TESIS DOCTORAL

Facultad de Veterinaria

Universidad de Córdoba, España

PARÁMETROS GENÉTICOS DE LOS CARACTERES MORFOLÓGICOS LINEALES DE LA RAZA CAPRINA MURCIANO-GRANADINA Y SUS RELACIONES CON OTROS CARACTERES FUNCIONALES

Genetic Parameters of Zoometric/Linear Appraisal Traits in Murciano-Granadina Goat Breed and their Relationship with other Functional Traits

Javier Fernández Álvarez

Directores Juan Vicente Delgado Bermejo, Francisco Javier Navas González, José Manuel León Jurado

TITULO: *Genetic Parameters of Zoometric/Linear Appraisal Traits in Murciano-Granadina Goat Breed and their Relationship with other Functional Traits*

AUTOR: *Javier Fernández Álvarez*

© Edita: UCOPress. 2023
Campus de Rabanales
Ctra. Nacional IV, Km. 396 A
14071 Córdoba

https://www.uco.es/ucopress/index.php/es/
ucopress@uco.es

FACULTAD DE VETERINARIA

DEPARTAMENTO DE GENÉTICA

PROGRAMA DE DOCTORADO EN RECURSOS NATURALES Y GESTIÓN SOSTENIBLE

PARÁMETROS GENÉTICOS DE LOS CARACTERES MORFOLÓGICOS LINEALES DE LA RAZA CAPRINA MURCIANO-GRANADINA Y SUS RELACIONES CON OTROS CARACTERES FUNCIONALES

Genetic parameters of Zoometric/Linear Appraisal Traits in Murciano-Granadina Goat Breed their Relationships with other Functional Traits

MEMORIA PARA OPTAR AL GRADO DE DOCTOR PRESENTADA POR

Javier Fernández Álvarez

BAJO LA DIRECCIÓN DE:

Juan Vicente Delgado Bermejo

Francisco Javier Navas González

José Manuel León Jurado

En Córdoba, a 30 de septiembre de 2022

TÍTULO DE LA TESIS: PARÁMETROS GENÉTICOS DE LOS CARACTERES MORFOLÓGICOS LINEALES DE LA RAZA CAPRINA MURCIANO-GRANADINA Y SUS RELACIONES CON OTROS CARACTERES FUNCIONALES

DOCTORANDO/A: JAVIER FERNÁNDEZ ÁLVAREZ

INFORME RAZONADO DEL/DE LOS DIRECTOR/ES DE LA TESIS

Don Juan Vicente Delgado Bermejo, catedrático del departamento de Genética de la Universidad de Córdoba, **Don José Manuel León Jurado,** funcionario de la Diputación de Córdoba y **Don Francisco Javier Navas González,** investigador postdoctoral del Instituto de Formación Agraria y Pesquera de Andalucía, como profesionales con experiencia en la formación de doctorado,

INFORMAN

Que el trabajo de tesis presentado por **D. Javier Fernández Álvarez**, titulado ***"Parámetros genéticos de los caracteres morfológicos lineales de la raza caprina Murciano-Granadina y sus relaciones con otros caracteres funcionales"*** ha sido realizado bajo nuestra dirección y cumple con los artículos 24 y 35 de la norma reguladora de los Estudios de Doctorado de la Universidad de Córdoba para su presentación como compendio de publicaciones, así como para obtener la mención industrial.

La tesis ha generado seis publicaciones, cuatro de ellas ya publicadas en revistas indexadas en la base de datos Journal Citation Reports y/o SCImago Journal Rank, y dos sometidas a revistas de igual categoría. Los avances de estos resultados se han presentado igualmente en diversos eventos internacionales en forma de dieciséis comunicaciones; seis en formato poster y diez comunicaciones orales, presentadas en conferencias internacionales y nacionales.

Asimismo, el doctorando no ha olvidado la transferencia al sector de sus resultados, aplicándolos directamente sobre el Programa de Cría de la raza caprina Murciano-Granadina.

Con todo lo expuesto, hacemos constar nuestro unánime sobre la madurez de la tesis y del candidato para proceder a su defensa.

Por todo ello, se autoriza la presentación de la tesis doctoral.

Córdoba, 25 de octubre de 2022

Firma de los directores

Fdo.: Juan Vicente Delgado Bermejo

Fdo.: José Manuel León Jurado

Fdo.: Francisco Javier Navas González

Agradecimientos

Podría decirse que esta tesis no viene a mí según lo “académicamente” establecido, es decir, tras terminar la carrera y el máster correspondiente para mejorar mi CV y poder optar a un trabajo en la universidad o en alguna entidad pública de investigación. En mi caso, fue el desempeño profesional de mi carrera como Ingeniero Agrónomo, el que me llevó un día a pisar el despacho de Juan Vicente Delgado allá por 2010 estando él como Genetista y yo como Secretario Ejecutivo del Caballo Hispano-árabe en la Unión Española de Ganaderos de Pura Raza Hispano-arabe (UEGHá). Desde el principio Juanvi, que es como llamamos a Juan Vicente sus amigos, me desmontó de un plumazo la idea preconcebida del profesor, director de departamento y después catedrático de Universidad. Su humanidad, humildad y carisma me llevaron a entender que las personas valen más por estos atributos que por su expediente, y que trabajando se puede llegar a donde uno quiera. Y así fue, trabajando, como me llegó la oportunidad de poder desempeñar el puesto de Secretario Ejecutivo en la Asociación de Criadores de Caprino de Raza Murciano-Granadina (Caprigran), una de las cinco razas más importantes y con más historia de España. Siempre le agradeceré ser mi mentor en al ámbito profesional y el precursor de esta tesis que hoy ve la luz, sin olvidarme de Esperanza, su mujer, quien acogió a mi familia y a mí como un miembro de la suya.

Y es así, pasando de los 40 años, casado, con dos hijas y en pleno desarrollo profesional en Caprigran como me encaminé a realizar mi Tesis, formando un triángulo en ocasiones imposible que me ha venido acompañando todo este tiempo. Y hablando de ayuda, en esta etapa han sido fundamentales todos los miembros del Grupo AGR218 que desde el principio se pusieron a mi disposición para ayudarme en todo lo necesario. Destacar la labor de José Manuel León como precursor de los primeros estudios de valoraciones genéticas de la Raza Murciano-Granadina y pieza fundamental del grupo en esta materia, así como de Francisco Javier Navas, investigador nato y trabajador incansable que ha sido clave en la publicación de los artículos necesarios para estructurar esta tesis. Eres un número uno y estoy seguro de que lo mejor está por venir.

A mis compañeros de profesión Sergio Nogales y Antonio González, gracias por compartir vuestros trabajos y experiencias de vuestras tesis en otras Razas

Autóctonas increíbles como la raza equina y vacuna Marismeña y la Gallina Utrerana, que me han sido de gran ayuda.

Agradecer a Carlos Iglesias por esas magníficas ilustraciones de la ficha de calificación de la Raza Murciano-Granadina, diecisiete regiones corporales que nos han permitido plasmar de forma clara el significado de cada una de ellas.

Cecilio y Amparo, gracias porque, aunque no hablemos a diario, sé que puedo contar con vosotros para todo. Muchas gracias por vuestro apoyo.

A todos los Criadores de la Asociación Nacional de Criadores de Caprino de Raza Murciano-Granadina, ganaderos que sois ejemplo de saber hacer en el mundo y de dignidad para que nadie vuelva a decir aquella frase de que “si no sirves para estudiar te metas a cabrero”, son ignorantes “con papeles”. Agradecer especialmente a su Presidente, José Javier Rodríguez Fernández, por ser fiel ejemplo de los valores de ganadero de cabras y enseñarme sus conocimientos en la morfología y funcionalidad de la Raza. También a mis compañeros de trabajo Emilio, Manolo, Ana Belén, Maripi y Saskia por hacer con su trabajo a esta Asociación más grande cada día. Sois el mayor capital que esta Asociación podría tener. Agradecer especialmente al gran Antonio Martín, nuestro calificador, maestro y compañero de trabajo con más de 50.000 cabras Murciano-Granadinas calificadas a sus espaldas, él es el alma y el precursor imprescindible de este humilde trabajo. Gracias.

A MI FAMILIA, por el sitio que ellos han ocupado, ocupan y ocuparan en mi vida. Una de las primeras bases de genética dice que el Fenotipo (lo que somos) es igual al Genotipo (nuestros genes heredados) más el Ambiente (todo aquello que nos rodea). Pues bien, todo lo que he plasmado en estos párrafos anteriores a significado el ambiente que me ha rodeado desde que ingresé allás por el año 1996 en la maravillosa Escuela Técnica Superior de Ingenieros Agrónomos y Montes (ETSIAM) de la Universidad de Córdoba hasta nuestros días y que evidentemente ha tenido un papel fundamental para conformar lo que soy (fenotipo). Ahora quiero agradecer a toda mi familia el haberme trasmitido sus genes para tener la mejor mochila a la que recurrir cuando el ambiente se complica, y hay que trascurrir por veredas angostas para seguir el camino que nos hemos marcado.

A mis abuelas y abuelos, Natividad y Esperanza, Javier y Antonio “El Cabrero” respectivamente a quienes tengo la satisfacción de haber podido devolverles una

parte de todos sus sacrificios para sacar adelante a sus hij@s en una época de guerra y hambre con carencias de todo menos de dignidad y de valores para manteneros en pié. Hoy más que nunca estáis en mis pensamientos. ¡Lo hemos conseguido!.

A mis Ti@s, prim@s, y resto de la familia, muchas gracias por todo el cariño y el amor que me demostráis a diario. Aunque dicen que la familia es la que toca, yo os volvería a elegir un millón de veces.

A mi hermano Juan Luís, por reinventarte cada día y tu capacidad para afrontar nuevos retos, ahora le llaman “resiliencia”. Eres un ejemplo para todos y un espejo para tus hij@s.

A mis padres Juan y Maravillas, como responsables de todo, de la genética y del ambiente. Gracias por dejarme soñar grande y acompañarme en este sueño. Espero que os sintáis tan orgullosos de mí como yo lo estoy de vosotros. ¡Infinitas gracias!

A mi esposa Gertru y a mis hijas Alejandra y Alba por ser la mejor excusa para ser mejor cada día. Sois primavera para todos los que estamos a vuestro alrededor. Gracias por acompañarme en este camino y dejarme acompañarte en el tuyo, porque este es solo un éxito más de todos los vividos y de los que nos quedan por vivir juntos.

A las cabras y a los cabreros por su contribución a la humanidad y hacer de este mundo un sitio más agradable para vivir

“Muchas personas dicen que el intelecto es lo que hace a un gran científico. Se equivocan, es el carácter.”

Albert Einstein

Index

Tesis Doctoral como

Compendio de Publicaciones

- Primera publicación:
  - Título: Applicability of an international linear appraisal system in Murciano-Granadina breed: fitting, zoometry correspondence inconsistencies, and improving strategies
  - Autores (por orden de firma): ***Javier Fernández Álvarez***, *J. M. León Jurado, F. J. Navas González, C. Iglesias Pastrana and J. V. Delgado Bermejo.*
  - Revista (año, volumen, paginación): *Italian Journal of Animal Science*. *Submitted on 4 July, 2022.*
  - Base de Datos Internaticional o Nacional en las que está indexada: *Journal of Citation Reports (JCR), 2021 datos año previo. Datos para 2022 no publicados.*
  - Área temática en la Base de Datos de referencia: *Veterinary Sciences.*
  - Índice de impacto de la revista en el año de publicación del artículo: *2.552.*
  - Lugar que ocupa/Nº de revistas del Área temática: *36/144 (Q1).*

- Segunda publicación:
  - Título: *Optimization and Validation of a Linear Appraisal Scoring System for Milk Production-Linked Zoometric Traits in Murciano-Granadina Dairy Goats and Bucks*
  - Autores (por orden de firma): ***Javier Fernández Álvarez,*** *J. M. León Jurado, F. J. Navas González, C. Iglesias Pastrana and J. V. Delgado Bermejo.*
  - Revista (año, volumen, paginación): *Applied Sciences. Submitted on 9 August, 2020.*
  - Base de Datos Internaticional o Nacional en las que está indexada: *Journal of Citation Reports (JCR), 2020 datos año previo. Datos para 2022 no publicados.*
  - Área temática en la Base de Datos de referencia: *Engineering, multidisciplinary.*
  - Índice de impacto de la revista en el año de publicación del artículo: *2.679.*
  - Lugar que ocupa/Nº de revistas del Área temática: *38/90 (Q2).*

- Tercera publicación:
  - Título: *CAPRIGRAN Linear Appraisal Evidences Dairy Selection Signs in Murciano-Granadina Goats and Bucks: Presentation of the New Linear Appraisal Scale*
  - Autores (por orden de firma): ***Javier Fernández Álvarez***, *J. M. León Jurado, F. J. Navas González, C. Iglesias Pastrana and J. V. Delgado Bermejo.*
  - Revista (año, volumen, paginación): *Archivos de Zootecnia 2021, 70 (271), 240-245.*
  - Base de Datos Internaticional o Nacional en las que está indexada: Scopus*, 2021.*

  - Área temática en la Base de Datos de referencia: *Agricultural and Biological Sciences/Animal Science and Zoology.*
  - Índice de impacto de la revista en el año de publicación del artículo: *0,8*
  - Lugar que ocupa/Nº de revistas del Área temática: *268/342 (Q4).*

- Cuarta publicación:
  - Título: *A decade of progress of linear appraisal traits heritabilities in Murciano-Granadina goats*
  - Autores (por orden de firma): ***Javier Fernández Álvarez****, J. M. León Jurado, F. J. Navas González, C. Iglesias Pastrana and J. V. Delgado Bermejo*
  - Revista (año, volumen, paginación): *Archivos de Zootecnia 2021, 70 (272), 352-356*
  - Base de Datos Internaticional o Nacional en las que está indexada: Scopus*, 2021*
  - Área temática en la Base de Datos de referencia: *Agricultural and Biological Sciences/Animal Science and Zoology.*
  - Índice de impacto de la revista en el año de publicación del artículo: *0,8*
  - Lugar que ocupa/Nº de revistas del Área temática: *268/342 (Q4)*

- Quinta publicación:
  - Título: *Analysis of the genetic parameters for dairy linear appraisal and zoometric traits: A tool to enhance the applicability of Murciano-Granadina goats major areas evaluation system*
  - Autores (por orden de firma): ***Javier Fernández Álvarez****, F. J. Navas González, J. M. León Jurado, C. Iglesias Pastrana y J.V. Delgado Bermejo*
  - Revista (año, volumen, paginación): *Animals. Submitted on 16th October, 2022*
  - Base de Datos Internaticional o Nacional en las que está indexada: *Journal of Citation Reports (JCR), 2021 datos año previo. Datos para 2022 no publicados*
  - Área temática en la Base de Datos de referencia: *Agriculture, Dairy and Animal Science*
  - Índice de impacto de la revista en el año de publicación del artículo: *3.231*
  - Lugar que ocupa/Nº de revistas del Área temática: 13/62 *(Q1)*

- Sexta publicación:
  - Título: *Linear appraisal/zoometric breeding values discriminant analysis on casein haplotypes and haplogroups*
  - Autores (por orden de firma): ***Javier Fernández Álvarez,*** *F. J. Navas González, J. M. León Jurado, A. González Ariza, M.A. Martínez Martínez, C. Iglesias Pastrana, M. G. Pizarro Inostroza and J. V. Delgado Bermejo*

- Revista (año, volumen, paginación): *Journal of Dairy Science (TBA)*
- Base de Datos Internaticional o Nacional en las que está indexada: *Journal of Citation Reports (JCR), 2021 datos año previo. Datos para 2022 no publicados.*
- Área temática en la Base de Datos de referencia: *Agriculture, Dairy and Animal Science.*
- Índice de impacto de la revista en el año de publicación del artículo: *4.225.*
- Lugar que ocupa/Nº de revistas del Área temática: *6/62 (D1/Q1).*

Producción Científica

Otras aportaciones científicas derivadas directamente de la Tesis Doctoral:

- Otras publicaciones Indexadas en el JCR:
    - María Gracia Luigi-Sierra, Almudena Fernández, Amparo Martínez, Dailu Guan, Juan Vicente Delgado, **Fernández Álvarez, J.**, Vincenzo Landi, Francesc Xavier Such, Jordi Jordana, María Saura & Marcel Amills (2022). Genomic patterns of homozygosity and inbreeding depression in Murciano-Granadina goats. Journal of Animal Science and Biotechnology, 13(1), 1-14.
    - Pizarro Inostroza, M. G., Landi, V., Navas González, F. J., León Jurado, J. M., Delgado Bermejo, J. V., **Fernández Álvarez, J.,** & Martínez Martínez, M. D. A. (2020). Integrating casein complex SNPs additive, dominance and epistatic effects on genetic parameters and breeding values estimation for murciano-granadina goat milk yield and components. Genes, 11(3), 309.
    - Morales-Jerrett, E., Mena, Y., Camúñez-Ruiz, J. A., **Fernández Álvarez, J.**, & Mancilla-Leytón, J. M. (2022). Characterization of dairy goat production systems using autochthonous breeds in Andalusia (Southern Spain). Classification and efficiency comparative analysis. *Small Ruminant Research*, p. 106743.
    - Pardo, G., del Prado, A., **Fernández-Álvarez, J.,** Yáñez-Ruiz, D. R., & Belanche, A. (2022). Influence of precision livestock farming on the environmental performance of intensive dairy goat farms. *Journal of Cleaner Production*, *351*, 131518.
    - Luigi-Sierra, M. G., Casellas, J., Martínez, A., Vicente Delgado, J.V., **Fernandez Alvarez, J.,** Such, F. X., ... & Amills, M. (2021). Markers with low GenTrain scores can generate spurious signals in genome-wide scans for transmission ratio distortion. *Animal Genetics*, *52*(5), 779-781.
    - D. Guan,A. Martínez,M. G. Luigi-Sierra,J. V. Delgado,V. Landi,A. Castelló, **Fernández Álvarez, J.**, X. Such,J. Jordana,M. Amills (2021). Detecting the footprint of selection on the genomes of Murciano-Granadina goats. *Animal Genetics*, *52*(5), 683-693.

