                     |                  | Nipple placement              | 90°–0°                             | 0°                         | 5 (45°)                | 1–9 points          | 9                   |
|                     |                  | Nipple diameter               | 0.5°–4.5°                          | 2 cm                       | 5 (2.5 cm)             | 1–9 points          | 4                   |
|                     |                  | Rear legs rear view           | Very close-parallel and separated   | Parallel and separated     | 5 (slightly close)     | 1–9 points          | 9                   |
|                     |                  | Rear legs side view           | Straight-very curved               | Desirable curvature. A short distance from an imaginary line to anterior curvature of hock | 5 (desirable curvature) | 1–9 points          | 5                   |
|                     |                  | Mobility                      | Very bad mobility due to skeleton structure-long and strong, straight and uniform stride | Good mobility. Easy and harmonic movement | 5 (moderate mobility) | 1–9 points          | 9                   |
| Bucks               | Structure and    | Stature (height to withers)   | 68–92 cm                           | 83 cm (young) and 86 cm (adult) | 5 (80 cm)              | 1–9 points          | 6 (young) and 7 (adult) |
| capacity            |                  | Chest width                   | 15–31 cm                           | 25 cm (young) and 27 cm (adult) | 5 (23 cm)              | 1–9 points          | 6 (young) and 7 (adult) |
|                     |                  | Body depth                    | Shallow-Extremely deep             | Intermediate              | 5 (elbow end matches rib depth) | 1–9 points          | 7 (young and adult) |
|                     |                  | Rump width                    | 14–22 cm                           | 19 cm (young) and 20 cm (adult) | 5 (18 cm)              | 1–9 points          | 6 (young) and 7 (adult) |
| Dairy structure     |                  | Rump angle                    | 55–31°                             | 31°                        | 5 (43°)                 | 1–9 points          | 9                   |
|                     |                  | Angulosity                    | Angulous extremity                 | Angulous extremity         | 5 (intermediate)        | 1–9 points          | 9                   |
|                     |                  | Bone quality                  | Round and rough bones-flat         | Flat and neat bones        | 5 (intermediate)        | 1–9 points          | 9                   |
|                     |                  | Rear legs rear view           | Very close-parallel and separated   | Parallel and separated     | 5 (slightly close)     | 1–9 points          | 9                   |

(continued)
the conditions of the place where animals inhabit (Vacca et al. 2014; Zeleke and Melese 2017; Radhika et al. 2018). This involves fodder access, orography or climatological conditions (Hassen et al. 2012), which promotes the existence of ecotypes within the species. For instance, taller goats (of over 92 cm) more heavily rely \( (P < 0.01) \) on shrubs than short goats during the rainy season (Mellado et al. 2004).

Although Murciano-Granadina primiparous and multiparous statures are standardised (Figure S1), a separate method for young and older bucks has not traditionally been implemented. In males, a maximum value of 9 (92 cm) is highly representative of those animals evaluated when the farm where they locate enrolls CAPRIGAN selection nuclei. By contrast, young bucks are evaluated when they are 1 year old on average hence, their middle reference value is set around 4 (77 cm) instead of 5 (80 cm). Consequently, a classification that discriminates between young (up to two years old) and older males (from two years old on) is proposed, for which the optimal stature is 6 (83 cm) and 7 (86 cm), respectively. To achieve this goal of a reference value of 5 (80 cm), the solution would be to evaluate bucks no sooner than 18 months of age.

A strong misrepresentation of animals below 71 cm and over 92 cm has historically occurred. Hence, the scale must be readjusted to capture the variability of animals measuring over 92 cm (to the right of the graph in Figure S1) or below 71 (to the left of the graph in Figure S1). For older bucks, the integration of the lowest level of the scale (1 for animals measuring 68 cm tall) into the following level in ascending order (2, animals of 71 cm) into a new 1 category (animals below 71 cm tall) is recommended as the lowest end of the curve tends to disappear in favour of higher categories (Figure S1). As a result, the new scale proposed may add upper categories from 92 cm (9) on for older bucks (at least two to represent animals being 93 and 94 cm tall). Similarly, the aforementioned category addition may be encouraged in young bucks as these are evolving towards growing taller. Indeed, such a trend may derive from the increased adaptability of the Murciano-Granadina breed when compared to other highly selected breeds for which LAS international scales were originally designed. The lack of fit of international LAS correspondence has promoted a traditional abnormal agglomeration of taller animals at the upper ends of the curve once both male groups have been separated, thus the inability of international scales to capture all the present variability in the Murciano-Granadina buck population (Figure S1).
The population is still far from the reference middle value of 5 in primiparous goats (3) but approaching it in multiparous goats, older and young bucks (4). However, values still need to progress to reach the optimum (6/7, for primiparous and multiparous does and bucks, respectively). Anyway, a change in the optimum is not recommended given the aforementioned increase in the number of levels in the scale may already be able to capture those individuals presenting statures higher than 92 cm.

The same findings were reported for chest width (Figure S2). The maximum value of 9 (31 cm) gathers all the bucks, evaluated for the first time when their farm joins the selective nuclei. Young bucks are evaluated at an average age of one-year-old, which decreases the reference middle value from 5 (23 cm) to 4 (21 cm). For these reasons, a single scale per each buck category (young and older) is proposed. The same optimum and reference middle values are suggested at 6 (25 cm) and 7 (27 cm), respectively for the older buck category (over 2 years old), albeit the practice of evaluation of young bucks is recommended not to be developed until these are 18 months old in order to maintain the reference middle value at 5 (23 cm). Additionally, a minimum value of 1 (≤21 cm) is proposed while the right end of the scale should be extended to two new points (10 and 11), which may correspond with individuals measuring 33 and 35 cm, respectively, given the scale did not represent the variability found in the population, with Murciano-Granadina bucks being wider at the chest than bucks from selected breeds for which the former international LAS was initially developed. Archana et al. (2018) and Dea et al. (2019) reported wider and
deeper chests significantly ($P < 0.05$) decrease heat stress, given they confer higher ventilatory and breathing abilities to goats, thus the characteristically higher extreme-temperature adaptability of Murciano-Granadina bucks to (Delgado et al. 2017).

The body depth scale appropriately captures the variability in the population (Figure S3). However, there is a misrepresentation of individuals in lower categories which becomes more patent in bucks than in does. For these reasons, 2 points and 1 point scale reductions are recommended, respectively. Contextually, body depth and width positively correlate with weight in migratory goats (Patbandha et al. 2018), with shallower (but not too shallow) bodies being preferable (traditionally 6 for primiparous does and bucks and 7 for multiparous does, turning into 6 and 5, respectively in the new scale proposal). Still, reference value stands a point below the aforementioned for each of the scales (either traditionally or in the new scale proposal), which may be a sign of the progress of selective practices, as animals slightly depart from the aims that are sought after.

Contrastingly, as suggested by Homeyer (2007), in selected breeds such as Boers goats, cylindrical or too shallow body depths translate into weaker chests and sharper curves below the shoulder which are prone to evolve into chest painful conditions. Parallelly, such individuals normally present thinner legs, slightly concave backs, weaker buttocks and occasionally, pointed muzzles (evolving into jaw overbite) which indirectly conditions the capability of individuals to manage food resources and adapt to the orographic conditions found in harsh environments.

Rump width (Figure S4) appropriately fits a normal curve with a large number of animals being ranked at optimum values in the scale whether it is for males or females. However, selection has promoted the lack of representative animals at the lower levels of the scale (1 and 2). For these reasons, a reduction to a 5-point scale, in the case of bucks, and to a 7-point scale, it does, with a middle reference value being set in 5 (17 cm) is proposed.