- María Gracia Luigi-Sierra, Joaquim Casellas, Amparo Martínez, Juan Vicente Delgado, **Fernández Álvarez,J.**, Francesc
  Xavier Such, Jordi Jordana, Marcel Amills (2021). Impact of SNP calling quality on the detection of transmission ratio distortion in goats. *bioRxiv*.
- Dailu Guan, Vincenzo Landi, María Gracia Luigi-Sierra, Juan Vicente Delgado, Xavier Such, Anna Castelló, Betlem Cabrera, Emilio Mármol-Sánchez, **Fernández Alvarez, J.**, José Luis Ruiz de la Torre Casañas, Amparo Martínez, Jordi Jordana & Marcel Amills (2020). Analyzing the genomic and transcriptomic architecture of milk traits in Murciano-Granadina goats. *Journal of animal science and biotechnology*, *11*(1), 1-19.
- Pizarro Inostroza, M. G., Landi, V., Navas González, F. J., León Jurado, J. M., Delgado Bermejo, J. V., **Fernández Álvarez, J.**, & Martínez Martínez, M. D. A. (2020). Integrating casein complex SNPs additive, dominance and epistatic effects on genetic parameters and breeding values estimation for murciano-granadina goat milk yield and components. *Genes*, *11*(3), 309.
- Maria Gracia Luigi-Sierra, Vincenzo Landi, Dailu Guan, Juan Vicente Delgado, Anna Castelló, Betlem Cabrera, Emilio Mármol-Sánchez, **Fernández Alvarez, J.**, Mayra Gómez-Carpio, Amparo Martínez, Xavier Such, Jordi Jordana, Marcel Amills (2020). A genome-wide association analysis for body, udder, and leg conformation traits recorded in Murciano-Granadina goats. Journal of dairy science, 103(12), 11605-11617.
- Pizarro, M. G., Landi, V., Navas, F. J., León, J. M., Martínez, A., **Fernández Álvarez, J.**, & Delgado, J. V. (2020). Non-parametric analysis of the effects of nongenetic factors on milk yield, fat, protein, lactose, dry matter content and somatic cell count in Murciano-Granadina goats. *Italian Journal of Animal Science*, *19*(1), 960-973.
- Delgado Bermejo, J. V., Limón Pérez, F. A., Navas González, F. J., León Jurado, J. M., **Fernández Álvarez, J.**, & Telo da Gama, L. (2020). Conditioning factors of linearized wood's function lactation curve

shape parameters, milk yield, fat and protein content in Murciano-Granadina primiparous does. *Animals*, *10*(11), 2115.

- Inostroza, M. G. P., González, F. J. N., Landi, V., Jurado, J. M. L., Bermejo, J. V. D., **Fernández Álvarez, J.**, & Martínez Martínez, M. D. A. (2020). Bayesian Analysis of the Association between Casein Complex Haplotype Variants and Milk Yield, Composition, and Curve Shape Parameters in Murciano-Granadina Goats. *Animals*, *10*(10), 1845.
- Pizarro Inostroza, M. G., Navas González, F. J., Landi, V., León Jurado, J. M., Delgado Bermejo, J. V., **Fernández Álvarez, J.**, & Martínez Martínez, M. D. A. (2020). Goat milk nutritional quality software-automatized individual curve model fitting, shape parameters calculation and Bayesian flexibility criteria comparison. *Animals*, *10*(9), 1693.
- Pizarro Inostroza, M. G., Navas González, F. J., Landi, V., León Jurado, J. M., Delgado Bermejo, J. V., **Fernández Álvarez, J.**, & Martínez Martínez, M. D. A. (2020). Software-automatized individual lactation model fitting, peak and persistence and Bayesian criteria comparison for milk yield genetic studies in Murciano-Granadina goats. *Mathematics*, *8*(9), 1505.
- Pizarro Inostroza, M. G., Landi, V., Navas González, F. J., León Jurado, J. M., Martínez Martínez, M. D. A., **Fernández Álvarez, J.,** & Delgado Bermejo, J. V. (2020). Non-parametric association analysis of additive and dominance effects of casein complex SNPs on milk content and quality in Murciano-Granadina goats. *Journal of Animal Breeding and Genetics*, *137*(4), 407-422.
- Pizarro Inostroza, M. G., Landi, V., Navas González, F. J., León Jurado, J. M., Martínez Martínez, A., **Fernández Álvarez, J.**, & Delgado Bermejo, J. V. (2019). Does the acknowledgement of αS1-casein genotype affect the estimation of genetic parameters and prediction of breeding values for milk yield and composition quality-related traits in Murciano-Granadina?. *Animals*, *9*(9), 679.
- Belanche, A., Martín-García, A. I., **Fernández-Álvarez, J.**, Pleguezuelos, J., Mantecón, Á. R., & Yáñez-Ruiz, D. R. (2019).

Optimizing management of dairy goat farms through individual animal data interpretation: A case study of smart farming in Spain. *Agricultural Systems*, *173*, 27-38.

- Libros:
  - Juan Vicente Delgado, Vincenzo Landi, Cecilio José Barba, **Fernández Álvarez, J.**, Mayra Mercedes Gómez, María Esperanza Camacho, María Amparo Martínez, Francisco Javier Navas & José Manuel León. 12 January 2018. Sustainable Goat Production in Adverse Environments: Volume II pp 205–219. Chapter: "Murciano-Granadina Goat: A Spanish Local Breed Ready for the Challenges of the Twenty-First Century" pp. 205-219.
  - Alejandro Belanche y **Javier Fernández Álvarez**. January 2022. Monografía Sostenibilidad en la Producción Ganadera pp 209-224. Capítulo 12: "La ganadería de precisión como estrategia para mejorar la productividad y sostenibilidad en el caprino lechero".
  - Alejandro Belanche, **Javier Fernández-Álvarez** and D.R. Yáñez-Ruiz. September 2022. Practical Precision Livestock Farming. Chapter 5: "RUMIA platform: a success story of PLF to optimize management of dairy goat farms" pp. 85-102.
- Trabajos bibliográficos y de divulgación:
  - Revista Tierras:
    - "Mejora Genética en Caprino: Caprigran". **J. Fernández Álvarez**. 2022
    - "Exportación de Razas Autóctonas Caprinas". **J. Fernández Álvarez**. 2021
    - "Implementación de un sistema de asesoramiento para la gestión sostenible del caprino andaluz: resultados del Grupo Operativo y retos.". Y. Mena[1]; E. Morales-Jerrett[1]; J.M. Mancilla-Leyton[1]; **J. Fernández[2]**; O. González[2]; C. Lara[2]; M.D. López[2]; S. Rey[2]; F. López; C. Díaz[3]; 2020

- "Cabrandalucía, 15 años de éxito como Federación Andaluza de Asociaciones de Ganado Caprino de Raza Pura". **J. Fernández Álvarez**. 2020
- I CURSO INTERNACIONAL DE LA RAZA MURCIANO-GRANADINA. CAPRIGRAN. **J. Fernández Álvarez**. 2019
- "El sector caprino de leche en Andalucía: diversidad de sistemas, razas y manejo. Y. Mena1; E. Morales-Jerrett1; **J. Fernández2**; O. González2; C. Lara2; M.D. López2. 2019
- "El futuro del modelo de producción del caprino en España". J. **Fernández Álvarez**. 2019
- "Estudio edad al primer parto en caprino de leche". **J. Fernández Álvarez**. 2019
- "Estudio producciones vitalícias en caprino de leche". **J. Fernández Álvarez.** 2019
- "Primer semestre de actividades del Grupo Operativo AMALTEA: Gestión Caprina Sostenible". E. Morales-Jerrett (1); S. Muñoz-Vallés (1); **J. Fernández (3)**; JM. Mancilla-Leytón (2); Y. Mena (1). 2018

- Ponencias invitadas:
    - "Programa de Mejora Genética de la Raza Murciano-Granadina". **J. Fernández Álvarez**. SEPOR 2017, 6-9 de noviembre de 2017, Lorca (Murcia).
    - "Breeding Pogram of Murciano-Granadina Goats Breed". **J. Fernández Álvarez**. IRANPLEX, 5-7 de Diciembre de 2017. Teherán (Irán)
    - "Programa de Mejora Genética de la Raza Murciano-Granadina**". J. Fernández Álvarez**. Curso de Formación de la Asociación de Criadores de la Raza Assaf, 17 de diciembre de 2017, Valladolid.
    - "El futuro de los Programas de Cría de las Asociaciones de Caprino de Razas Puras". **J. Fernández Álvarez**. Jornadas CABRAMA, 5-6 de septiembre de 2018. CEULAJ de Mollina (Málaga).

- "Evolución del Programa de Mejora Genética de la Raza Murciano-Granadina". **J. Fernández Álvarez**. FIAPE, 3 de abril de 2019, Estremoz (Portugal).
- "Implementación de un Sistema de Asesoramiento para la Gestión Sostenible del Caprino Andaluz". **J. Fernández Álvarez**, Y. Mena Guerrero. Intercambio de experiencias entre Grupos Operativos y Proyectos Innovadores. Red Rural Nacional (MAPA), 18 de noviembre de 2020. On-line.

- Contribuciones a congresos:
  a. Comunicaciones orales:
     - "Breeding Program of Murciano-Granadina Goats Breed". **J. Fernández Álvarez**. College of Animal Science and Tecnology, Northwest A&F University, 10-12 de octubre de 2017, Quian Xian, Shaanxi (China).
     - "La Mejora Genética desde las Cooperativas". **J. Fernández Álvarez**. Seminario de Mejora Genética en Pequeños Rumiantes, ICIA, 18 de abril de 2017, La Laguna-Tenerife-I. Canarias.
     - "Eskardillo: a platform based on individual animal data collection to improve decision making in dairy goats farms". **J. Fernández Álvarez**. FAO CIHEAM, Proyecto ISAGE, 3-4 de octubre de 2017, Vitoria-Gasteiz.
     - "Programa de Mejora Genética de la Raza Murciano-Granadina". **J. Fernández Álvarez**. Congreso Nordestino de Producción Animal (CNPA), 17 de Noviembre de 2018, Joao Pessoa (Brasil).
     - "Control de Rendimientos en la Raza Murciano-Granadina: Control Lechero y Calificación Morfológica Lineal". J. Fernández Álvarez. I Curso Internacional de la Raza Murciano-Granadina, IFAPA Camino de Purchil, 8-12 de Abril de 2019. Granada.
     - "Control Lechero Oficial en la Especie Caprina". J. Fernández Álvarez. Situación y perspectivas de futuro del control del rendimiento lechero

en España. Ministerio de Agricultura, Pesca y Alimentación (MAPA), 20 de noviembre de 2019. Madrid

- "Utilización de una herramienta ("Eskardillo") para optimizar la gestión de explotaciones de caprino lechero: Influencia en la huella de carbono". Guillermo Pardo (BC3), Agustín del Prado (BC3), **J. Fernández Álvarez** (CABRANDALUCÍA), David R. Yáñez-Ruiz (CSIC), Alejandro Belanche (CSIC). VIII Remedia Workshop, 22-23 sseptiembre de 2020, Elche.
- "Importancia de las bases de datos en la gestión de Explotaciones Ganaderas: Modelo de gestión de la Asociación Nacional de Criadores de Caprino de la Raza Murciano-Granadina''. **J. Fernández Álvarez**. Curso Internacional en Sistemas de Producción Caprinos. Universidad Nacional Autónoma de México, 3 de septiembre de 2021, On-line.
- "Porgrama de Mejora Genética de la Raza Murciano-Granadina". **J. Fernández Álvarez**. II CONCAPRI, 18 de noviembre de 2021. Brasil. On-line
- "Valorización e Internacionalización de la Raza Autóctona Caprina Murciano-Granadina". **J. Fernández Álvarez**. 6º Foro Ganadero CONBIAND, 22 de noviembre de 2021. On line
- "La Cabra Murciano-Granadina, una raza autóctona española frente a los desafíos del siglo XXI". **J. Fernández Álvarez**. SIRGEAC, 3 de Diciembre de 2021, Colombia. On-line

b. Posters:

- Benhamou-Prat A, Morales-Jerrett E, Mena Y, Lara C, **Fernández J**, Sánchez O, López MD, Carrasco F, Mancilla-Leytón JM, Martín Collado D. 2022. "Fortaleciendo la Resilencia de los Sistemas Ganaderos de pequeños rumiantes de razas locales: De la Covid-19 al cambio global (RUMIRES). El caso del capino lechero andaluz". XII Foro Nacional de Caprino celebrado en Aracena (Huelva) los días 30 de junio y 1 de julio de 2022
- Morales-Jerrett, E.; Mena Guerrero, Y.; Mancilla-Leytón, J.M.; Camúñez, J.A.; Lara, C.; **Fernández, J.**; Sánchez, O.; López, M.D. Análisis

de la eficiencia "Análisis de la eficiencia de los diferentes sistemas de producción de caprino de leche en Andalucía". XII Foro Nacional de Caprino celebrado en Aracena (Huelva) los días 30 de junio y 1 de julio de 2022.

- Peláez, M.P., Navas-González, F.J., **Fernández-Álvarez, J.**, Herrera, J. , Delgado, J.V., Delgado, M., Fernández, S., León, J.M., Arando, A. "Análisis no paramétrico de los factores que condicionan la fertilidad en cabras de la raza Murciano-Granadina". XII Foro Nacional de Caprino celebrado en Aracena (Huelva) los días 30 de junio y 1 de julio de 2022.
- Delgado J.V., León J.M., Gómez M.M.¸ **Fernández J.**, "Test de Normalidad realizado sobre caracteres morfológicos en caprino lechero de raza Murciano-Granadina"**.** XVII Simposio iberoamericano sobre conservación y utilización de recursos zoogenéticos. Argentina 2016. Red CONBIAND – Facultad de Ciencias Veterinarias de la UNNE. ISBN: 978-987-3619-12-0
- Delgado J.V., León J.M., Gómez M.M.¸ **Fernández J.**, "Cálculo de las tendencias genéticas para producción de leche y componentes en caprino Murciano-Granadino"**.** XVII Simposio iberoamericano sobre conservación y utilización de recursos zoogenéticos. Argentina 2016. Red CONBIAND – Facultad de Ciencias Veterinarias de la UNNE. ISBN: 978-987-3619-12-0
- José Manuel León Jurado*, **Fernández J.**, Amparo Martínez, Mayra Gómez, Jorge Castillo, Esperanza Camacho y Juan Vicente Delgado. "Convergencia Acrimur/Caprigran para el desarrollo de un programa genético nacional de la raza Murciano-Granadina". VII Foro Nacional Caprino celebrado en Ronda (Málaga) el 30 de junio y 1 de julio de 2016.

Summary

Linear appraisal systems (LAS) are effective strategies for systematically collecting zoometric information from animal populations. Traditionally applied LAS in goats was developed considering the variability and scales found in highly selected breeds. Implementing LAS may reduce time, personnel, and resource needs when performing zoometric large-scale collection. Moreover, selection for zoometrics defines individuals' productive longevity, endurance, enhanced productive abilities, and consequently, long-term profitability. 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.

In the first study, an evaluation of the distribution and symmetry properties of twenty-eight zoometric traits was developed. 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. Thus, 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.

The aim of the second study was to propose a method to optimize and validate LAS in opposition to traditional measuring protocols routinely implemented in Murciano-Granadina goats. The data sample consisted of 41323 LAS and traditional measuring records, belonging to 22727 herdbook registered primipara does, 17111 multipara does, and 1485 bucks. Each record comprised information on 17 linear traits for primipara and multipara does, and 10 traits for bucks. All zoometric parameters were scored on a 9-points scale. Cronbach's alpha values suggested a high internal consistency of the optimized variable panel. Model fit, variability explanation power, and predictive power (MSE, AIC/AICc, and BIC, respectively) suggested a model comprising zoometric LAS scores performed better than traditional zoometry. Optimization procedures result in reduced models able to capture variability for dairy-related zoometric traits without noticeable detrimental effects on model validity properties.

The third study aimed to perform a particular analysis of each variable that permits determining specific strategies for each trait and serves as a model for other breeds. Among the strategies proposed are the reduction/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. Murciano-Granadina goat breed 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. Hence, such strategies 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.

The objective of the fourth study was to evaluate the progress of heritabilities of the traits comprising the linear appraisal system in the Murciano-Granadina breed during the complete decade from December 2011 to December 2021. The estimated values for heritability were obtained from multivariate analyzes using the BLUP methodology and MTDFREML software. For 2021 heritabilities, a simple animal model was applied to records collected from 22727 primiparous goats and 17111 multiparous goats belonging to 85 herds. The model included the linear and quadratic and linear components of the covariates age and days in milk, respectively. The fixed effects considered in the model were herd, reproductive status, calving month, and herd/year interaction. The animal was considered as a random effect. The variables studied included five characteristics related to structure and capacity, two traits related to dairy structure, six related to the mammary system, and three related to legs and feet. The heritabilities for structure and capacity characters progressed from 0.22 to 0.28 including non-convergent variables in June 2012 to values between 0.10 and 0.41 with all variables converging in June 2021. Heritabilities for dairy structure progressed from 0.18 with non-convergent variables in 2011 to 0.17 to 0.25 in 2021. Heritabilities for mammary system traits progressed from 0.12 to 0, 27 with non-convergent variables in 2012 to between 0.10 and 0.41 in 2021. For legs and feet, heritabilities progressed from 0.16 to 0.17 with non-convergent variables to 0.09 a 0.22. Genetic progress is not only evident in heritability values, but there has been a notable reduction in the standard error of heritabilities from 0.1000 (0.080-0.120) to 0.000 (0.000-0.001) from 2011 to 2021. These results provide evidence of the enhancement in the effectiveness and precision of the linear qualification system applied during the past decade and its successful integration into the breeding program of the Murciano-Granadina breed.

The fifth study estimates genetic and phenotypic parameters for zoometric/LAS traits in Murciano-Granadina goats, estimate genetic and phenotypic correlations among all traits, and to determine whether major area selection would be appropriate or if adaptability strategies may need to be followed. Heritability estimates for the zoometric/LAS traits were low to high, ranging from 0.09 to 0.43 and the accuracy of estimation has improved after decades rendering standard errors negligible. Scale inversion of specific traits may need to be performed before major areas selection strategies are implemented. Genetic and phenotypic correlations suggest that negative selection against thicker bones and higher rear insertion heights, indirectly results in the optimization of selection practices in the rest of the traits, especially of those in the structure and capacity and mammary system major areas. The integration and implementation of the strategies proposed within Murciano-Granadina breeding program maximize selection opportunities and the sustainable international competitiveness of the Murciano-Granadina goat in the dairy goat breed panorama.

The objective of the sixth study was to develop a discriminant canonical analysis (DCA) tool that permits outlining the role of the individual haplotypes of each component of the casein complex (αS1, β, αS2, and κ-casein) on zoometrics/linear appraisal breeding values. The relationship of the predicted breeding value for 17 zoometric/Linear appraisal traits and αS1, β, αS2, and κ-casein genes haplotypic sequences was assessed. Results suggest that, although a lack of significant differences ($P>0.05$) was reported across the predictive breeding values of zoometric/linear appraisal traits for αS1, αS2 and κ casein, significant differences were found for β Casein ($P<0.05$), respectively. The presence of β Casein haplotypic sequences GAGACCCC, GGAACCCC, GGAACCTC, GGAATCTC, GGGACCCC, GGGATCTC, and GGGGCCCC, linked to differential combinations of increased quantities of greater quality milk in terms of its composition, may also be connected to increased zoometric/linear appraisal predicted breeding values. Selection must be performed carefully, given the fact that the consideration of apparently desirable animals that present the haplotypic sequence GGGATCCC in the β Casein gene, due to their positive predicted breeding values for certain zoometric/linear appraisal traits such as rear insertion height, bone quality, anterior insertion, udder depth, rear legs side view and rear legs rear view may lead to an indirect selection against the rest of zoometric/linear appraisal traits and in turn lead to an inefficient selection towards an optimal dairy morphological type in Murciano-Granadina goats. Contrastingly, the consideration of animals presenting the GGAACCCC haplotypic sequence involves also considering animals which increase the genetic potential for all zoometric/linear appraisal traits, thus making them recommendable as breeding animals. The information derived from the present analyses will enhance the selection of breeding individuals seeking a rather desirable dairy type, through the determination of the haplotypic sequences that they present in the β Casein locus.