The still patent representativity of lower values in the traditional scale in the population conditions the setting of optimum values at 6 (18 cm) and 7 (19 cm) for primiparous and multiparous does, and at 3 (19 cm) and 4 (20 cm) in bucks of any age. Despite the findings by Nardone et al. (2006) suggest a significant reduction in hip width may occur in Holstein Friesian calves subjected to thermal stress compared to calves kept under thermo-neutral conditions, our results suggest this may not analogously occur in goats. This is supported by the findings by Pragna et al. (2018), who suggested thermal stress does not significantly condition hip width in Osmanabadi, Malabari, and Salem Black Indian locally adapted breeds. Many researchers have reported the particular morphology (among other physiological aspects) of goats helps them coping with the challenges offered by the environment across the different ecosystem possibilities. Their compact body size not only allows them to more efficiently escape from the high radiant heat load (using thermally buffered microclimates), but also provides them with a lower absolute requirement for energy, water, and home range which in turn, enhances their ability to cope with seasonal biotopes characterised by feed and water shortage periods (Araújo et al. 2010; Fuller et al. 2016).

A similar patent lack of representativity of the individuals at both ends of the distribution (scale) was described for rump angle (Figure S5). Rump angle must be measured on animals while standing, compelling the assistance of an additional operator which makes its recording difficult. Such a lack of representative individuals is especially relevant in the upper end of the traditional scale (animals that reach the optimum value of 9 (31°)). The lack of representative individuals in the lower levels of the scale (wider angles) calls for a 3 point/2 point reduction in the scale used for males/females, which translates into a 6-point and a 7-point scale, respectively. Rump angle correlates with lifetime productivity (milk and kid production). For instance, goats approaching level rump angles were significantly 1.68 times more likely ($P < 0.01$) to have larger litters, compared with goats with extremely sloped rump angles (1.48 vs 1.37) (Mellado et al. 2008) and less slopped rump angles have been found to be associated with an increase possibility of multiple births in does (Haldar et al. 2014), which may somehow explain the genetic correlation that exists with teat location traits, as certain teat locations may translate into a rather accessible udder.

Dairy structure

Angulosity (Figure S6) is strongly conditioned by goats’ body score condition and weight (Fernández Álvarez et al. 2020), which makes its scoring on live animals difficult. As a result, not only does the definition of appropriate categories (primiparous and multiparous), become especially relevant, but also setting the most appropriate moment during lactation when body condition is not suffering sharp increases or decreases to perform zoometric measurements. This is
especially important in rustic, hardy, and well-adapted breeds such as Murciano-Granadina, for which strong capacities to recover body reserves and maintain body condition after scarcity periods have been described (by increasing their feed intake upon forages of low nutritional value) (Kharrat and Bocquier 2010).

Bucks and does fit the traditional scale correspondence for angularity well, although the addition of a new level (10) may be recommended in the case of multiparous does. The middle reference value is set at 5 (90°) in primiparous goats and in 6 (97.5°) in multiparous goats, respectively. The most frequent values reported for angularity whether it is primiparous, multiparous or bucks up to and over 2 years are in the range of those reported for other adapted breeds who tiparous or bucks up to and over 2 years are in the range of those reported for other adapted breeds who tiparous goats, respectively. The most frequent values evaluated given its strong relationship with age (osteo-ramus in elderly does (Siu et al. 2004)) and the hormonal changes especially occurring in does (Yu et al. 2015).

Murciano-Granadina characterises intermediate to flat and neat bones with round and rough bones being rarely seen in either does or bucks. There is a lack of representative individuals of the lower levels in the bone quality scale (<5, traditional scale). Buck bone quality scale top is a little lower than that found in females as suggested by the lack of representativity of the 9th level in the traditional scale. Does’ bone quality is high (>5, traditional scale) and limedly variable, which may derive from the need in females for better quality bone due to its implication with the calcium fraction in dairy production. As a result, the reduction of the scale used for females from a 9-point scale to a 5-point scale, starting from the former 5 (1 in the new scale) is recommended. Parallely, the scale used for males should also be reduced from 9 to 5 points although the top level may be placed at the former 8 (5 in the new scale) instead of the former 9 traditionally used which was not present in the population (Figure S7). This means four lower levels may be discarded from the traditional scale used in either multiparous or primiparous goats, while three lower levels and the top upper level of the scale should not be considered for bucks, respectively. Bone quality should be carefully evaluated given its strong relationship with age (osteoporosis in elderly does (Siu et al. 2004)) and the hormonal changes especially occurring in does (Yu et al. 2015).

Legs and aplomb

Rear legs rear view (Figure S8) is a highly selected (lowly variable) trait as it can be inferred from the lack of individuals at the lower end of the scale, which would correspond to cow-hocked or very cow-hocked does and bucks. This flaw can be easily recognisable from a very early age and may determine the early discard of individuals. As a result, a reduction to a 7 and 6 points scale is suggested for does and bucks, respectively. In these regards, the middle reference value should be changed to 5 and 4 for does (either primiparous or multiparous) and bucks, respectively, marking and slightly cow-hocked animal, while the values of 7 and 6 may depict an animal in which although rear extremities are parallel, hocks separate. A slightly sloping rump and very slight cow- or sickle hocks have been deemed characteristic of some goat breeds such as Indigenous Veld Goats given its implication with better aid towards giving birth (Du Pisanie 2019). These distribution patterns are replicated by the rear legs side view (Figure S9), with a clear displacement of the curve to the left, either it does or bucks, with a great representativity of individuals located at lower levels in the scale (2, 3 and 4). Such a finding denotes the characteristic trend of Murciano-Granadina individuals to present upright aplomb rather than sickled ones, which indeed may reflect the aforementioned flaws detected from rear legs’ rear view (Figure S8).

With the aim to reach a better fit of the scale correspondence in the population, a reduction of 3 points in the scale is proposed for both sexes, even if the optimum and middle reference values (which coincide) are maintained at 5. As suggested by Khan (2016), for Nachi local breed, post-legged and sickle-hocked kids evolve into poor moving, ill-structured goats. Given early bowlegged or cow-hocked animals evolve into worse-legged animals with age, potential bucks should be selected carefully so that there is as much space as possible between hocks. Potentially, forelimb side and frontal views may be relevantly considered, which are currently disregarded. In these regards, as suggested by Khan (2016), forelimbs should be set smoothly against the chest wall and withers. Forelimbs should be straight with some curving allowed (front view), which was reported for rear limbs in Murciano-Granadina goats as well. The knees on the forelegs should also be smooth and in direct line with the front legs. From knee downwards, strong pasterns and small symmetrical and size-proportioned front hooves are preferred.

The gait scoring systems commonly used in dairy goats base on 4-point scales (5 at most) that focus on detecting and judging the severity of a definite limp (Deeming et al. 2018), through the identification of
severe flaws, which may reduce the length of productive life of the animals. This becomes especially relevant in breeds for whom gaits or movements are economically important such as the Nachi breed (Khan 2016).

The present scoring system applied in Murciano-Granadina goats ranks the animals across 9 levels. However, the variability within the Murciano-Granadina breed may not be as wide as to be supported on such a broad scale, given serious aplomb ab/adduction or short stride-related defects are rarely present (Figure S11). This translates into traditional scale <5 levels being strongly misrepresented, which encourages the reduction to a 5 point scale as suggested by Deeming et al. (2018). The middle reference value of 3 (former 7) represents a straight and uniform step with long but not strong strides. According to Vilensky (1987), long stride lengths, generally linked to distally heavy limbs (Raichlen 2006), are advantageous as they reinforce forward push when the animal is moving, promoting body mass centre vertical displacement, thus increasing external power (Raichlen 2006).

Lameness and abnormalities of gait may result from neurological disease, conformational defects, muscular dysfunction, skeletal trauma, infectious and non-infectious arthritis, and diseases of the foot (Smith and Sherman 2009). Even if the role of movements in the Murciano-Granadina goat is rather functional than aesthetical, an uneven gait, such as a shortened stride or not tracking up, is arguably the precursor to the development of a limp; thus, identifying such changes in gait could provide an opportunity for early diagnosis and treatment. The acknowledged genetic basis for the regulation of the expression of this trait and the correlation with other functional traits such as lifelong productivity makes it a priority in breeding schemes for dairy goats (Tariba et al. 2017).