The aforementioned studies seek the obtention of deeper knowledge of the linear morphological characters of the Murciano-Granadina goat breed and their relationships with other functional characteristics. This lays the basis for strategies of standardization and improvement of the productive capacity and dairy morphotype of Murciano-Granadina goats and will help to reach its competitive consolidation in the international dairy goat panorama

Resumen

Los sistemas de evaluación lineal (SEL) son estrategias efectivas para recopilar sistemáticamente información zoométrica de las poblaciones animales. Los SEL han sido aplicados tradicionalmente en cabras y se desarrollaron teniendo en cuenta la variabilidad y las escalas encontradas en razas altamente seleccionadas. La implementación de SEL puede reducir las necesidades de tiempo, personal y recursos al realizar una recopilación zoométrica a gran escala. Además, la selección para la zoometría define la longevidad productiva, la resistencia, las capacidades productivas mejoradas de los individuos y, en consecuencia, la rentabilidad a largo plazo. Como resultado, es posible que los SEL tradicionales ya no cubran los diferentes contextos de las razas de cabras extendidas en todo el mundo, y las desviaciones de la normalidad pueden ser indicativas de las diferentes etapas de selección en las que se puede encontrar una determinada población.

En el primer estudio, se desarrolló una evaluación de las propiedades de distribución y simetría de veintiocho rasgos zoométricos. Después de realizar el análisis de simetría, la propuesta de reajuste de escala sugirió que se implementasen estrategias específicas, como la reducción de escala de los niveles inferiores o superiores, la determinación de un momento de configuración para evaluar y recopilar información de machos jóvenes (hasta 2 años) y adultos (más de 2 años), se realizó la adición de categorías superiores en los machos debido a que los valores superiores en la escala se agruparon incorrectamente. Así, el análisis particular de cada variable permite determinar estrategias específicas para cada rasgo y servir de modelo para otras razas, ya sea seleccionadas o en términos de selección.

El objetivo del segundo estudio fue proponer un método para optimizar y validar SEL frente a los protocolos de medición tradicionales implementados de forma rutinaria en cabras Murciano-Granadina. La muestra de datos consistió en 41323 registros SEL y de medición tradicional, pertenecientes a 22727 cabras primíparas registradas en el libro genealógico, 17111 cabras multíparas y 1485 machos cabríos. Cada registro comprendía información sobre 17 rasgos lineales para primíparas y multíparas, y 10 rasgos para machos. Todos los parámetros zoométricos se puntuaron en una escala de 9 puntos. Los valores alfa de Cronbach sugirieron una alta consistencia interna del panel de variables optimizado. El ajuste del modelo, el poder de explicación de la variabilidad y el poder predictivo (MSE, AIC/AICc y BIC, respectivamente) sugirieron un modelo que comprendía puntuaciones SEL zoométricas que funcionaron mejor que la zoometría tradicional. Los procedimientos de optimización dan como resultado modelos reducidos capaces de capturar la variabilidad de los rasgos zoométricos relacionados con los productos lácteos sin efectos perjudiciales notables en las propiedades de validez del modelo.

El tercer estudio tuvo como objetivo realizar un análisis particular de cada variable que permitió determinar estrategias específicas para cada rasgo y sirvió de modelo para otras razas. Entre las estrategias propuestas se encontraron la reducción/reajuste de los niveles en la escala como ocurrió con los rasgos relacionados con las extremidades, la ampliación de la escala como ocurrió en la estatura de los machos, o la subdivisión de la escala utilizada en los machos en dos categorías, machos menores de dos años y machos de dos años en adelante. La raza caprina Murciano-Granadina ha evolucionado hacia mejores rasgos morfológicos ligados a la producción láctea pero sin perder el fundamento de la base zoométrica que le confiere una mayor adaptabilidad al medio. Por lo tanto, dichas estrategias pueden ayudar a lograr una mejor comprensión del impulso de selección de caracteres zoométricos ligados a la producción en la esta población y su evolución futura para mejorar la rentabilidad y la eficiencia de los planes de mejora.

El cuarto estudio tuvo como objetivo evaluar la evolución de las heredabilidades de los caracteres que componen el sistema de valoración lineal en la raza Murciano-Granadina durante la década completa de diciembre de 2011 a diciembre de 2021. Los valores estimados de heredabilidad se obtuvieron a partir de análisis multivariante utilizando el Metodología BLUP y software MTDFREML. Para las heredabilidades de 2021, se aplicó un modelo animal simple a los registros recolectados de 22727 cabras primíparas y 17111 cabras multíparas pertenecientes a 85 rebaños. El modelo incluyó los componentes lineal y cuadrático y lineal de las covariables edad y días en leche, respectivamente. Los efectos fijos considerados en el modelo fueron rebaño, estado reproductivo, mes de parto e interacción rebaño/año. El animal fue considerado como un efecto aleatorio. Las variables estudiadas incluyeron cinco características relacionadas con la estructura y la capacidad, dos rasgos relacionados con la estructura lechera, seis relacionados con el sistema mamario y tres relacionados con patas y pies. Las heredabilidades para caracteres de estructura y capacidad progresaron de 0,22 a 0,28 incluyendo variables no convergentes en junio de 2012 a valores entre 0,10 y 0,41 con todas las variables convergentes en junio de 2021. Las heredabilidades para la estructura lechera progresaron de 0,18 con variables no convergentes en 2011 a 0,17 a 0,25 en 2021. Las heredabilidades para los rasgos del sistema mamario progresaron de 0,12 a 0,27 con variables no convergentes en 2012 a entre 0,10 y 0,41 en 2021. Para patas y pies, las heredabilidades progresaron de 0,16 a 0,17 con variables no convergentes a 0,09 un 0,22. El progreso genético no solo es evidente en los valores de heredabilidad, sino que ha habido una reducción notable en el error estándar de las heredabilidades de 0,1000 (0,080-0,120) a 0,000 (0,000-0,001) de 2011 a 2021. Estos resultados proporcionan evidencia de la mejora en la eficacia y precisión del sistema de calificación lineal aplicado durante la última década y su exitosa integración en el programa de cría de la raza Murciano-Granadina.

El quinto estudio estimó parámetros genéticos y fenotípicos para rasgos zoométricos/SEL en cabras Murciano-Granadina, estimó correlaciones genéticas y fenotípicas entre todos los rasgos, y determinó si la selección de áreas principales era apropiada o si era necesario seguir estrategias de adaptabilidad. Las estimaciones de heredabilidad para los rasgos zoométricos/SEL fueron de bajas a altas, con un rango de 0,09 a 0,43 y la precisión de la estimación mejoró después de décadas, lo que hizo que los errores estándar sean insignificantes. Es posible que fuese necesario realizar una inversión de escala de rasgos específicos antes de implementar las estrategias de selección de áreas principales. Las correlaciones genéticas y fenotípicas sugirieron que la selección negativa contra huesos más gruesos y alturas de inserción trasera más altas, indirectamente resultaron en la optimización de las prácticas de selección en el resto de los rasgos, especialmente en las áreas principales de estructura y capacidad y sistema mamario. La integración e implementación de las estrategias propuestas dentro del programa de cría murciano-granadina maximizan las oportunidades de selección y la competitividad internacional sostenible de la cabra murciano-granadina en el panorama de la raza caprina lechera.

El objetivo del sexto estudio fue desarrollar una herramienta de análisis canónico discriminante que permitió delinear el papel de los haplotipos individuales de cada componente del complejo de caseína (αS1, β, αS2 y κ-caseína) en los valores de cría de zoometría/calificación lineal. Se evaluó la relación del valor de cría predicho para 17 rasgos de zoometría/calificación lineal y las secuencias haplotípicas de los genes αS1, β, αS2 y κ-caseína. Los resultados sugieren que, aunque se reportó de una falta de diferencias significativas ($P>0,05$) en los valores de cría predichos de los rasgos de zoometría/calificación lineal para la αS1, αS2 y κ-caseína, se encontraron diferencias significativas para la β-caseína ($P<0,05$), respectivamente. La presencia de secuencias haplotípicas de β-caseína GAGACCCC, GGAACCCC, GGAACCTC, GGAATCTC, GGGACCCC, GGGATCTC y GGGGCCCC, vinculadas a combinaciones diferenciales de mayores cantidades de leche de mayor calidad en términos de su composición, también puede estar relacionada con una mayor valoración zoométrica/lineal de la predicción de los valores de cría. La selección debe realizarse con cuidado, dado que la consideración de animales aparentemente deseables que presentan la secuencia haplotípica GGGATCCC en el gen de la β-caseína, debido a sus valores genéticos predichos positivos para ciertos rasgos de zoometría/calificación lineal, como la altura de la inserción trasera, la calidad ósea , la inserción anterior, la profundidad de ubre, la vista lateral de patas traseras y la vista trasera de patas traseras pueden conducir a una selección indirecta frente al resto de rasgos de zoometría/calificación lineal y a su vez conducir a una selección ineficiente hacia un tipo morfotipo lechero óptimo en cabras Murciano-Granadina. Por el contrario, la consideración de animales que presentan la secuencia haplotípica GGAACCCC implica también considerar animales que aumentan el potencial genético para todos los rasgos de zoometría/calificación lineal, haciéndolos así recomendables como reproductores. La información derivada de los presentes análisis mejorará la selección de individuos reproductores que busquen un tipo lechero bastante deseable, a través de la determinación de las secuencias haplotípicas que presentan en el locus β-caseína.

Todos estos estudios persiguen la obtención de un conocimiento más profundo de los caracteres morfológicos lineales de la raza caprina Murciano-Granadina y sus relaciones con otras características funcionales. Esto sienta las bases para estrategias de normalización y mejora de la capacidad productiva y el morfotipo lechero de la cabra Murciano-Granadina y ayudará a alcanzar su consolidación competitiva en el panorama caprino lechero internacional.

Introduction

Goat farming now extends to almost all the countries around the world, due to the competitive prices and the high nutritional value of products (especially milk) derived from this species, which attracts new investment companies and farmers [1].

Developing countries account for the largest fraction of the world goat census due to the great adaptability potential of the species to marginal territories, and its ability to thrive under adverse climatic conditions and within low-tech farming systems [2].

Such a scenario contrasts with that of Europe and North American countries, where highly developed and intensive conditions rule the goat industry. This defines a highly focused milk production industry supported by the exploitation of high-yielding breeds genetically managed under the scope of breeding schemes [3].

Still, the development of the areas of genetics, nutrition, and animal management in the goat is rather limited compared to the level of integration and technification that these methods reach in other ruminant species [4].

Thus, morphology is a pivotal indicator of livestock health and value, whether it is for breeding, function, or production [5]. 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 [6] and in turn, the long-term profitability of these animals [7].

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 [8]. This score is usually normalized to 100 points and is evaluated by highly qualified and experienced personnel, whose objective judgment 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 [9]. In these contexts, zoometry jumps from focusing 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.

The American Dairy Goat Association published the first Linear Appraisal System (LAS) for dairy goats. LAS appeared in the scene as an attempt to search for more predictive and objective methods to link zoometry and productivity in 1993. The benefits deriving from the application of LAS comprise the evaluation of moderately heritable zoometric traits which hold a significant relationship with productive traits. This evaluation is performed on each animal and uniformly across the population, using scales able to capture the variability between observed biological extremes in economically important traits.

Combined Caprine Index (ICC) [10] and Morphological Index began to be applied in French dairy breeds in 1999. Since these very first attempts, many breeds (Alpine, Lamancha, Nigerian Dwarf, Nubian, Oberhasli, Saanen, Sable, or Toggenburg) have implemented LAS. In the most representative cases, the number of linear appraisals performed increased by up to 3,828.40% during the period ranging from 2005 to 2019 [11].

The National Association of Breeders of Murciano-Granadina goat breed (CAPRIGRAN) routinely performs the numerical description of 17 zoometric linear traits on a 1 to 9-point scale. Such scale is used to represent the biological range for each particular trait that exists in the current population. Then, these linear trait data, plus a final score for each animal are used to develop individual reports for does and bucks. The importance of the system is denoted by the fact that LAS observations have reached a number of almost 400,000 in the past 5 years [12]. Moreover, the efficiency of implementation of CAPRIGRAN LAS has been maximized through the integration of the association within "Cabrandalucía", the Andalusian Federation of Purebred Goat Associations, set up on February 24th, 2005 as an initiative to share the projects that, until that moment, each association of goat breeders in Andalusia had implemented.

Contextually, although CAPRIGRAN LAS [13] has a strong basis on ADGA and USDA's LAS, it is relatively new, as its application only dates back to 2010. Murciano-Granadina goat linear appraisals increased by 16.05% from 2018 to 2019. After a decade of progress, the most remarkable international achievement obtained by Murciano-Granadina breed may relate to the fact that figures have multiplied by more than ten the most promising results reported by other breeds. For instance, the Nigerian Dwarf Goat breed, which had experienced the greatest increase in the number of linear appraisals up to the date, with 3182 new linear appraisals performed in 2019 [11].

A few years ago, CAPRIGRAN performed routine LAS through a team of raters who used PDA and “Escardillo” technical-economic management software to collect individual ratings [14]. Raters evaluated each animal across four structural areas (structure and capacity, dairy conformation, mammary system, and legs aplomb). The degree of resemblance of the measure observed on each individual to the optimal standard measure for Murciano-Granadina dairy goats depended on the scores provided for each zoometric variable. Then, the scores of the variables comprising each major area were summed and multiplied by a coefficient. This coefficient depended on the preestablished relevance of each major area to define the dairy morphotype and breed standard. However, Cabrandalucía Federation has recently implemented the concept of smart farming relying on a PLF platform (Web-App RUMIA). Web-App RUMIA incorporates PLF-like principles based on the integration of individual animal data to optimize decision-making through a smartphone-based terminal and substitutes the previous “Escardillo” software used by CAPRIGRAN [9]. The improvements achieved in the collection of zoometric/LAS information rely on the axioma which lays the basis for the Web-App RUMIA platform, that is the systematic remote on-farm individual data recording and acquisition, storage processing, and interpretation by a supercomputer placed at Cabrandalucía headquarters, and provides interactive feedback of processed data to the farmer for farm management tasks optimization [15].

Selection, either natural or artificial, is well known to imply the reduction in variability for the target trait it intends to select for [16]. However, selection may also strongly condition the fitness of a population, with this being understood as the capacity of 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 stabilizing selection [17].

Stabilizing selection occurs naturally, but in this case, it is replicated by artificial selection. Stabilizing selection favors individuals with phenotypes close to an optimum value (i.e. if these phenotypes have higher fitness in a natural selection or if they are linked to desirable levels of expression of an economically important trait in artificial selection) and penalizes those individuals which are far from it [18,19]. In these regards, Johnson [20] proved that stabilizing 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 normalizes.

According to Xiao *et al.* [21], the normal distribution of quantitative traits occurs as an intermediate consequence of the interaction between group equal assortment of genes and 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, 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 most visual consequences is the normalization of the population. However, selection must not be regarded as a static process. For instance, the centrifugal effect of 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 [22]. In this context, the analysis of normality and the deviations from it may provide insights in 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 which depart the non-normal distribution are often found, especially in non-selected populations [23]. Many authors have ascribed this lack of normality to the fact that populations comprise individuals at a different life moment being evaluated altogether [24], 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, age, among others) [25].

In light of the aforementioned, current selection practices for functional and biometric rely trait normalization around an optimum as their theoretical basis. In this regard, the opposition of the population distribution curve shape against the bilateral symmetry-based pose normalization framework applied to livestock has been suggested to be an effective tool to evaluate selection efficiency [5].

On the other hand, for breeding, structure and capacity, dairy conformation, mammary system, and legs aplomb areas are multiplied by 25 percent, 15 percent, 40 percent, and 20 percent, respectively. For breeding bucks and goats which have not given birth yet, the areas to be scored are reduced to structure and capacity, dairy conformation and legs aplomb, and their relative scores are multiplied by 50, 20, and 30 percent, respectively. Then the final score may sum up to 100 points depending on the relative scores for each of the areas obtained by each animal.

Afterward, points are translated into a verdict as follows; Insufficient (IN) when a certain animal sums up from 60 to 69 points, Mediocre (R) from 70 to 74 points, Good (B) from 75 to 79 points, Pretty Good (BB) from 80 to 84, Very Good (MB) from 85 to 89 points, or Excellent (EX) 90 points or above [26]. Then, the final score relative to each major category of each animal is used by raters to compute each animal's final score to provide individualized reports per animal to the owner of each herd. Afterward, final records are registered in the computerized record and used to rank sires and dams in official catalogues. Finally, all the information is made public using codes for each animal to accomplish Data Protection Policies.

Provided the need to ensure the applicability of LAS at a large scale, CAPRIGRAN LAS simplification was one of the first priority challenges to address when applying on-farm protocols in goats [27]. At this point, statistical optimization and validation became crucial practices to perform to ensure the capacity and reliability of LAS to describe the ranges for zoometric measures found in the population. Contextually, Principal Component Analysis (PCA) has been widely applied as a method to discard potentially redundant or confounding zoometric traits [28,29], which can maximize the predictive power of linear appraisal scales efficiently.

Once large variable sets have been reduced preserving the greatest fraction of variance possible, scales must still be tested. Scale testing aims at determining whether the results reported by linear appraisal techniques are comparable to those reported by traditional zoometric assessment. The comparison of both methods enables the calculation of an index of the degree to which an artificially built scale can depict zoometric patterns in a population. For this purpose, regression analysis and canonical correlation analysis between LAS and traditional zoometric scales can help to determine their greater or lesser resemblance.

After LAS validation, its application in the context of breeding for the most desirable zoometric patterns may enable the obtention of a maximized productive objective. Furthermore, large-scale LAS may grant access to large amounts of very valuable readily available information for breeders. This information may enhance selection potentialities through the improvement of selection accuracy of breeding stock or when making decisions about purchases, as relatively quick diagnoses about the quality of certain animals and their specific suitability for dairy production can be issued in the context of the breeds' morphological panorama. These methods may also be implemented at a lower time and resource cost, as assessors may progressively become acquainted with the spectrum of possible levels and thresholds, more easily identifying the value of new animals in comparison with the optimal levels described in the breed's standard.

Another of the challenges starts as if a metric character is determined by an effectively infinite number of loci, selection cannot cause any permanent change in the genetic variance but will cause a temporary change which is rapidly reversed when selection ceases. This is due entirely to the correlation between pairs of loci induced by selection. When the correlation is negative it may lead to a reduction in the genetic variance under stabilizing or directional selection. However, when it is positive, it may lead to an increase in the variance under disruptive selection [30]. Such a term is also a synonym for diversifying selection, which describes changes in population genetics in which extreme values for a trait are favoured over intermediate values. Hence, the variance of the trait increases and the population is divided into two distinct groups where more individuals acquire peripheral character value at both ends of the distribution curve [31].

When selection ceases, the correlation rapidly disappears as joint equilibrium at pairs of loci is reestablished, and the variance returns to its original value. An expression is derived for the predicted amount of change in the genetic variance due to disequilibrium in the absence of linkage. The change is likely to be small under selection intensities found under natural conditions, but it may be appreciable under intense artificial selection. This limiting result shows that the magnitude of any permanent change in the variance due to selection must decrease as the number of loci involved increases and that, when the number of loci is large, it is likely to be much less than the temporary change due to disequilibrium.

In these regards, the ideal morphotype would be equivalent to that structure on which the greatest dairy potential of a breed would be based. What we do is compare the morphology of a specific animal with the ideal dairy morphotype [32].

The early signs of selection for these traits, in the context of a locally adapted breed to harsh conditions and orography define 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 an enhanced adaptability to the environment [12,33].

Even if data registration and the integration of the linear morphological appraisal system in the dairy goat improvement genetic program of Murciano-Granadina breed had started two years ealier [10], the genetic background of linear appraisal traits of Murciano-Granadina goats would not be preliminarily approached until 2011, with the first evaluation of genetic parameters and breeding values [34].

Still the system was strongly subjetive in nature and as recently revealed, may not represent the variability found within the population of the Murciano-Granadina breed. As a consequence, CAPRIGRAN and the AGR218 PAIDI reasearch group from the University of Córdoba set up a project with the aim to evaluate the disribution properties of zoometric linear appriasal traits within Murciano-Granadina population, to define the scales which better represent the variability for zoometric traits present in the population, to optimize and validate such scales, and to perform a comprbensive genetic evaluation of the heritable component and correlations among linear appraisal traits.

Best Linear Unbiased Prediction (BLUP) methods and the Animal Model application in livestock, including the caprine sector occurred during the mid-1980s [35,36]. This would lead to the increase in the complexity of the methodologies that breeding schemes could implement, especially for genetic parameter estimations and breeding value calculations.

This in turn enabled the access to reliable, structured, and complete genealogical information and to its integration into genetic evaluations, but also marked the moment when animals phenotypically controlled under widely different environmental conditions were evaluated altogether. BLUP model permitted disentangling and isolating the effect of environmental (non-genetic) factors from genetic ones, thus permitted the estimation of the heritable fraction of functional traits [37].

One of the main drawbacks derived from the extrapolation of ADGA LAS to build CAPRIGRAN LAS relies on the scarce amount of information that exists on the heritability of structural traits in dairy goats. Indeed, although genetic parameters may be similar, according to relative indications and experience, the absolute heritability of traits is not known or expected to be the same for dairy cattle and dairy goats. For example, the heritabilities used in the selection of traits for ADGA LAS are based on 4 years of dairy cattle linear data, hence, they were inferred in other species, and specifically, barely any information is present in regards to the genetic correlations across zoometric or LAS traits.

Consequently, the specific computation of genetic parameters and the study of the relationship between zoometric and LAS traits must be performed. However, for this to occur, sufficient data has to be gathered to perform the calculations so as for information to be enough to issue valid and replicable conclusions.

Selection for zoometrics defines individuals' productive longevity, endurance, enhanced productive abilities, and consequently, its long-term profitability [10,38]. When zoometric analysis is aimed at in large highly selected populations or in those at different selection momentums, LAS may provide a timely selection response. However, the particular selective context of the breed must be evaluated. The particular analysis of each variable permits tailoring specific strategies for each trait and serve as a model for other breeds, either selected or in terms of selection. For CAPRIGRAN LAS to be deemed effective, zoometric and LAS computed genetic parameters must be comparable, but also, they must be heritable (genetically controlled) enough (heritability of 0.15 or higher is accepted as indicating at least moderate heritability of a trait) so that progress or improvement can be made at an acceptable rate through the selection of sires. Traits that are not at least moderately heritable are more effectively handled through herd management practices (such as culling) and are no suitable for inclusion in LAS.

The value of CAPRIGRAN LAS relies on the possibility of dairy goat breeders using the information provided by these animal evaluation programs as guidance in making their management decisions such as mating plans that involve the selection of sires or dams used in their breeding programme. In turn, these management decisions may not only influence the structural correctness and genetic potential of individual animals, which determines their lifetime in the herd and their overall production level but also may help to understand how the condition of type traits affects the structural durability and the reproductive and production efficiency of an animal is critical to effective herd management. This means dairy goat herds evaluated with the LAS will be instrumental in helping develop the database needed to determine the heritability of structural traits in dairy goats and, eventually, their relationship to longevity and production, and thus, their economic value.

By last, the genomic information obtained from goat microsatellite studies allowed the development of research based on the relationship between Quantitative Trait Loci (QTL), which are regions of the genome for which an association with the phenotypic variation of a certain trait has been demonstrated [39], with certain desirable production traits [40].

This association was supported by the theory that the QTL regions may contain genes that code for the specific regulation of the expression of a certain functional characteristic. Early on, many QTLs were described using microsatellite genetic markers [41].

Although microsatellites still constitute and are indeed preferable as a valid analysis tool when economic resources for research are scarce, the large size of some QTL makes their mapping resolution and confidence intervals limited, which therefore, led to the development of other more efficient techniques [42].

In this regard, Single Nucleotide Polymorphisms (SNPs) studies were developed since these markers offer a higher degree of polymorphism and genome coverage [43]. This caused the SNPs to replace microsatellites as the most widespread genetic marker in research studies. As a result, geneticists became able to identify and select individuals with superior genetic potential but with an improved accuracy which was not possible with microsatellites [44,45].

Casein complex comprises a series of genes located on the goat's chromosome 6. Specifically, casein genes are encoded by four loci (CSN1S1, CSN1S2, CSN2, CSN3) clustered within the 250kb segment of this chromosome [46]. Casein SNPs act as genetic units that are closely linked through epistatic relationships [47]. These markers are transmitted as haplotypes [48]. The genetic polymorphism of the casein complex (αS1, β, αS2, and κ-casein genes), either in form of SNPs, haplotypes or haplogroups, associates to specific productive traits (milk yield, components and lactation curve parameters) of interest from an economic and research point of view [49,50].

The consideration of casein haplotypes rather than the use of a single gene or genetic marker has been suggested to maximize the comprehension of heritable mechanisms and how they affect the expression of functional traits related to milk yield, its different components (protein, fat, dry extract and/or lactose) production, the cumulative milk production, and the greater or lesser presence of somatic cells [49,51]. Although SNPs, haplotype or haplogroup associations across casein genes and casein variants with milk production traits has been previously reported [49], the relationship of casein haplotype variants with morphometry and linear appraisal has not been investigated in depth.

Despite the phenotypic relationship between zoometrics and dairy production (either milk yield, components or even transformed products such as cheese) has been investigated [52-54] and tools seeking the optimal dairy goat type have been developed [9,55,56], the role that traditionally dairy linked genes, such as those in the casein complex, play on growth or zoometrics remains unexplored.

In line with this situation, the definition of the breed's genetic background, the functionality of its linear appraisal traits, its productive role, and the interconnections between both aspects became compulsory to maximize Murciano-Granadina potential to satisfy current commercial demands. The compendium of these studies will help to plan strategies that support the standardization and improvement of the productive capacity of this native goat breed to seek the consolidation of the breed in the international dairy goat panorama.



Aims

The main objective of this PhD thesis was to evaluate the efficiency of the current linear appraisal system used by CAPRIGRAN to represent the zoometric variability present in the Murciano-Granadina breed. Afterwards, the genetic background supporting such variability was evaluated as well as the potential connections between zoometric traits and other functional traits. For this reason, a series of specific aims was established Across the three chapters that comprise the Phd Thesis:

A) First Chapter

Study of Symmetry, Biological Representativity, Optimization and Validation of CAPRIGRAN Linear Appraisal System

Objectives

1. To evaluate the distribution of the seventeen morphological characteristics comprised in the zoometric panel routinely measured in Murciano-Granadina does and bucks.
2. To determine the degree of selection that the Murciano-Granadina breed
3. To identify critical points on which to work, to promote the selection efficiency of LAS practices applied in the Murciano-Granadina breed population.
4. The optimization of the systematic visual LAS that is routinely applied in the Murciano-Granadina breed.
5. To validate the replicability of the results derived from the application of CAPRIGAN LAS, in comparison to the actual zoometric measurements collected from the individuals on the whole Murciano-Granadina breed herdbook.
6. To present the new linear appraisal scale to be applied in Murciano-Granadina goats and bucks basing on previous research progresses in regards the application of statistical tools for scale optimization and validation and the analysis of the biological representativity of the scale for zoometric traits observed in the current population.

B) Second Chapter

Genetic Parameters for Zoometric/Linear Appraisal Traits in the Murciano-Granadina goat

Objectives

1. To determine whether phenotypic, genotypic and environmental parameters for traditional zoometric analysis and CAPRIGRAN LAS are translatable and comparable.
2. To perform the comparative evaluation of the heritabilities of the seventeen linear traits that comprise Murciano-Granadina linear appraisal system, a decade after the first preliminary results were issued.
3. To compare heritabilities across years to infer the success of the integration and implementation of the linear appraisal system in Murciano-Granadina breeding program.
4. To test the zoometric or LAS items comprising each mayor category to determine the categorization system which is appropriate.
5. To propose enhancement measures to ensure the potential of selection strategies is maximized.
6. To evaluate the viability of selection strategies based on the relationship across zoometric and LAS traits as a base for future studies evaluating potential benefits linked to an increased productive longevity.

C) Third Chapter

Relationship of Zoometric/Linear Appraisal Traits with other Functional Traits in the Murciano-Granadina goat

Objectives

1. To develop a discriminant canonical analysis (DCA) tool that permits outlining the role of the individual haplotypes of each gene of the casein complex (αS1, β, αS2, and κ-casein) on linear appraisal and zoometrics breeding values of Murciano-Grandina goats.

Results

Chapter 1.

Study of Symmetry, Biological Representativity, Optimization and Validation of CAPRIGRAN Linear Appraisal System

- *Javier Fernández Álvarez, J. M. León Jurado, F. J. Navas González, C. Iglesias Pastrana and J. V. Delgado Bermejo.* ***Applicability of an international linear appraisal system in Murciano-Granadina breed: fitting, zoometry correspondence inconsistencies, and improving strategies***
- *Javier Fernández Álvarez, J. M. León Jurado, F. J. Navas González, C. Iglesias Pastrana and J. V. Delgado Bermejo.* ***Optimization and Validation of a Linear Appraisal Scoring System for Milk Production-Linked Zoometric Traits in Murciano-Granadina Dairy Goats and Bucks***
- *Javier Fernández Álvarez, J. M. León Jurado, F. J. Navas González, C. Iglesias Pastrana and J. V. Delgado Bermejo.* ***CAPRIGRAN Linear Appraisal Evidences Dairy Selection Signs in Murciano-Granadina Goats and Bucks: Presentation of the New Linear Appraisal Scale***

ITALIAN JOURNAL OF ANIMAL SCIENCE
2022, VOL. 21, NO. 1, 1232–1245
https://doi.org/10.1080/1828051X.2022.2102544

Taylor & Francis
Taylor & Francis Group

PAPER

OPEN ACCESS
Check for updates

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

Javier Fernández Álvarez[a], Jose Manuel León Jurado[b], Francisco Javier Navas González[c,d], Carlos Iglesias Pastrana[d] and Juan Vicente Delgado Bermejo[d]

[a]aAsociación Nacional de Criadores de Caprino de Raza Murciano-Granadina (CAPRIGRAN), Fuente Vaqueros, Granada, Spain; [b]Centro Agropecuario Provincial de Córdoba, Diputación Provincial de Córdoba, Córdoba, Spain; [c]Instituto de Investigación y Formación Agraria y Pesquera (IFAPA), Córdoba, Spain; [d]Departamento de Genética, Universidad de Córdoba, Campus Universitario Rabanales, Córdoba, Spain

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.

ARTICLE HISTORY
Received 14 February 2022
Revised 17 June 2022
Accepted 4 July 2022

KEYWORDS
Goat; local breed; conservation; normality; scale adjustment

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

CONTACT Dr. Francisco Javier Navas González fjng87@hotmail.com
Supplemental data for this article is available online at https://doi.org/10.1080/1828051X.2022.2102544.

© 2022 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

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 ($\mu \pm$ 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 (B) 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 used 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 ≈ 3 (excess ≈ 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 ≈ 3 (excess ≈ 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/ Multiparous does	Structure and capacity	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)
		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)
		Rump width	13–21 cm	18 cm (primiparous) and 19 (multiparous)	5 (17 cm)	1–9 points	6 (primiparous) and 7 (multiparous)
		Rump angle	55°–31°	31°	5 (43°)	1–9 points	9
	Dairy structure	Angulosity	Angulous extremity-Rough extremity	Angulous extremity	5 (intermediate)	1–9 points	9
		Bone quality	Round and rough bones-flat and neat bones	Flat and neat bones	5 (intermediate)	1–9 points	9
	Mammary system	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 (0 cm/at hock level)	1–9 points	3 (primiparous) and 5 (multiparous)
		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
	Legs aplomb	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 capacity	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)
		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[a]	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)
		Rump angle	55–31°	31°	5 (43°)	1–9 points	9
	Dairy structure	Angulosity[a]	Angulous extremity-Rough extremity	Angulous extremity	5 (intermediate)	1–9 points	9
		Bone quality[a]	Round and rough bones-flat and neat bones	Flat and neat bones	5 (intermediate)	1–9 points	9
	Legs aplomb	Rear legs rear view[a]	Very close-parallel and separated	Parallel and separated	5 (slightly close)	1–9 points	9

(*continued*)

Table 1. Continued.

Gender/Status	Major area	Linear trait	Zoometric scale/ categorical scale	Zoometric optimum scoring	Reference/ Middle point	LAS extrapolation	LAS optimum scoring
		Rear legs side view[a]	Straight-Very curved	Desirable curvature. Short distance from an imaginary line to anterior curvature of hock	5 (desirable curvature)	1–9 points	5
		Mobility[a]	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

[a]Same criteria for males and females.

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 enrols 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).

Table 2. Descriptive statistics, Kurtosis, Skewness for Murciano-Granadina Linear appraisal system (LAS) zoometric traits.

Sex/Status	Zoometric traits	*N*	Mode	Skewness	Std. error of skewness	Kurtosis	Std. error of kurtosis	Range	Percentiles		
									25	50	75
Bucks	Stature (height to withers)	1485	9	0.180	0.064	−1.294	0.127	8	4	5	8
	Chest width	1485	9	0.044	0.064	−1.371	0.127	7	5	6	9
	Body depth	1485	6	0.135	0.064	−0.084	0.127	8	5	6	7
	Rump width	1485	6	0.054	0.064	0.388	0.127	7	5	6	6
	Rump angle	1485	6	0.169	0.064	1.147	0.127	7	5	6	6
	Angulosity	1485	5	−0.183	0.064	0.223	0.127	8	5	5	6
	Bone quality	1485	6	−0.342	0.064	−0.087	0.127	4	6	6	7
	Rear legs rear view	1485	7	−0.404	0.064	0.337	0.127	5	6	7	7
	Rear legs side view	1485	4	0.190	0.064	−0.211	0.127	6	3	4	4
	Mobility	1485	7	−1.897	0.064	15.222	0.127	7	7	7	7
Primiparous does	Stature (height to withers)	22727	3	0.511	0.016	0.366	0.032	8	2	3	4
	Chest width	22727	5	0.354	0.016	0.214	0.032	8	4	5	6
	Body depth	22727	6	−0.095	0.016	0.212	0.032	8	5	6	6
	Rump width	22727	5	−0.005	0.016	0.318	0.032	8	4	5	5
	Rump angle	22727	6	0.227	0.016	0.646	0.032	7	5	6	6
	Angulosity	22727	5	0.107	0.016	−0.097	0.032	8	4	5	6
	Bone quality	22727	7	−0.528	0.016	0.469	0.032	8	7	7	8
	Anterior insertion	22727	6	0.049	0.016	0.360	0.032	7	5	6	6
	Rear insertion height	22727	7	−0.372	0.016	0.185	0.032	7	6	6	7
	Median suspensor ligament	22727	3	0.758	0.016	1.647	0.032	8	3	3	4
	Udder width	22727	7	−0.099	0.016	−0.347	0.032	8	6	7	8
	Udder depth	22727	3	0.364	0.016	0.355	0.032	8	3	4	5
	Nipple placement	22727	6	−0.273	0.016	1.101	0.032	8	6	6	7
	Nipple diameter	22727	4	0.675	0.016	−0.045	0.032	8	4	5	6
	Rear legs rear view	22727	7	−0.372	0.016	0.388	0.032	8	6	7	7
	Rear legs side view	22727	3	0.269	0.016	−0.292	0.032	7	3	4	4
	Mobility	22727	7	−0.336	0.016	1.971	0.032	8	7	7	7
Multiparous does	Stature (height to withers)	17111	4	0.414	0.019	0.141	0.037	8	3	4	5
	Chest width	17111	6	−0.108	0.019	−0.121	0.037	8	5	6	7
	Body depth	17111	7	−0.482	0.019	0.501	0.037	8	6	6	7
	Rump width	17111	5	−0.030	0.019	0.263	0.037	7	5	5	6
	Rump angle	17111	6	0.165	0.019	0.388	0.037	7	5	6	6
	Angulosity	17111	6	−0.243	0.019	−0.264	0.037	7	5	6	7
	Bone quality	17111	7	−0.497	0.019	0.446	0.037	6	7	7	8
	Anterior insertion	17111	6	0.092	0.019	0.284	0.037	8	5	6	6
	Rear insertion height	17111	6	−0.589	0.019	0.694	0.037	8	5	6	7
	Median suspensor ligament	17111	3	0.491	0.019	−0.105	0.037	8	3	4	5
	Udder width	17111	7	−0.331	0.019	−0.113	0.037	6	7	7	8
	Udder depth	17111	5	−0.016	0.019	−0.452	0.037	8	5	5	7
	Nipple placement	17111	6	−0.044	0.019	0.339	0.037	8	6	6	7
	Nipple diameter	17111	4	0.949	0.019	0.016	0.037	7	4	4	6
	Rear legs rear view	17111	7	−0.476	0.019	0.958	0.037	8	6	6	7
	Rear legs side view	17111	3	−0.150	0.019	−0.755	0.037	7	3	4	5
	Mobility	17111	7	−0.363	0.019	2.159	0.037	8	6	7	7

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 angulosity 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 angulosity 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 develop their life in slopy terrains (83.3°–117.1) (Zhang et al. 2018). Indeed, it is precisely these values that permit Murciano-Granadina goats to adapt to the different slopes in the hilly and mountainous areas where they locate (Delgado et al. 2017).

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 limitedly 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. Parallelly, 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 diagnose 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 reduction/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.

Acknowledgements

This work would not have been possible if it had not been for the support and assistance of the National Association of Breeders of Murciano-Granadina Goat Breed, Fuente Vaqueros (Spain) and the PAIDI AGR 218 research group.

Ethical approval

The study followed the premises described in the Declaration of Helsinki. The Spanish Ministry of Economy and Competitivity 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.

Funding

The present research was carried during the covering period of a predoctoral contract (FPU Fellowship) funded by the Spanish Ministry of Science and Innovation.

ORCID

Javier Fernández Álvarez http://orcid.org/0000-0003-0450-5869
Jose Manuel León Jurado http://orcid.org/0000-0001-8969-574X
Francisco Javier Navas González http://orcid.org/0000-0002-0093-5151
Carlos Iglesias Pastrana http://orcid.org/0000-0003-3765-1627
Juan Vicente Delgado Bermejo http://orcid.org/0000-0003-1657-8838

Data availability statement

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

References

Alonso J, Bahamonde A, Villa A, Castañón ÁR. 2007. Morphological assessment of beef cattle according to carcass value. Livest Sci. 107(2–3):265–273.

Araújo GGLd, Voltolini TV, Chizzotti ML, Turco SHN, Carvalho FFRd. 2010. Water and small ruminant production. R Bras Zootec. 39(suppl spe):326–336.