**Mammary system (in does)**

Figure S11 shows primiparous goats present improved anterior insertions when compared to multiparous goats, with values approaching the theoretical optimum of nine points (Fernández Álvarez et al. 2020). However, the traditional International LAS (Sánchez Rodríguez et al. 2012), does not represent the individuals in the population, with a patent lack of representation of individuals within the categories below 4 (below 60°) and over 8 (over 120°). This may derive from the traditional incorrect application of a scale that was extrapolated from highly selected breeds that did not present the morphotype of Murciano-Granadina goats, but which also lack their improved adaptability to harsh environmental conditions (Delgado et al. 2017). A 5-point scale with 15 degrees interlevel interval is proposed, with 1 being the minimum and corresponding to 60°, a maximum of 5 (120°) and a reference median value of 3 (90°), respectively.

Selection for rear insertion height is evidenced by the trend of values towards the theoretical optimum of nine points (more patent in primiparous than multiparous does) (Figure S12). Again, the traditional LAS (Sánchez Rodríguez et al. 2012), was not representative of the individuals in the population, with a patent lack of representation of individuals within the categories below 4 (over 8 cm) and over 8 (over below 4 cm), which again suggest the inappropriate extrapolation of a scale developed to score highly selected breeds which did not ascribe to Murciano-Granadina goats morphotype and lacked their improved adaptability to harsh environmental conditions (Delgado et al. 2017). In these regards, a reduction of the scale from 9 to 5 points is proposed setting a reference median value of 3 (6 cm), respectively. Although inter-breed differences have been reported, Castañeda-Bustos et al. (2017) reported that conformation and udder-related traits are breeding criteria to consider when aiming at increasing lifetime productivity without compromising the fitness of the animals (Luigi-Sierra et al. 2020). Indeed, such differences across native breeds may derive from attempts of the animals to adapt to the orographic conditions of the area in which they are reared, with extremes ranging from small and poorly attached udders to high, baggy udders of the narrow base. This finding may suggest that the relationship between udder height and attachment is not linear which may be ascribed to the distribution properties of the international LAS scale correspondence used to score anterior insertion and rear insertion height, respectively (Milerski et al. 2011), which did not fit Murciano-Granadina reality.

The evaluation of the distribution curve of median suspensor ligament suggests (Figure S13) that the current reference middle value of the population is 3 (3 cm) instead of 5 (% cm), which is the optimal level to attain according to the traditionally applied scale. A patent broad margin for selection is denoted given the optimal level of 5 cm is not likely to be found in the current population. As a result, the new scale proposal consists of reducing the current 9-point scale to a 6-point scale with a minimum of 1 cm and a maximum of over 6 cm, a middle reference value of 3 cm and an optimal value of 5 cm. An indirect increase in
longevity is possible by selecting goats with extreme scores for udder fore attachment and suspensory ligament (Castañeda-Bustos et al. 2017). Median suspensor ligament strength has been indirectly measured via udder cleft or the depth of the intermammary groove (Novotna et al. 2018).

Even more reduced scales (5-point scales) have been reported for other goat breeds such as the Czech White Shorthaired goat or Bilà Kratkosrsta Koza (a cross between native Czech landrace goats crossed with Swiss Saanen goats between 1900 and 1930 (Rychtarova et al. 2017)), with 3 being the most frequently found category as reported by our results (Novotna et al. 2018). The genetic relationship between median suspensor ligament and somatic cells count has frequently been reported in the literature (Rychtarova et al. 2017), due to the important economic repercussions of increased levels of somatic cells counts derived from milk yield losses, changes in milk composition and their effects on cheese-making aptitude (Rychtarova et al. 2017).