Archana PR, Sejian V, Ruban W, Bagath M, Krishnan G, Aleena J, Manjunathareddy GB, Beena V, Bhatta R. 2018. Comparative assessment of heat stress induced changes in carcass traits, plasma leptin profile and skeletal muscle myostatin and HSP70 gene expression patterns between indigenous Osmanabadi and Salem Black goat breeds. Meat Sci. 141:66–80.

Ariff O, Hifzan R, Zuki A, Jiken A, Lehan S. 2010. Maturing pattern for body weight, body length and height at withers of Jamnapari and Boer goats. Pertanika J Trop Agric Sci. 33(2):269–276.

Bukar-Kolo Y, Mustapha M, Zakariah M, Allo A, Adamu L. 2016. Relationships between zoometric measurements, coat colors and body condition scores of the Nigerian indigenous dogs in Maiduguri. Northeastern Nigeria Res J Vet Pract. 4(3):51–59.

Castañeda-Bustos V, Montaldo H, Valencia-Posadas M, Shepard L, Pérez-Elizalde S, Hernández-Mendo O, Torres-Hernández G. 2017. Linear and nonlinear genetic relationships between type traits and productive life in US dairy goats. J Dairy Sci. 100(2):1232–1245.

Chadwick R. 2017. Normality as convention and as scientific fact. In: Handbook of the philosophy of medicine, 1st ed. The Netherlands: Springer; p. 17–28.

Dea D, Melesse A, Mekasha Y. 2019. Application of morphometric traits and body indices in assessing the type and function of local goats reared in two districts of Gamo-Gofa Zone, South Ethiopia. Anim Prod. 19(1):73–90.

Deeming L, Beausoleil N, Stafford K, Webster J, Zobel G. 2018. The development of a reliable 5-point gait scoring system for use in dairy goats. J Dairy Sci. 101(5):4491–4497.

Delgado JV, Landi V, Barba CJ, Fernández J, Gómez MM, Camacho ME, Martínez MA, Navas FJ, León JM. 2017. Murciano-Granadina goat: a Spanish local breed ready for the challenges of the twenty-first century. In: Sustainable goat production in adverse environments: Volume II. Cham, Switzerland: Springer; p. 205–219.

Du Pisanie K. 2019. Indigenous veld goats: cornerstone of the goat industry. Stockfarm. 9(11):22–23.

Fernández Álvarez J, León Jurado JM, Navas González FJ, Pastrana CI, Delgado Bermejo JV. 2020. Optimization and validation of a linear appraisal scoring system for milk production-linked zoometric traits in Murciano-Granadina dairy goats and bucks. Appl Sci. 10(16):5502.

Fuller A, Mitchell D, Maloney SK, Hetem RS. 2016. Towards a mechanistic understanding of the responses of large terrestrial mammals to heat and aridity associated with climate change. Clim Change Resp. 3(1):1–19.

García-Ballesteros S, Gutiérrez JP, Varona L, Fernández J. 2017. The influence of natural selection in breeding programs: a simulation study. Livest. Sci. 204:98–103.

García-Dorado A, Avila V, Sánchez-Molano E, Manrique A, López-Fanjul C. 2007. The build up of mutation–selection–drift balance in laboratory Drosophila populations. Evolution. 61(3):653–665.

Goh L, Yap VB. 2009. Effects of normalization on quantitative traits in association test. BMC Bioinformatics. 10(1): 415–418.

González-Velasco HM, García-Orellana CJ, Macías-Macías M, Gallardo-Caballero R, García-Manso A. 2011. A morphological assessment system for 'show quality'bovine livestock based on image analysis. Comput Electron Agric. 78(1):80–87.

Goyache F, del Coz JJ, Quevedo JR, López S, Alonso J, Ranilla J, Luaces O, Alvarez I, Bahamonde A. 2001. Using artificial intelligence to design and implement a morphological assessment system in beef cattle. Anim Sci. 73(1): 49–60.

Guo H, Li Z, Ma Q, Zhu D, Su W, Wang K, Marinello F. 2019. A bilateral symmetry based pose normalization framework applied to livestock body measurement in point clouds. Comput Electron Agric. 160:59–70.

Haldar A, Pal P, Datta M, Paul R, Pal SK, Majumdar D, Biswas CK, Pan S. 2014. Prolificacy and its relationship with age, body weight, parity, previous litter size and body linear type traits in meat-type goats. Asian-Australas J Anim Sci. 27(5):628–634.

Hassen H, Baum M, Rischkowsky B, Tibbo M. 2012. Phenotypic characterization of Ethiopian indigenous goat populations. Afr J Biotechnol. 11(73):13838–13846.

Homeyer F. 2007. Breeding better boers-reasons behind breed standards. Ranch Rural Living. 89(2):17.

Johnson T, Barton N. 2005. Theoretical models of selection and mutation on quantitative traits. Philos Trans R Soc Lond B Biol Sci. 360(1459):1411–1425.

Khan MS. 2016. Nachi goats: judging and selection guide. Pakistan: AIP-ILRI publication. International Livestock Research Institute.

Kharrat M, Bocquier F. 2010. Adaptive responses at the whole lactation scale of Baladi dairy goats according to feed supply and level of body reserves in agro-pastoral feeding system. Small Ruminant Res. 90(1–3):120–126.

Kingsolver JG, Hoekstra HE, Hoekstra JM, Berrigan D, Vignieri SN, Hill C, Hoang A, Gibert P, Beerli P. 2001. The strength of phenotypic selection in natural populations. Am Nat. 157(3):245–261.

Li Z, Möttönen J, Sillanpää MJ. 2015. A robust multiple-locus method for quantitative trait locus analysis of non-normally distributed multiple traits. Heredity. 115(6):556–564.

Luigi-Sierra MG, Landi V, Guan D, Delgado JV, Castelló A, Cabrera B, Mármol-Sánchez E, Alvarez JF, Gómez-Carpio M, Martínez A, et al. 2020. A genome-wide association analysis for body, udder, and leg conformation traits recorded in Murciano-Granadina goats. J Dairy Sci. 103(12):11605–11617.

Lynch M, Conery J, Burger R. 1995. Mutation accumulation and the extinction of small populations. Am Nat. 146(4): 489–518.

Manfredi E, Piacere A, Lahaye P, Ducrocq V. 2001. Genetic parameters of type appraisal in Saanen and Alpine goats. Livest Prod Sci. 70(3):183–189.

Mellado M, Mellado J, Valencia M, Pittroff W. 2008. The relationship between linear type traits and fertility traits in high-yielding dairy goats. Reprod Domest Anim. 43(5): 599–605.

Mellado M, Rodrıǵuez A, Villarreal JA, Lopez R. 2004. Height to withers and abdominal circumference effects on diets of grazing goats. Appl Anim Behav Sci. 88(3–4):263–274.

Milerski M, Margetín M, Čapistrák A, Apolen D, Špánik J, Oravcová M. 2011. Relationships between external and internal udder measurements and the linear scores for udder morphology traits in dairy sheep. Czech J Anim Sci. 51(9):383–390.

Murciano-Granadina ANdCdCdR 2020. Calificación morfológica lineal. [accessed 2020 January 26]. http://www.caprigran.com/.

Nardone A, Ronchi B, Lacetera N, Bernabucci U. 2006. Climatic effects on productive traits in livestock. Vet Res Commun. 30(S1):75–81.

Novotna K, Svitáková A, Rychtářová J, Fantová M, Nohejlová L. 2018. Methodology of udder description and the effect on somatic cell count in Czech White Shorthaired goat breed. Med Weter. 74(8):497–500.

Olechnowicz J, Kneblewski P, Jaśkowski J, Włodarek J. 2016. Effect of selected factors on longevity in cattle: a review. J Anim Plant Sci. 26:1533–1541.

Patbandha T, Pata B, Trivedi S, Gohil B, Boradiya P, Sharma A, Savalia K. 2018. Evaluating phenotypic correlation between body weight and biometric traits of migratory goats. J Entomol Zool Stud. 6(1):560–564.

Peng B, Yu RK, DeHoff KL, Amos CI. 2007. Normalizing a large number of quantitative traits using empirical normal quantile transformation. BMC Proc. 1(S1):S156.

Pizarro M, Landi V, Navas F, León J, Martínez A, Fernández J, Delgado J. 2020. Non-parametric analysis of the effects of nongenetic factors on milk yield, fat, protein, lactose, dry matter content and somatic cell count in Murciano-Granadina goats. Ital J Anim Sci. 19(1):960–973.

Pragna P, Sejian V, Bagath M, Krishnan G, Archana PR, Soren NM, Beena V, Bhatta R. 2018. Comparative assessment of growth performance of three different indigenous goat breeds exposed to summer heat stress. J Anim Physiol Anim Nutr. 102(4):825–836.

Radhika G, Raghavan K, Mercey K, Sunanda C, Rojan P. 2018. Assessment of genetic diversity in goat genetic groups of Kerala, (India) using morphobiometric markers. Indian J Anim Res. 52(3):331–336.

Raichlen DA. 2006. Effects of limb mass distribution on mechanical power outputs during quadrupedalism. J Exp Biol. 209(Pt 4):633–644.

Rychtarova J, Sztankoova Z, Svitakova A. 2017. Association of polymorphism at BTN1A1, SCD and LPL gene on somatic cell count in czech white shorthaired goat breed. J Hyg Eng Des. 21:64–69.

Sánchez Rodríguez M, Cárdenas Baena JM, Blanco del Campo G. 2012. Rasgos descriptivos lineales. In: Federación Cabrandalucía, Ed., Valoración morfológica del ganado caprino lechero. Zaragoza, Spain: Servet Diseño y Comunicación.

Siu W, Qin L, Cheung W, Leung K. 2004. A study of trabecular bones in ovariectomized goats with micro-computed tomography and peripheral quantitative computed tomography. Bone. 35(1):21–26.

Smith MC, Sherman DM. 2009. Goat medicine. Hoboken, New Jersey, USA: John Wiley & Sons.

Tariba B, Kostelić A, Roić B, Benić M, Šalamon D. 2017. Influence of caprine arthritis encephalitis virus infection on milk production of French Alpine goats in Croatia. Mljekarstvo/Dairy. 67(1):42–48.

Vacca GM, Ledda S, Paschino DP. 2014. Investigating the genetic and productive characteristics of autochthonous Sarda goat. Phd Theses. Sassary, Italy: University of Sassari.

Vilensky JA. 1987. Locomotor behavior and control in human and non-human primates: comparisons with cats and dogs. Neurosci Biobehav Rev. 11(3):263–274.

Wiggans GR, Hubbard SM. 2001. Genetic evaluation of yield and type traits of dairy goats in the United States. J Dairy Sci. 84:E69–E73.

Xiao PT. 1995. Observations on the normal distribution of quantitative traits. Med Hypotheses. 45(4):386–388.

Yu Z, Wang G, Tang T, Fu L, Yu X, Zhu Z, Dai K. 2015. Long-term effects of ovariectomy on the properties of bone in goats. Exp Ther Med. 9(5):1967–1973.

Zeleke B, Melese M. 2017. On farm phenotypic characterization of indigenous goat populations in Gamo Gofa zone South Western Ethiopia. J Adv Stud Agric Biol Environ Sci. 4:29.

Zhang F, Zheng L, Wang W, Wang Y, Wang J. 2018. Development of agricultural bionic mechanisms: investigation of the effects of joint angle and pressure on the stability of goats moving on sloping lands. Int J Agric Biol Eng. 11(3):35–41.

View publication stats

applied sciences

MDPI

Article

Optimization and Validation of a Linear Appraisal Scoring System for Milk Production-Linked Zoometric Traits in Murciano-Granadina Dairy Goats and Bucks

Javier Fernández Álvarez [1], Jose Manuel León Jurado [2], Francisco Javier Navas González [3,*], Carlos Iglesias Pastrana [3] and Juan Vicente Delgado Bermejo [3]

[1] National Association of Breeders of Murciano-Granadina Goat Breed, Fuente Vaqueros, 18340 Granada, Spain; j.fernandez@caprigran.com

[2] Centro Agropecuario Provincial de Córdoba, Diputación Provincial de Córdoba, 14071 Córdoba, Spain; jomalejur@yahoo.es

[3] Department of Genetics, Faculty of Veterinary Sciences, University of Córdoba, 14071 Córdoba, Spain; ciglesiaspastrana@gmail.com (C.I.P.); juanviagr218@gmail.com (J.V.D.B.)

* Correspondence: fjng87@hotmail.com; Tel.: +34-651-679-262

Received: 15 July 2020; Accepted: 6 August 2020; Published: 9 August 2020

check for updates

Featured Application: Linear appraisal systems (LAS) determine individuals' degree of fitness to an optimal morphological standard. These methods are efficient tools that help saving the time, personnel and economic resources when zoometric phenotype collection is performed at large population scale. Reducing the complexity of zoometric panels may maximize phenotype collection outcomes at the minimum possible accuracy cost. Once panel optimization has succeeded, LAS/Traditional measuring validation must be performed to ensure traditional zoometric results are replicable when LAS is performed. After validation, reduced models proved to be effective to capture and predict for dairy-related zoometric variability in Murciano-Granadina bucks and does.

Abstract: Implementing linear appraisal systems (LAS) may reduce time, personnel and resource costs when performing large-scale zoometric collection. However, optimizing complex zoometric variable panels and validating the resulting reduced outputs may still be necessary. The ack of cross-validation may result in the loss of accuracy and value of the practices implemented. Special attention should be paid when zoometric panels are connected to economically-relevant traits such as dairy performance. This methodological proposal aims to optimize and validate LAS in opposition to the traditional measuring protocols routinely implemented in Murciano-Granadina goats. The sample comprises 41,323 LAS and traditional measuring records from 22,727 herdbook-registered primipara does, 17,111 multipara does and 1485 bucks. Each record includes information on 17 linear traits for primipara/multipara does and 10 traits for bucks. All zoometric parameters are scored on a nine-point scale. Cronbach's alpha values suggest a high internal consistency of the optimized variable panels. Model fit, variability explanation power and predictive power (mean square error (MSE), Akaike (AIC)/corrected Akaike (AICc) and Bayesian information criteria (BIC), respectively) suggest the model comprising zoometric LAS scores performs better than traditional zoometry. Optimized reduced models are able to capture variability for dairy-related zoometric traits without noticeable detrimental effects on model validity properties.

Keywords: principal component analysis; dairy zoometry; scale reliability; categorical regression

1. Introduction

The American Dairy Goat Association (ADGA) published the first linear appraisal system (LAS) for dairy goats. LAS was presented as an attempt to search for more predictive and objective methods to link zoometry and productivity in 1993. The benefits derived from the application of LAS comprise the evaluation of moderately heritable zoometric traits that hold a significant relationship with productive traits. This evaluation is performed for each animal and uniformly across the population, using scales that are able to capture the variability between observed biological extremes in economically important traits.

The combined Caprine Index (ICC) [1] and Morphological Index began to be applied in French dairy breeds in 1999. Since these very first attempts, many breeds (Alpine, Lamancha, Nigerian Dwarf, Nubian, Oberhasli, Saanen, Sable or Toggenburg) have implemented LAS. In the most representative cases, the number of linear appraisals performed increased by up to 3828.40% during the period ranging from 2005 to 2019 [2].

The National Association of Breeders of the Murciano-Granadina goat breed (CAPRIGRAN) routinely performs a numerical description of 17 zoometric linear traits on a one to nine-point scale. This scale is used to represent the biological range for each particular trait that exists in the current population. Then, these linear trait data—plus a final score for each animal —are used to develop individual reports for does and bucks. The importance of the system is denoted by the fact that LAS observations have reached a number of almost 400,000 in the past 5 years [3].

Contextually, although CAPRIGRAN LAS [4] has a strong basis on ADGA and USDA's LAS, it is relatively new, as its application only dates back to 2010. Murciano-Granadina goat linear appraisals increased by 16.05% from 2018 to 2019. After a decade of progress, the most remarkable international achievement obtained by Murciano-Granadina breeding may be that figures have exceeded the most promising results reported by other breeds by more than 10 times. For instance, the Nigerian Dwarf Goat breed had previously shown the greatest increase in the number of linear appraisals, with 3182 new linear appraisals performed, in 2019 [2].

CAPRIGRAN performs routine LAS using a team of raters who use PDA and "Escardillo" technical–economic management software to collect individual ratings [5]. Raters evaluate each animal across four structural areas (structure and capacity, dairy conformation, mammary system and legs aplomb). The scores provided for each zoometric variable depend on the degree of resemblance of the measure observed on each individual to the optimal standard measure for Murciano-Granadina dairy goats. Then, the scores of the variables comprising each major area are summed and multiplied by a coefficient. This coefficient depends on the preestablished relevance of each major area to define the dairy morphotype and breed standard.

For breeding does, the structure and capacity, dairy conformation, mammary system and legs aplomb areas are multiplied by 25%, 15%, 40% and 20%, respectively. For breeding bucks and goats which have not yet given birth, the areas to be scored are reduced to structure and capacity, dairy conformation and legs aplomb, and their relative scores are multiplied by 50%, 20% and 30%, respectively. Then, the final score may total up to 100 points depending on the relative scores for each of the areas obtained by each animal.

Afterward, points are translated into a verdict as follows: insufficient (IN) when a certain animal totals from 60 to 69 points; mediocre (R), from 70 to 74 points; good (B); from 75 to 79 points; quite good (BB), from 80 to 84; very good (MB), from 85 to 89 points; or excellent (EX), at 90 points or above [6]. Then, the final score relative to each major category of each animal is used by raters to compute each animal's final score to provide individualized reports per animal to the owner of each herd. Afterward, final records are registered in the computerized record and used to rank sires and dams in official catalogues. Finally, all the information is made public using codes for each animal to fulfil the requirements of Data Protection Policies.

The collection of large sets of zoometric variables is essential when performing the characterization of breeds. However, it can be time-consuming, human resource-demanding and unprofitable when the standard of a breed has already been defined or if large-scale zoometric assessment is needed. CAPRIGRAN LAS differs from ADGA and UDGA's systems in the fact that raters translate biological variability on a point scale ranging from one to nine.

Given the need to ensure the applicability of LAS at a large scale, the simplification of CAPRIGRAN LAS is one of the top-priority challenges to address when applying on-farm protocols in goats [7]. At this point, statistical optimization and validation are crucial practices to perform to ensure the capacity and reliability of LAS to describe the ranges of zoometric measures found in the population. Contextually, principal component analysis (PCA) has been widely applied as a method to discard potentially redundant or confounding zoometric traits [8,9], which can maximize the predictive power of linear appraisal scales efficiently.

Once large variable sets have been reduced, preserving the greatest fraction of variance possible, the scales must still be tested. Scale testing aims to determine whether the results reported by linear appraisal techniques are comparable to those reported by traditional zoometric assessment. The comparison of both methods enables the calculation of an index of the degree to which an artificially built scale can depict zoometric patterns in a population. For this purpose, regression analysis and canonical correlation analysis between LAS and traditional zoometric scales can help to determine their greater or lesser levels of resemblance.

After LAS validation, its application in the context of breeding for the most desirable zoometric patterns may enable a maximized productive objective to be obtained. Furthermore, large-scale LAS may grant access to large amounts of very valuable, readily available information for breeders. This information may enhance selection potentialities through the improvement of the selection accuracy of breeding stock or when making decisions about purchases, as relatively quick diagnoses of the quality of certain animals and their specific suitability for dairy production can be issued in the context of the breeds' morphological traits. These methods may also be implemented at a lower time and resource cost, as assessors may progressively become acquainted with the spectrum of possible levels and thresholds, more easily identifying the value of new animals in comparison with the optimal levels described in the breed's standard.

Thus, the present study aimed at implementing two main objectives: first, the optimization of the systematic visual LAS that is routinely applied in the Murciano-Granadina breed; second, the validation of the replicability of the results derived from the application of CAPRIGAN LAS in comparison to the actual zoometric measurements collected from the individuals in the entire Murciano-Granadina breed herdbook.

2. Materials and Methods

2.1. Statistical Assumption Testing

Historical zoometric records for the Murciano-Granadina goat breed collected until December 2019 were tested for common parametric assumptions. Kolmogórov–Smirnov and Levene tests were used to evaluate normality and homoscedasticity, respectively, using the statistical software Statistical Package for the Social Sciences (SPSS Statistics) for Windows (Version 25.0, 2017, IBM Corp., Armonk, NY, USA).

2.2. Animal Sample and Linear Appraisal Records

The complete pedigree of Murciano-Granadina goats consisted of 279,264 animals (266,793 does and 12,971 bucks) born from June 1966 to November 2019. The linear appraisal database comprised information from 41,418 individuals evaluated year-round. 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 were officially issued for all the farms considered in the study. All farms considered were controlled and officially declared tuberculosis-free (C3), brucellosis-free (M4) (Order of 22 June 2018 and Directive 91/68/EEC) and Scrapie Controlled Risk (SCRAPIE RC) (Regulation (EC) No 999/2001 of the European

Parliament and the Council). These farms also followed voluntary control plans for Caprine Contagious Agalactia (CCA) (National CCA Surveillance, Control, and Eradication Programme 2018–2020) and Caprine arthritis encephalitis (CAEV) (Order AYG/287/2019 of 28 of February of 2019). Goats were clinically examined by an official veterinarian, and animals presenting signs of illness or disease conditions were officially declared and removed from the herds; thus, they were not considered in the analyses. All farms followed permanent stabling practices, with ad libitum water, foraging 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.

The sample was evaluated and filtered. As a result, 95 individuals with missing or incomplete zoometric and linear appraisal records were discarded. The final dataset comprised 41,323 records belonging to 22,727 herdbook registered primipara does, 17,111 multipara does and 1485 bucks which were retained in the statistical analysis. Average age ranges for primipara and multipara does and bucks in the sample were 1.61 ± 0.35 years, 3.96 ± 1.74 years and 2.43 ± 1.49 years ($\mu \pm$ SD), respectively.

2.3. Murciano-Granadina Linear Appraisal System (LAS)

For primipara and multipara does, each animal's registry comprises the raters' score for the four major categories of structure and capacity, dairy structure, mammary system and legs aplomb. For bucks, young males and goats that have not yet given birth, the mammary system was not evaluated, resulting in three major categories being considered. In the case of primipara and multipara does, each record comprised information on 17 linear traits rated on a nine-point scale. As bucks were not scored for traits in the mammary system major category, only 10 traits were scored for them following the same nine-point scale. Body depth from the structure and capacity as major categories and the major categories of dairy structure and legs and feet followed the same criteria for males and females.

Each final score represents how closely the animal resembles the overall optimal dairy standard. The Murciano-Granadina LAS establishes that each major category contributes to the final score, with 25% for structure and capacity, 15% for dairy structure, 20% for legs and feet and 40% for the mammary system for primipara and multipara does (any doe which has ever begun to produce 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 final scores are translated into one of the six category qualifications considered by CAPRIGRAN as follows: insufficient (IN) for animals which 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) at 70% to 74% of optimal standard, which translates into a final score between 70 and 74 points; good (B) from 75% to 79% of the optimal standard, which translates into a final score from 75 to 79 points; quite good (BB) from 80% to 84% of the optimal standard, which translates into a final score from 80 to 84 points; very good (MB) from 85% to 89% of the 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 final score higher than 90 points. A detailed description of the scales used and the translation process from zoometric traits can be found in Sánchez Rodríguez, et al. [4], Table 1 and Figures S1–S27.

Age elements (such as the age of the doe or lactation stage) have been reported to condition dairy linear or type appraisal-related traits [10]. As a result, age elements—often recorded for does at appraisal—permit the adjustment of models for the outputs of linear or type appraisal records [11]. The Pearson product–moment correlation coefficient between the lactation phase and age in years was 0.705 ($P < 0.01$); thus, a certain redundancy could be presumed for the outputs of linear or type appraisal when both age elements were considered simultaneously. For this reason, the lactation phase was considered, and results for primipara and multipara goats were broken down in the present study.

Table 1. Detailed description of the scales used and the translation process from zoometric traits to linear appraisal scoring system (LAS) scores in Murciano-Granadina goat and bucks.

Gender/Status	Major Area	Linear Trait	Zoometric Scale/Categorical Scale	Zoometric Optimum Scoring	Reference/Middle Point	LAS Extrapolation	LAS Optimum Scoring
Primipara/Multipara does	Structure and capacity	Stature (height to withers)	62–78 cm	72 cm (primipara) and 74 cm (multipara)	5 (70 cm)	1–9 points	6 (primipara) and 7 (multipara)
		Chest Width	15–23 cm	20 cm (primipara) and 21 cm (multipara)	5 (19 cm)	1–9 points	6 (primipara) and 7 (multipara)
		Body Depth	Shallow-Extremely deep	Intermediate	5 (elbow end matches rib depth)	1–9 points	7 (primipara and multipara)
		Rump Width	13–21 cm	18 cm (primipara) and 19 (multipara)	5 (17 cm)	1–9 points	6 (primipara) and 7 (multipara)
		Rump Angle	55–31°	31°	5 (43°)	1–9 points	9
	Dairy structure	Angulosity	Angulous extremity–rough extremity	Angulous extremity	5 (Intermediate)	1–9 points	9
		Bone Quality	Round and rough bones-flat and neat bones	Flat and neat bones	5 (Intermediate)	1–9 points	9
	Mammary system	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 to 10 cm	−5 cm (5 cm over hock level) and 0 cm (udder bottom at hock level)	5 (0 cm/at hock level)	1–9 points	3 (primipara) and 5 (multipara)
		Nipple placement	90–0°	0°	5 (45°)	1–9 points	9
		Nipple Diameter	0.5–4.5 cm	2 cm	5 (2.5 cm)	1–9 points	4
	Legs aplomb	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 capacity	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)
		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 [a]	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)
		Rump Angle	55–31°	31°	5 (43°)	1–9 points	9
	Dairy structure	Angulosity [a]	Angulous extremity–rough extremity	Angulous extremity	5 (Intermediate)	1–9 points	9
		Bone Quality [a]	Round and rough bones–flat and neat bones	Flat and neat bones	5 (Intermediate)	1–9 points	9
	Legs aplomb	Rear Legs Rear View [a]	Very close–parallel and separated	Parallel and separated	5 (slightly close)	1–9 points	9
		Rear Legs Side View [a]	Straightb–ery curved	Desirable curvature. Short distance from an imaginary line to anterior curvature of hock	5 (desirable curvature)	1–9 points	5
		Mobility [a]	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

[a] Same criteria for males and females.

2.4. Dimensionality Reduction: Linear Appraisal System Optimization

The optimization of the LAS used in Murciano-Granadina goats was performed using principal component analysis (PCA). PCA can be used to perform an efficient selection of the minimum number of zoometric traits which are able to capture the highest fraction possible of variability for a given set of traits. Birth data for all animals were provided by CAPRIGRAN. Zoometric data collection was performed using a zoometric stick, a zoometric compass and a tape measure. All measurements were recorded once by the same person to avoid inter-recorder effects. Descriptive statistics were calculated for each of the 17 zoometric variables studied, and Spearman's correlation coefficients were computed for all possible combinations of the variables. A significant Spearman's correlation between two variables in a pair may result when the two variables involved in the comparison are monotonically related, even if they share a nonlinear relationship [12]. The correlation matrix for the variables must contain at least two correlations of |0.30| or greater [13] in terms of the absolute value, which is the minimum magnitude for variables to be suitable for structure detection and thus for PCA to be valid.

Data for the PCA were generated from the variance–covariance matrix. The Kaiser–Meyer–Olkin (KMO) test of sampling adequacy and Bartlett's test of sphericity were computed to establish the validity of the data set for structure detection (the KMO test determines whether the common factor model is appropriate as it measures the extent to which the original variables belong together). The KMO should be greater than 0.5 for a satisfactory factor analysis to proceed. Bartlett's test of sphericity tests the hypothesis that a correlation matrix is an identity matrix, which would indicate that variables are unrelated and therefore unsuitable for structure detection. Small p-values (less than 0.05) of the significance level indicate that factor analysis may be useful for the analysis of data [14].

Communalities were assessed to determine which variables should be maintained or discarded from PCA. Initial communalities are indicative of the total amount of variance that certain original variables share with all other variables included in the analysis. Extraction communalities are estimates of the variability of each variable that can be accounted for by the factors in the factor solution. Small values (close to zero) are indicative of variables that do not fit well within the factor solution and thus should possibly be dropped from the analysis. Communalities after extraction should be above 0.3 [15].

The rotation of principal components was performed to transform components into a simple structure. The raw varimax criterion of the orthogonal rotation method was used for the rotation of the factor matrix. The varimax rotation aims to maximize the sum of variances of a quadratic weight. Furthermore, when varimax rotation is applied via Kaiser normalization, it corrects for the bias resulting from the fact that some factors may have high correlations with a small number of variables and zero correlations with the others.

The cumulative proportion of variance criterion was finally used to determine the number of components to extract. Cronbach's alpha statistic was used to confirm the reliability and validity of the reduced variable set. The concept of procedure validity can be understood as the degree to which a certain scale measures the factor which it claims to measure. Cronbach's alpha measure of validity assumes a high correlation among the elements measuring the same construct. The closer the value of alpha is to 1, the greater the internal consistency of the analyzed elements. George and Mallery [16] provided a rule of thumb for the interpretation of Cronbach alpha which establishes thresholds as follows: 0.9 is excellent, 0.8 is good, 0.7 is acceptable, 0.6 is questionable, 0.5 is poor, and less than 0.5 is unacceptable. All statistical tests referred above were performed using the statistical software SPSS Statistics for Windows, Version 25.0 [17].

PCA was used to discard variables which had a confounding nature and as a result did not significantly contribute to the fraction of explained variability but significantly increased the likelihood of type I errors, introducing bias as a result. Component loadings below |0.5| were ruled out given their confounding nature. Highly loaded variables (with component loadings equal to or over |0.5|) in the same dimension may reveal strong common underlying correlations among those variables.

2.5. Linear Regression Modelling for Zoometric Traits

After redundant variables had been identified and eliminated, Categorical Regression (CATREG) analysis was performed using the SPSS Statistics package for Windows, version 25.0, to identify the linear relationship among the zoometric traits measured. The general simple linear regression model designed followed the simple equation $Zy' = \beta x Z$, and was as follows:

$$Zy'_{finalscore} = \beta_{stature} x Z_{stature} + \beta_{chestwidth} x Z_{chestwidth} + \beta_{bodydepth} x Z_{bodydepth} + \beta_{rumpwidth} x Z_{rumpwidth} + \beta_{rumpangle} x Z_{rumpangle} + \beta_{angulosity} x Z_{angulosity} + \beta_{bonequality} x Z_{bonequality} + \beta_{anteriorinsertion} x Z_{anteriorinsertion} + \beta_{rearinsertionheight} x Z_{rearinsertionheight} + \beta_{mediansuspensorligament} x Z_{mediansuspensorligament} + \beta u_{dderwidth} x Z_{udderwidth} + \beta_{udderdepth} x Z_{udderdepth} + \beta_{nippleplacement} x Z_{nippleplacement} + \beta_{nipplediameter} x Z_{nipplediameter}] + \beta_{rearlegsrearview} x Z_{rearlegsrearview} + \beta_{rearlegssideview} x Z_{rearlegssideview} + \beta_{mobility} x Z_{mobility}$$

where $Zy'_{finalscore}$ is the final zoometric score record for each animal; β is the standardized coefficient or population slope coefficient for each zoometric predictor (independent variables, IV) as marked by the subindex for the whole population; and Z is the specific value for that predictor for each individual, with each predictor being scored using Murciano-Granadina linear appraisal systems. Variables between brackets comprise the mammary system major category and were only scored in does as described in previous sections; thus, these variables were only included in the model for mature females.

2.6. Linear Regression Modelling Validation

The main application of linear regression is the identification of linear relationships between variables in multivariate analysis. For instance, even if correlational analysis is frequently used to validate and compare scales which measure the same construct, regression analysis is still preferred to quantify the validity of the correlational analysis of large variable sets [18,19]. Regression analysis have been proven to surpass the performance of correlational analysis between scale scores and its validity to quantify a certain construct. One of the advantages of regression analysis is that it provides a way to quantify a scale–construct association in meaningful units, which facilitates the issuance of a verdict on the validity of the relationship being tested.

Additionally, regression analysis can quantify the underlying variability accounted for by a set of estimators/predictors for a certain trait in a population, while it simultaneously prevents confounding effects from distorting the validity of a judgment. This in turn increases the repeatability of the results obtained [20].

Thus, we performed CATREG analyses using the aforementioned general regression model as a reference. The first CATREG analysis aimed to compute the ability to describe the variability in the population regarding the final scores for zoometric traits, which were considered as a dependent variable (DV), and considered the actual scores for the complete set of 17 measurements directly taken from the Murciano-Granadina primipara and multipara does and bucks, which were taken as the independent variable (IV) in the model. Then, we performed a second regression analysis to evaluate the variability in the population for the final scores of zoometric traits, but instead using the 17 LAS variables (on a nine-point scale) routinely evaluated in Murciano-Granadina goats. Then, the comparison of the determination power or prediction efficiency of both regression models was used to validate the performance of CAPRIGRAN LAS. Regression analyses were separately performed for primipara and multipara does and bucks, as traits comprising the mammary system were excluded from the appraisals of males.

Comparative regression models for validity testing contrast with the predictive regression models described in the previous section for primipara and multipara does and bucks as these comprise combinations of the 17 traits scored through LAS without including those identified as redundant.

For model validity comparison, the variables of body depth, angulosity, bone quality, rear legs rear view and side view and mobility were excluded from does and bucks' comparative regression models. This decision was made based on the fact that, even during regular zoometric assessment, these zoometric parameters may rely on descriptive hedonic measurements rather than providing actual direct measurements for a certain zoometric trait; thus, no comparison could be performed as they were always scored using a specific LAS. The designed models can be seen in Table S2.

As the variables in our study comprised levels categorized following different criteria, we used standardized coefficients to interpret and compare their effects on our DV, as these are not unit-dependent. The stepwise linear regression model applied to the transformed variables resulted in the standardized and unstandardized coefficients being equal. Thus, unstandardized coefficients could be interpreted. As a rule, we assumed that the standardized results reported used full standardization (both DV and IVs were converted to standard scores) and that the Z formula was used for standardization. The general standardized regression equation followed the following model: $Z'y = \beta_1 Z_{X1} + \beta_2 Z_{X2} + \ldots$, where Z'y is the predicted value of Y in Z scores, β1 represents the standardized partial regression coefficient for X_1, β_2 represents the standardized partial regression coefficient for X_2 and Z_{X1} and Z_{X2} are the Z score values for the variables X_1 and X_2, respectively. The interception point will always equal 0.00 when standardization is based upon Z scores and both DV and IVs are standardized. Once the regression equation is standardized, the partial effect of a given X upon Y—or of Zx upon Zy—becomes somewhat easier to interpret because the interpretation is in standard deviation units for all estimators/predictors. Following the common notation models, the regression model for each predictor variable was $Y_n = \beta_n Z_n + \epsilon$, where Y_n is the n variable predictor, β_n is the regression coefficient for the n variable obtained in the n main component, Z_n is the score obtained in the field for n variable and ϵ represents the estimation error.

Likewise, to estimate the mean square error of prediction (MSEP) of each categorical regression model, we used the bootstrap 0.632 estimates as some authors have suggested it to be preferable given that it provides the least unbiased estimation of the error of prediction in conditions of a large sample size in comparison to other commonly used cross-validation methods [21].

2.7. Ethical Approval

The study followed the premises described in the Declaration of Helsinki. The Spanish Ministry of Economy and Competitivity 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 22/09/2010. Furthermore, the present study works with records rather than live animals directly, and these records were obtained after minimal handling; thus, no special permission was necessary.

3. Results

3.1. Statistical Assumption Testing, Zoometric and Linear Appraisal Records

Common parametric assumptions were violated; thus, a nonparametric approach was suggested. A summary of the descriptive statistics for zoometric traits derived from linear appraisal and zoometric assessment in primipara and multipara does and bucks is reported in Tables S3–S5, respectively.

3.2. Dimensionality Reduction: Linear Appraisal System Optimization

Spearman's correlation coefficients between almost all pairs of linear appraisal-derived zoometric traits in Murciano-Granadina primipara and multipara does and bucks were over |0.3|, as shown in Tables S6–S8, which supported the use of principal components analysis. The Kaiser–Meyer–Olkin measures of sampling adequacy for the principal component analysis of linear appraisal variables were 0.791, 0.712 and 0.767 in Murciano-Granadina bucks, primipara and multipara does, respectively, and Bartlett's test of sphericity reported a highly statistically significant value of 0.001 for the three animal categories; thus, the correlation matrix was applicable and PCA results were valid. All communalities were over 0.379, 0.444 and 0.457 for bucks, primipara and multipara does, respectively; thus, no variable was omitted from the PCA. Tables 2 and 3 report linear appraisal system varimax with Kaiser normalization rotated component loadings, eigenvalues and percentages of variance explained for Murciano-Granadina primipara and multipara does and bucks, respectively. Figure 1 represents eigenvalues across dimensions for primipara and multipara does and bucks, respectively.

Table 2. LAS varimax with Kaiser normalization rotated component loadings, eigenvalues and percentages of variance explained for Murciano-Granadina primipara and multipara does.