Udder width (Figure S14), is strongly related to rear udder attachment (UA) and evaluates the degree of agreement between the width and how well the udder fills the space between hind legs as suggested by Novotna et al. (2018). These authors suggested using a 5-point scale. Selection signs for udder width are evident given the most frequent value of 9 (11 cm) is easily found in the population, which was also reported as the optimum in the traditional international scale applied. In these regards, the reference middle value changed from 5 points (7 cm) to 9 points (11 cm), which defines a wider or better-inserted udder. The new proposal suggests changing the scale from 9 to 5 points, with values ranging from ≤7 cm to ≥12 cm, respectively and a reference medium (optimal) value of 11 cm (traditionally 9, but currently 3).

A double peak curve is detected in multiparous does when udder depth was evaluated (Figure S15). This double peak may derive from the fact that individuals who have given birth twice are considered within the same category as those who gave birth to more than two, thus are evaluated at older ages, when their farm started implementing the LAS methodology. Elder animals present deeper udders (5, 7.5 and 10 cm). Consequently, optimisation for udder depth proposes to retain the scale used, but either consider age as a correction factor or determine additional scales to score animals at different breeding statuses. Anyway, an appropriate selection response of this trait can be inferred as denoted by the high number of primiparous individuals reporting optimal values of −5 cm, with individuals presenting hanging udders/a greater depth with values over 0 being anecdotal. The optimal value for multiparous animals is 0, which also concentrates the highest frequency of multiparous animals with the independence of their age. This is of particular relevance, given udder depth has been significantly reported to influence somatic cell counts, as opposed to other traits in which variability conditions the impossibility to determine the existence of a significant linear relationship (Novotna et al. 2018).

The evaluation of nipple placement and diameter (Figures S16 and S17) suggests selection response follows a favourable trend toward the former optimal value of 0° (9 in the traditional international scale and 6 in the current scale), which becomes even more patent in primiparous animals nipple placement, with nipple diameter being correctly represented by the traditionally used scale. Such a selective positive trend is still in progress as optimal value representatives are still very unlikely in the population. Additionally, there is a misrepresentation of animals presenting a nipple placement equal or over 56.25° which does not reflect a change in the distribution of nipple diameter. Hence, our finding suggests continuing directing selective efforts towards reaching the optimal standards of 0° (6 in the new scale and 9 in the former traditional international scale), reducing the scale from 9 to 6 points at an 11.25° interval, setting a minimum value of 0° and a maximum value of 56.25°, with 33.75° (3 in the scale) being the middle reference value, respectively, and maintaining the optimal nipple diameter at 4 cm.

Conclusions

The analysis of the symmetry on the distribution curve of linear appraisal traits reveals the international scales which have traditionally been used do not fit the distribution of data found in the population of Murciano-Granadina does and bucks. In-deed, it is the early signs of selection for these traits, in the context of a locally adapted breed to harsh conditions and orography which defines the zoometric profile of a breed. Murciano-Granadina has drifted towards better dairy-linked conformation traits but without losing the grounds of the zoometric basis which confers it with enhanced adaptability to the environment. The particular analysis of each variable permits determining specific strategies for each trait and serve as a model for other breeds, either selected or in terms of selection. Among the strategies proposed are the re-
duction/readjustment of the levels in the scale as it happens for limb-related traits, the extension of the scale as it occurs in the stature of males, or the subdivision of the scale used in males into two categories, bucks younger than two years and bucks of two years old and older, respectively can help to achieve a better understanding of the momentum of selection for dairy-linked zoometric traits in Murciano-Granadina population and their future evolution to enhance the profitability and efficiency of breeding plans.

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Ethical approval

The study followed the premises described in the Declaration of Helsinki. The Spanish Ministry of Economy and Competitiveness through the Royal Decree-Law 53/2013 and its credited entity the Ethics Committee of Animal Experimentation from the University of Córdoba permitted the application of the protocols present in this study as cited in the fifth section of its second article, as the animals assessed were used for credited zootechnical use. This national Decree follows the European Union Directive 2010/63/UE, from the 22nd of September 2010. Furthermore, the present study works with records rather than live animals directly, and these records were obtained after minimal handling, hence no special permission was compulsory.

Disclosure statement

The authors declare no conflict of interest.

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Data availability statement

Data will be made available from the corresponding author F.J.N.G. upon reasonable request.

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