Primipara Does (Rotation Converged in Seven Iterations)	**1**	**2**	**3**	**4**	**5**
Stature (Height to withers)	**0.757**	−0.002	−0.048	0.011	−0.117
Chest width	**0.830**	−0.061	0.172	0.082	0.118
Body depth	0.364	**0.532**	0.436	−0.064	−0.037
Rump width	**0.799**	−0.185	0.109	0.067	0.082
Rump angle	0.169	0.463	−0.074	0.110	0.469
Angulosity	**0.658**	0.154	0.203	0.089	0.261
Bone quality	**−0.638**	−0.041	0.135	0.063	0.227
Anterior insertion	0.079	−0.075	0.088	−0.175	**0.772**
Rear insertion height	**−0.612**	−0.100	0.329	−0.040	−0.034
Median suspensor ligament	0.155	0.254	−0.130	**0.694**	−0.085
Udder width	0.250	0.077	**0.791**	0.048	−0.106
Udder depth	0.115	−0.176	0.112	**0.514**	−0.457
Nipple placement/insertion	−0.166	−0.075	0.182	**0.544**	0.424
Nipple diameter	0.018	−0.078	0.054	**0.656**	−0.064
Rear legs rear view	−0.313	0.008	**0.552**	0.101	0.259
Rear legs side view	−0.094	**0.807**	−0.013	−0.017	−0.090
Mobility	−0.188	**0.500**	0.417	−0.031	0.200
Cronbach's alpha *	0.771	0.579	0.409	0.300	0.118
Eigenvalues (9.785)	3.554	1.590	1.584	1.558	1.499
% of variance explained	20.904	30.256	39.576	48.739	57.558
Multipara does (Rotation converged in 17 iterations)	**1**	**2**	**3**	**4**	**5**
Stature (Height to withers)	0.304	**−0.637**	0.100	0.020	0.027
Chest width	**0.755**	−0.409	0.006	−0.056	−0.003
Body depth	**0.517**	0.012	0.217	0.426	−0.249
Rump width	**0.599**	−0.463	−0.148	−0.161	0.122
Rump angle	0.229	−0.118	−0.155	0.453	0.039
Angulosity	**0.695**	−0.220	0.044	0.123	−0.056
Bone quality	−0.174	**0.666**	−0.053	−0.032	−0.015
Anterior insertion	0.210	0.047	**−0.677**	0.028	0.096
Rear insertion height	−0.074	**0.665**	0.078	−0.036	−0.048
Median suspensor ligament	0.139	−0.126	**0.640**	0.218	0.336
Udder width	**0.541**	0.393	0.011	0.082	0.190
Udder depth	0.264	0.053	**0.741**	−0.262	0.045
Nipple placement/insertion	−0.030	0.040	−0.031	0.169	**0.761**
Nipple diameter	0.009	−0.042	0.122	−0.149	**0.657**
Rear legs rear view	0.186	**0.517**	−0.262	0.086	0.335
Rear legs side view	−0.106	−0.083	0.203	**0.788**	−0.053
Mobility	0.016	0.201	−0.203	**0.617**	0.094
Cronbach's alpha **	0.717	0.475	0.472	0.429	0.282
Eigenvalues (9.256)	3.133	1.854	1.636	1.449	1.184
% of variance explained	18.427	29.335	38.957	47.478	54.445

* Total Cronbach's alpha of 0.956 based on the total eigenvalue. ** Total Cronbach's alpha of 0.949 based on the total eigenvalue. Numbers in bold are indicative of significantly loaded components ≥|0.5|.

Table 3. LAS varimax with Kaiser normalization rotated component loadings, eigenvalues and percentage of variance explained for Murciano-Granadina bucks.

Bucks (Rotation Converged in 9 Iterations)	1	2	3
Stature (Height to withers)	**0.779**	−0.235	0.369
Chest width	**0.807**	−0.167	0.408
Body depth	**0.611**	−0.001	0.277
Rump width	**0.830**	−0.151	0.027
Rump angle	0.400	0.458	0.096
Angulosity	**0.759**	0.192	−0.352
Bone quality	−0.245	**0.589**	−0.085
Rear legs rear view	−0.04	**0.774**	0.038
Rear legs side view	0.258	−0.019	**0.770**
Mobility	−0.029	0.474	**0.520**
Cronbach's alpha (0.936 total based on the total eigenvalue)	0.774	0.710	0.471
Eigenvalues (6.093)	3.518	1.524	1.051
% of variance explained	35.178	15.242	10.512
Cumulative % of variance explained	35.178	50.419	60.932

Numbers in bold are indicative of significantly loaded components ≥|0.5|.

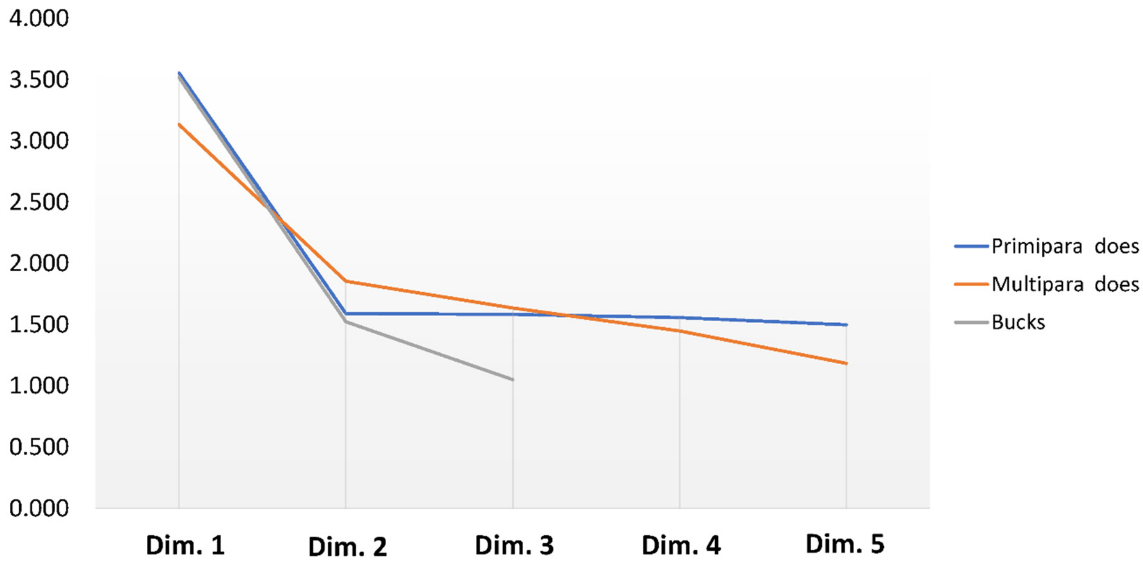

Figure 1. Representation of principal component analysis (PCA) eigenvalues for dimensions 1 to 5 (Dim. 1–5) for LAS scores in Murciano-Granadina primipara and multipara does and dimensions 1 to 3 in bucks.

3.3. Linear Regression Modelling for Zoometric Traits

Apart from the reasons reported above, categorical linear regression (CATREG) models for primipara and multipara does did not include the variable of rump angle as it had been shown to redundant in the PCA comprising LAS data (with component loadings < |0.5| across dimensions). For this reason, it was also excluded from the zoometric scale regression comparative model. Similarly, for adult and young males, the linear regression model did not include the variables included in the mammary system major category (anterior insertion, rear insertion height, median suspensor ligament, udder width, udder depth, nipple placement/insertion and nipple diameter) as these were not measured in males. Tables 4–6 report the results of β-standardized coefficients for each variable for the two linear regression models comprising LAS traits and Murciano-Granadina zoometric traditional assessment for primipara and multipara does and bucks, respectively. Each Z score was replaced by an observation (either LAS or traditional zoometric measurements) for each particular variable in each of the respective equations in Table S2.

Table 4. β-standardized coefficients to replace the Z score in each of the respective equations in Supplementary Table S5 and a 0.632 bootstrap mean squared error of prediction (MSEP) for the comparison of model validity between the two linear regression models using linear appraisal traits as opposed to Murciano-Granadina zoometric traditional assessment in does.

Primipara Does	Standardized Coefficients		df	F	Sig.
LAS Scores	Beta	Bootstrap (1000) MSEP			
Stature (height to withers)	0.065	0.009	4	57.649	0.001
Chest width	0.171	0.005	5	1071.447	0.001
Rump width	0.060	0.004	6	176.72	0.001
Angulosity	0.277	0.005	7	3722.306	0.001
Rear insertion height	0.083	0.004	6	388.694	0.001
Median suspensor ligament	0.514	0.006	3	6373.985	0.001
Udder width	0.156	0.005	8	1054.802	0.001
Udder depth	−0.387	0.008	7	2220.205	0.001
Nipple placement/insertion	0.065	0.005	6	196.097	0.001
Nipple diameter	−0.347	0.008	6	2056.723	0.001
Primipara Does	**Standardized Coefficients**		**df**	**F**	**Sig.**
Measurements	**Beta**	**Bootstrap (1000) MSEP**			
Stature (height to withers) in cm	0.020	0.007	1	7.835	0.005
Chest width in cm	0.130	0.008	1	250.042	0.001
Rump width in cm	0.104	0.008	1	190.155	0.001
Angulosity in degrees	0.249	0.007	1	1414.712	0.001
Anterior insertion in cm	−0.100	0.006	1	251.958	0.001
Median suspensor ligament in cm	0.313	0.008	1	1604.109	0.001
Udder width in cm	0.178	0.006	1	889.746	0.001
Udder depth in cm	−0.223	0.006	1	1185.176	0.001
Nipple placement/insertion in cm	−0.104	0.006	1	298.665	0.001
Nipple diameter in cm	−0.232	0.006	1	1348.291	0.001

Table 5. β-standardized coefficients to replace the Z score in each of the respective equations in Supplementary Table S5 and a 0.632 bootstrap mean squared error of prediction (MSEP) for the comparison of model validity between the two linear regression models using linear appraisal traits as opposed to Murciano-Granadina zoometric traditional assessment in does.

Multipara does	Standardized Coefficients		df	F	Sig.
LAS Scores	Beta	Bootstrap (1000) MSEP			
Stature (height to withers)	0.065	0.009	4	57.649	0.001
Chest width	0.171	0.005	5	1071.447	0.001
Rump width	0.060	0.004	6	176.72	0.001
Angulosity	0.277	0.005	7	3722.306	0.001
Rear insertion height	0.083	0.004	6	388.694	0.001
Median suspensor ligament	0.514	0.006	3	6373.985	0.001
Udder width	0.156	0.005	8	1054.802	0.001
Udder depth	−0.387	0.008	7	2220.205	0.001
Nipple placement/insertion	0.065	0.005	6	196.097	0.001
Nipple diameter	−0.347	0.008	6	2056.723	0.001
Primipara does	**Standardized Coefficients**		**df**	**F**	**Sig.**
Measurements	**Beta**	**Bootstrap (1000) MSEP**			
Stature (height to withers) in cm	0.020	0.007	1	7.835	0.005
Chest width in cm	0.130	0.008	1	250.042	0.001
Rump width in cm	0.104	0.008	1	190.155	0.001
Angulosity in degrees	0.249	0.007	1	1414.712	0.001
Anterior insertion in cm	−0.100	0.006	1	251.958	0.001
Median suspensor ligament in cm	0.313	0.008	1	1604.109	0.001
Udder width in cm	0.178	0.006	1	889.746	0.001
Udder depth in cm	−0.223	0.006	1	1185.176	0.001
Nipple placement/insertion in cm	−0.104	0.006	1	298.665	0.001
Nipple diameter in cm	−0.232	0.006	1	1348.291	0.001

Table 6. β-standardized coefficients to replace the Z score in each of the respective equations in Supplementary Table S5 and a 0.632 bootstrap mean squared error of prediction (MSEP) for the comparison of model validity between the two linear regression models using linear appraisal traits as opposed to Murciano-Granadina zoometric traditional assessment in bucks.

Bucks	Standardized Coefficients		df	F	Sig.
LAS Scores	Beta	Bootstrap (1000) MSEP			
Stature (Height to withers)	0.274	0.028	6.000	98.843	0.001
Chest width	0.212	0.027	4.000	61.434	0.001
Rump width	0.174	0.023	4.000	57.311	0.001
Angulosity	0.282	0.018	7.000	250.375	0.001
Bucks	**Standardized Coefficients**		**df**	**F**	**Sig.**
Measurements	**Beta**	**Bootstrap (1000) MSEP**			
Stature (Height to withers) in cm	0.250	0.036	1.000	48.220	0.001
Chest Width in cm	0.236	0.036	1.000	42.081	0.001
Rump Width in cm	−0.264	0.026	1.000	107.334	0.001
Angulosity in degrees	0.353	0.017	1.000	451.181	0.001

3.4. Categorical Linear Regression (CATREG) Modelling Validation

Tables 4–6 report a summary of the parameters computed to compare the CATREG models comprising Murciano-Granadina LAS scores to those comprising zoometric traditional assessment variables. Concretely, Tables 4 and 5 report a 0.632 bootstrap mean squared error of prediction (MSEP) to test for model cross validation in bucks and does, respectively. Table 6 shows a summary of the determination coefficients (R^2 and Adj. R^2) to compare the explanatory variability. R^2 values were 0.779, 0.660 and 0.734 for primipara does, multipara does and bucks, respectively, when computed through the model using Murciano-Granadina zoometric traditional assessment.

Values of R^2 slightly (0.859) to moderately/highly increased (0.883 and 0.813) for bucks, primipara and multipara does, respectively, for models which used LAS scores (Table 7). All models reported a highly statistically significant ability to predict the outcome of the variables measured when compared to the raw models exclusively consisting of the interception but excluding any predictor, as suggested by the values of MSPE and $P < 0.001$ for the ANOVA for regression analysis.

Table 7. β-standardized coefficients to replace the Z score in each of the respective equations in Supplementary Table S5 and a 0.632 bootstrap mean squared error of prediction (MSEP) for the comparison of model validity between the two linear regression models using linear appraisal traits as opposed to Murciano-Granadina zoometric traditional assessment in does and bucks.

Gender	Method	Multiple R	R Square (R^2)	Adjusted R Square (Adj, R^2)
Primipara does	Measurements	0.631	0.399	0.398
	LAS Scores	0.883	0.779	0.779
Multipara does	Measurements	0.630	0.397	0.397
	LAS Scores	0.813	0.661	0.660
Bucks	Measurements	0.804	0.647	0.646
	LAS Scores	0.859	0.738	0.734

Following the premises of information theory, several methods have been presented for the comparison of models with regard to their ability to explain or capture the variability observed in the data set being studied (Akaike information criterion (AIC) and corrected Akaike information criterion (AICc)) and the predictive potential (Bayesian information criterion (BIC)) of the model designed for the data being modeled. Additionally, the mean square residual or error (MSE) measures how close a regression line is to a set of points; that is, how well a certain model fits the data being observed. The minimum mean-square residual or error (MMSE) was calculated as shown in Asherson, et al. [22]:

$$\text{MMSE} = (1/\text{N}) \times (\text{MSE}) \quad (1)$$

where N is the number of animals and MSE is the mean square residual or error.

The Akaike information criterion (AIC), Corrected Akaike information criterion (AICc) and Bayesian information criterion (BIC), were calculated as suggested in [23] as follows:

$$\text{AIC} = \text{N}\ln(\text{RSS}/\text{N}) + 2\text{K} \quad (2)$$

where RSS is the residual sum of squares, N is the number of data points and K is the number of IVs of the model.

With data sets without a large number of data points (N) or for models containing several parameters, the corrected AICc may be more accurate; however, similar results of AIC and AICc are likely to be reported if a high number of observations are studied.

$$\text{AICc} = \text{AIC} + 2\text{K}(\text{K} + 1)/\text{N}(\text{N} + 1) \quad (3)$$

where K is the number of parameters and N is the number of observations.

The Bayesian information criterion (BIC; [24]) is a model order selection criterion which penalizes more complicated models for the inclusion of additional parameters.

$$\text{BIC} = \text{N} \times \text{N}\ln(\text{RSS}/\text{N}) + \text{K} \times \ln(\text{N}) \quad (4)$$

A small numerical value of MSE, MMSE, AIC, AICc and BIC indicates a better fit when comparing models. Table 8 shows a summary of the measures for model fit using the mean square residual or error and minimum square residual or error (MSE and MMSE), explanatory variability power using the Akaike information criterion (AIC) and corrected Akaike information criterion (AICc) and predictive power using the Bayesian information criterion for the two linear regression models comprising linear appraisal traits as opposed to Murciano-Granadina zoometric traditional assessment in does and bucks.

Table 8. Summary of the measures for model fit using the mean square residual or error and minimum square residual or error (MSE and MMSE), explanatory variability power using the Akaike information criterion (AIC) and corrected Akaike information criterion (AICc) and predictive power using the Bayesian information criterion for the two linear regression models comprising linear appraisal traits as opposed to Murciano-Granadina zoometric traditional assessment in does and bucks.

Sex/Lactation Phase	Primipara Does		Multipara Does		Bucks	
Parameters	LAS Scores	Measurements	LAS Scores	Measurements	LAS Scores	Measurements
RSS	5012.853	13,665.474	5804.558	10,318.972	389.064	523.915
MSE	0.221	0.602	0.340	0.603	0.267	0.354
MMSE	0.000	0.000	0.000	0.000	0.000	0.000
N	22,727.000	22,727.000	17,111.000	17,111.000	1485.000	1485.000
K	10.000	10.000	10.000	10.000	4.000	4.000
AIC	−34,332.961	−11,540.796	−18,478.327	−8633.672	−1981.048	−1539.133
AICc	−34,332.961	−11,540.796	−18,478.327	−8633.672	−1981.048	−1539.133
BIC	−780,739,648.63	−262,742,116.00	−316,524,770.59	−148,072,892.00	−2,953,706.92	−2,297,463.71

4. Discussion

The present study aimed to compare, validate and optimize the linear appraisal methodological approaches proposed by Martinez et al. (2010) for does and bucks in the Murciano-Granadina goat breed to determine the quality of the LAS, which is routinely applied in opposition to traditional zoometric analysis, for dairy-related morphological traits. The combination of principal components and regression analyses has been reported to yield good estimates for the coefficients of explanatory variables aiming to measure the same DV. Reddy and Claridge [25] suggested that regression analysis and principal component analysis (PCA) can be used to determine reduced numbers of explanatory variables to explain the variability described by a certain DV.

With regard to the optimization of CAPRIGRAN LAS, principal components analysis reported quite conservative results, as only the rump angle was omitted from the variables considered for primipara and multipara does and bucks. Additionally, the optimization of the models reported a substantial internal consistency [26]; i.e., the optimized linear appraisal scales used showed good reliability (with values over 0.9). Thus, there was a significant validated ability to explain internal variability, as suggested by the Cronbach's alpha values.

The Cronbach's alpha values were slightly higher for primipara and multipara does than for bucks, with the set of variables evaluated for does reporting a Cronbach's alpha value of 0.956 and 0.949 as opposed to the value of 0.936 reported for bucks, which suggested a slightly greater internal consistency in the case of females, which could be attributed to the dairy-related nature of the zoometric traits used in this study. However, the variability that each of the models was able to explain was moderately higher in males than in females, with values of 60.932% for bucks as opposed to values of 57.558 and 54.445% for primipara and multipara does. This could be ascribed to the slightly greater variability found in bucks, which was suggested by the descriptive statistics shown in Tables S3–S5, respectively.

The computation of Cronbach's alpha was used as it is based on the comparison of the reliability of a test relative to other tests with the same number of items and measuring the same construct of interest [27]; thus, its application in the validation of linear appraisal system scales allowed us to report solid and objective results regarding the reliability of the translation from zoometric measurements to LAS scores.

PCA identifies the variables that explain the highest fraction of variability in a dataset, and then it uses this information to create a dataset with a reduced number of variables with minimal loss of descriptive power. Bearing this in mind, the greater percentage of variability explained in the case of bucks may be ascribed to the greater variability found in the population of males, as suggested by the descriptive statistics in Tables S3–S5.

One of the advantages that datasets with a reduced number of variables present compared to more complex datasets is that these should have less noise in the data, thus requiring less processing power, which in turn results in optimized variable sets that can be considered to explain or estimate a joint outcome; for example, in the present paper, the dairy-related morphological value of a certain animal. Still, the features of the most highly variable predictors may not necessarily be the best predictors of the variability in the whole dataset. Concretely, the most relevant predictors will bethose with a higher influence on the dimensions identified by PCA and thus with a larger absolute component loading (shown in Tables 2 and 3 for primipara and multipara does and bucks, respectively).

According to Wang and Wu [28], in PCA, the differences in the variability of the features considered may differ as a result of the differences in their related eigenvalues. However, this difference is not equivalent to that of the importance of the different components to the PCA pattern classification described. Indeed, these authors suggest that the contribution of each component is determined by the specific construct itself (the dairy-related morphological value of each animal).

In this context, some elements may address common features of all the dimensions that are included in the analyses, while others may be less significant in the process of classification across dimensions. In contrast, other elements or features may correspond to the characteristics of individual dimensions and thus may present a greater significance in PCAs. Because of the differences in variability across the different elements, it could be stated that the largest variabilities shown in Tables S3–S5 may be caused mainly by the differences between different dimensions. Such differences are larger in bucks than in does; thus, a rather significant contribution could be expected in the process of the classification of variables into principal components (dimensions), which may translate into a higher ability to capture the variability in the dataset.

Our results suggest the existence of five reorganized major categories (principal components/ dimensions). In the case of primipara does (Table 2), the first category includes the variables of stature (height to withers), chest width, rump width, angulosity, bone quality and rear insertion height, as suggested by values of component loadings over |0.5|. In this case, the results suggest the restructuration of the existing major categories of structure and capacity, dairy structure and mammary system. Although chest width, rump width and angulosity kept their relative importance within the first dimension of PCA for both primipara and multipara does, udder width and body depth became relevant for multipara does to the detriment of stature, bone quality and rear insertion height.

Considering the variables classified in the first dimension for both primipara and multipara does, the newly statistically suggested major category could be called "structural dairy-related capacity". The relationship between morphological characteristics and dairy production-related traits reported by our results has been widely described in the literature. The relationship between indirectly dairy-related morphological variables and dairy-related morphological ones may be based on the fact that Murciano-Granadina goats could be ascribed to a dairy morphological trunk, as suggested by Jordana, et al. [29]. From a genetic–morphological perspective, the inclusion of the Murciano-Granadina breed within a dairy purpose-linked morphological pattern suggests that the morphological characteristics which may be empirically related to milk production may be relevant to define the purpose of certain breeds, but may also address the fact that other zoometric features somehow adapt, through selection practices, to the maximization of the achievement of this purpose.

The second dimension in primipara does clusters together variables in the fourth dimension for multipara does. These dimensions comprised the variables of body depth, rear legs side view and mobility, which suggests a relationship between rump conformation and rear legs with mobility quality. Additionally, the variable of rump angle was clustered in the fourth dimension of multipara does as well. In view of our results, we propose the category of the "mobility and propulsion system" for the identified principal component/dimension. Although no reference has been reported for the connection of these measurements for goats or large ruminants, a close connection between limb mobility and the back was reported by Dyce, et al. [30], due to the continuity of some soft tissue structures; for instance, the common aponeurosis of the longissimus dorsi muscle given its implication with the development of back motion, and the middle gluteal muscle given its instrumental role in the mechanisms of propulsion. Additionally, Jeffcott [31] suggested that the protraction of the forelimbs extends the back, as does the retraction of the hindlimbs; thus, forelimb retraction and hindlimb protraction may have opposite effects, which accounts for the statistical exclusion of forelimb-related variables from this dimension. Although the relationship of movements with goat milk yield and quality has not been directly approached in the literature, Di Grigoli, et al. [32] suggested goats that goats possess a great capacity of movement which is improved by a lower milk yield but compensated by a better milk quality and a reduction in manpower. Both aspects may represent interesting research lines given the economic importance derived from increasing milk quality at a lower production cost.

The fourth and fifth dimensions for primipara does and third and fifth dimensions for multipara does comprised anterior insertion, rear insertion height, median suspensor ligament, udder width, udder depth, nipple placement/insertion and nipple diameter. Thus, for primipara does, median suspensor ligament, udder depth, nipple placement/insertion and nipple diameter were clustered together in the fourth dimension, while anterior insertion was taken separately in the fifth dimension. This suggests the denomination of the fourth dimension as "udder stability quality and nipple configuration" and the fifth dimension as "anterior insertion of the udder" in primipara does. The fourth and fifth dimensions in primipara does and third and fifth dimensions in multipara does suggested the evolution of the importance of the suspensory system of the udder as the lactation of certain does progress over time.

Contextually, for multipara does, variables within the third and fifth dimensions are clustered in such a way that the third dimension could be defined as the major category of "udder stability quality" (anterior insertion, median suspensor ligament and udder depth). This could be supported by the relationship that has been identified by our results and those of other authors [33], who suggested that the variables comprising this dimension should be treated equally with respect to their importance and the increase in the coefficients by which they should be multiplied to improve dairy-related morphological selection indexes aimed at the maximization of dairy production in Ayrshire cattle.

Then, the fifth and last dimension in multipara does comprised the variables of nipple placement and nipple diameter; thus, we decided to name this major category "nipple configuration". Studies in regards to the relationship between nipple characteristics and milk yield or quality-related traits are scarce. Among the nipple characteristics, the spacing between the nipples has been suggested to affect the peak lactation of goat milk production [34], and nipple length may present a positive effect on goat milk production, as suggested by El-Gendy, et al. [35]. This was supported by the results of other authors who reported that values of nipple morphological parameters such as length, and the circumference of nipples may have a positive correlation to goat milk production [36], which may support our results, according to which nipple diameter may be a relevant factor to explain population variability with regard to milk production-related traits.

Despite nipple attributes being directly related to milk quality in goats, as previously suggested, studies have focused rather on the relationship between the technological features of the udder in terms of its adaptability to milking machines, and the relationship of nipple position with dairy production-related traits is infrequent. In this context, the relationship between udder conformation traits and milk composition—and as a consequence, its effects on milk quality—was supported by the findings of the study by Wagay, et al. [37]. These authors suggested that animals presenting thinner teats and less fore-udder depth will produce milk with higher fat and solids-not-fat (SNF) percentages, while animals with teats held high from the ground and deeper and wider udders will produce healthy milk with a lower somatic cell count, which may imply a potential relationship between nipple attributes—especially, nipple diameter and milk quality—in cattle. In this context, for goats, the study by Eyduran, et al. [38] reported a significant relationship between teat angle (which could indirectly measure nipple position) and lactation duration or milk yield, which may support our results.

The third dimension of primipara does and the second dimension of multipara does comprise the variable of rear legs rear view. However, for primipara does, rear legs rear view is clustered together with the variable of udder width. Given this finding, the dimension could be designated as "udder size and mobility permission". The importance of the mobility of milk quality has already been suggested in the paragraph above; however, additionally, the relationship between udder size and rear limbs has been addressed in the literature by authors such as Bölling and Pollott [39], who suggested that more bulgy udders of mature animals may form an obstacle for hindlimbs and force animals to describe a circle to circumvent the udder [40,41], which may result in a splay-legged walk, uneven footwear and could lead to lameness [42], with consequent detrimental effects on mobility and a potential effect on the reduction of milk quality. By contrast, for multipara does (second dimension), udder width loses its relevance in favor of stature (height to the withers), bone quality and rear insertion height. Rear insertion height is the distance between the vulva and the noble secretor tissue. This suggests that, as lactation phases progress, the udder starts to hang lower from its insertion, which may be counteracted by the stature and bone quality of the animal. This was suggested given the significant component loadings for these variables in the second dimension for multipara does, who reported the opposite sign; thus, a relationship to the first dimension in primipara does was shown, by which stature (height to the withers) and bone quality were clustered together. This may suggest that "structural dairy-related capacity" in multipara does is not affected by the conformation of the rump and angulosity of the animal, as occurs in primipara does. Additionally, stature may play a stronger role in structural dairy-related capacity when does are in the first phase of lactation, while rear insertion height and bone quality may be decisive as lactation phases progress. Thyroid hormone responsive (THRSP) gene has been reported to encode for small acidic nuclear protein, which is associated with growth, and to promote the synthesis of medium-chain fatty acids in goat mammary epithelial cells [43,44], which may account for the clustering patterns found in our study.

In the case of bucks, only rump angle was discarded given its lack of representation in the explanation of milk yield and milk quality-related traits. In the case of males, this lack of representation may be ascribed to the lack of milk production capacity, which reduces the implication and relevance of this variable. Three principal components/dimensions were identified; thus, only three major categories were determined, which are listed as follows.

The first dimension comprised the variables of stature (height to withers), chest width, body depth, rump width, and angulosity, which may match the observations previously been described for does. However, in this case, we opted to term this dimension "body structure". After comparing the results for males and females, we observed moderate repercussions of body depth in males and a lack of repercussions in females. This could agree with the results found by Waheed, et al. [45], who reported body depth at heart to be moderately genetically but slightly phenotypically correlated to milk productive traits such as lactation milk yield or lactation length (0.42 ± 0.09 and 0.28 ± 0.09 genetic correlations with milk yield and lactation length, respectively, and 0.29 ± 0.07 and 0.22 ± 0.07 phenotypic correlations with milk yield and lactation length, respectively). The same authors reported that these correlations increased when body depth was measured at the belly (with genetic correlations of 0.82 ± 0.09 and 0.28 ± 0.11 with milk yield and lactation length, respectively, and phenotypic correlations of 0.43 ± 0.07 with milk yield and 0.29 ± 0.08 lactation length, respectively). As we can observe from the values reported by these authors, the standard errors of prediction were high in comparison to the magnitude of the correlations detected, which may account for the variability with regard to these traits. This moderate effect is supported by the component loading of 0.611 for males and can be inferred as it is slightly below the limits of |0.5| for does in the third dimension, which we have previously designated as the "mobility and propulsion system". The moderate (0.02; i.e., below the threshold for component loadings) relationship between body depth (the distance between the top of the spine and the bottom of the barrel at the last rib, as described by Akpa, et al. [46]) with the rest of variables within the "mobility and propulsion system" for does may be ascribed to the involvement of back muscles in the development of hindlimb mobility and propulsion, which has already been mentioned in the present paper and suggested by Dyce, et al. [30]. Contrastingly, this increase in the relevance of body depth in males, and its inclusion within the "body structure" dimension, rather than its relationship with the movement quality and propulsion system could be derived from the residual destination of kids for meat production, which may have indirectly resulted in the selection of this trait in male kids.

The second dimension comprised the variables of bone quality and rear legs rear view, while the third dimension comprised the variables of rear legs side view and mobility. These results match our findings for does except for bone quality, which in the case of does was clustered in "structural dairy-related capacity", while in males it appeared to be related to "bone structure and aplomb". Such a difference between the ascription of bone quality to markedly different dimensions when males and females are compared may derive from the changes which occur in bone quality across lactational stages in does [47]. However, for males, according to Guo, et al. [48], a potential explanation of the relationship between these two variables may stem from the single nucleotide polymorphism (SNP) effects that have been reported for the lactoferrin gene on milk production traits. For instance, the same authors reported a significant effect on bone growth and the content of milk protein. Furthermore, bovine or human lactoferrin has been suggested to influence skeletal tissue as an anabolic factor and a potent osteoblast survival factor [49], as it may stimulate the proliferation of bone formation promotion cells, osteoblasts and cartilage cells at physiological concentrations in vitro. The third dimension in bucks comprised the same variables as in does, except for rump angle, which could not be attributed to any dimension. For these reasons, we decided to name this dimension or major category as "mobility" for the reasons that have been already reported for does.

Categorical regression analysis and 0.632 bootstrap estimates confirmed that the models comprising LAS scores for all the variables studied across major areas for does and males were more capable of capturing and explaining the variability found in the population as suggested by the R^2 values in the range of 80% and adjusted values of R^2 in the range of 0.7 in opposition to those reported by the model comprising direct zoometric measurements expressed in cm and degrees (Table 7). All models were statistically significant and presented a negligible squared error of prediction, which suggested the high reliability of the linear regression models proposed.

When model fit (scored by MSE), variability explanation power (scored by AIC and AICc) and predictive power (scored by BIC) of linear regression models for Murciano-Granadina LAS scores and zoometric traditional assessment were compared in does and bucks, LAS scores always reported a better fit, a better ability to capture the variability in the data sets and better predictive potential as suggested by the lower values for each respective parameter (Table 8). Bucks reported lower estimates for the aforementioned parameters; however, the differences in the number of variables comprised by the two models and the nature of the variables considered may make it necessary to carefully analyze these estimates when the objective is to make a direct comparison of models between genders. This drawback can be overcome as, when the coefficients used to build regression models are standardized, the intercept obtains a value of 0.00 from the compensation of standard deviation after the standardization process. Thus, MSE, AIC, AICc, and BIC can be directly used to compare each model with one exclusively comprising the interception on each case, without the need to include the same variables, for these variables to be scored using the same methods or even for these variables to be scored using the same measurement units, as in our study, in which an ordinal LAS scale is compared to a numeric zoometric scale with variables expressed in centimeters and degrees.

5. Conclusions

Principal component analyses determined that the linear scoring system was solid and internally consistent for the measurement and capture of the variability of zoometric parameters related to dairy performance. However, the resulting models were quite conservative, as only one variable from the whole zoometric panel was discarded for bucks and does. The outputs of linear regression demonstrate that an optimal fit, variability explanatory power and predictive potential can be achieved by modeling a reduced number of variables from the entire linear appraisal scoring system and traditional zoometric evaluation for Murciano-Granadina does and bucks. Conclusively, our results suggest that the combination of PCA and categorical regression (CATREG) may be successful for the optimization and validation of the reduction of zoometric evaluation procedures and linear appraisal scoring systems such that they are not only able to describe the status of a certain population but can also be used to predict the future evolution of parameters based on their linear correlations.

Supplementary Materials: The following are available online at http://www.mdpi.com/2076-3417/10/16/5502/s1, Figure S1: Graphical depictions of the scale for stature in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S2: Graphical depictions of the scale for chest width in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S3: Graphical depictions of the scale for body depth in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S4: Graphical depictions of the scale for rump width in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S5: Graphical depictions of the scale for rump angle in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S6: Graphical depictions of the scale for angulosity in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S7: Graphical depictions of the scale for bone quality in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S8: Graphical depictions of the scale for anterior insertion in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S9: Graphical depictions of the scale for rear insertion height in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S10: Graphical depictions of the scale for median suspensor ligament in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S11: Graphical depictions of the scale for udder width in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S12: Graphical depictions of the scale for udder width in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S13: Graphical depictions of the scale for nipple placement in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S14: Graphical depictions of the scale for nipple diameter in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S15: Graphical depictions of the scale for rear legs, rear view in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S16: Graphical depictions of the scale for rear legs, side view in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S17: Graphical depictions of the scale for mobility in Murciano-Granadina does for dairy purpose-related zoometric assessment; Figure S18: Graphical depictions of the scale for stature in Murciano-Granadina bucks for dairy purpose-related zoometric assessment; Figure S19: Graphical depictions of the scale for chest width in Murciano-Granadina bucks for dairy purpose-related zoometric assessment; Figure S20: Graphical depictions of the scale for body depth in Murciano-Granadina bucks for dairy purpose-related zoometric assessment; Figure S21: Graphical depictions of the scale for rump width in Murciano-Granadina bucks for dairy purpose-related zoometric assessment; Figure S22: Graphical depictions of the scale for rump angle in Murciano-Granadina bucks for dairy purpose-related zoometric assessment. Figure S23: Graphical depictions of the scale for angulosity in Murciano-Granadina bucks for dairy purpose-related zoometric assessment; Figure S24: Graphical depictions of the scale for bone quality in Murciano-Granadina bucks for dairy purpose-related zoometric assessment; Figure S25: Graphical depictions of the scale for rear legs, rear view in Murciano-Granadina bucks for dairy purpose-related zoometric assessment; Figure S26: Graphical depictions of the scale for rear legs, side view in Murciano-Granadina bucks for dairy purpose-related zoometric assessment; Figure S27: Graphical depictions of the scale for mobility in Murciano-Granadina bucks for dairy purpose-related zoometric assessment; Table S1. Detailed and analytical composition of the diet provided to the animals; Table S2. Summary of descriptive statistics for zoometric traits in Murciano-Granadina primipara does derived from linear appraisal and zoometric assessment; Table S3. Summary of descriptive statistics for zoometric traits in Murciano-Granadina multipara does derived from linear appraisal and zoometric assessment; Table S4. Summary of descriptive statistics for zoometric traits in Murciano-Granadina bucks derived from linear appraisal and zoometric assessment; Table S5. Spearman's correlation coefficients for linear appraisal-derived zoometric traits in Murciano-Granadina primipara does; Table S6. Spearman's correlation coefficients for linear appraisal-derived zoometric traits in Murciano-Granadina multipara does; Table S7. Spearman's correlation coefficients for linear appraisal-derived zoometric traits in Murciano-Granadina bucks; Table S8. Simplification process of categorical linear regression (CATREG) models for does and bucks from the general description to a reduced dimensionality after principal components analysis (PCA) and development of linear comparative models to determine the validity of linear appraisal traits as opposed to Murciano-Granadina zoometric traditional assessment.

Author Contributions: Conceptualization, F.J.N.G. and J.V.D.B.; Data curation, J.M.L.J., F.J.N.G., C.I.P. and C.I.P.; Formal analysis, J.M.L.J., F.J.N.G. and C.I.P.; Funding acquisition, J.V.D.B.; Investigation, J.F.Á. and F.J.N.G.; Methodology, F.J.N.G., C.I.P. and J.V.D.B.; Project administration, J.V.D.B.; Resources, J.F.Á. and J.V.D.B.; Software, J.M.L.J. and F.J.N.G.; Supervision, F.J.N.G. and J.V.D.B.; Validation, J.V.D.B.; Writing—original draft, J.F.Á., F.J.N.G. and J.V.D.B.; Writing—review & editing, J.M.L.J., F.J.N.G. and J.V.D.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Acknowledgments: This work would not have been possible without the support and assistance of the National Association of Breeders of the Murciano-Granadina Goat Breed, Fuente Vaqueros (Spain) and the PAIDI AGR 218 research group.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Martinez, B.; Vicente, C.; Picchioni, M.; Sanchez, M.; Gómez, E.; Peris, C. Integration of the linear morphological appraisal system in the dairy goat improvement genetic program of Murciano-Granadina breed. In Proceedings of the XXXV Congreso de la Sociedad Española de Ovinotecnia y Caprinotecnia (SEOC), Valladolid, España, 22–24 September 2010; pp. 470–474.
2. Association, A.D.G. Recent Goat Type Appraisal Data (Number of Appraisals by Year). Available online: http://adga.org/36856-2/ (accessed on 26 January 2020).
3. Delgado, J.V.; Landi, V.; Barba, C.J.; Fernández, J.; Gómez, M.M.; Camacho, M.E.; Martínez, M.A.; Navas, F.J.; León, J.M. Murciano-Granadina goat: A Spanish local breed ready for the challenges of the twenty-first century. In *Sustainable Goat Production in Adverse Environments: Volume II*; Springer: Cham, Switzerland, 2017; pp. 205–219.
4. Sánchez Rodríguez, M.; Cárdenas Baena, J.M.; Blanco del Campo, G. Rasgos descriptivos lineales. In *Valoración Morfológica del Ganado Caprino Lechero*; Cabrandalucía, F., Ed.; Servet Diseño y Comunicación: Zaragoza, Spain, 2012.
5. Asociación Nacional de Criadores de Caprino de Raza Murciano-Granadina. Calificación Morfológica Lineal. Available online: http://www.caprigran.com/ (accessed on 26 January 2020).
6. Vieira, A.; Brandão, S.; Monteiro, A.; Ajuda, I.; Stilwell, G. Development and validation of a visual body condition scoring system for dairy goats with picture-based training. *J. Dairy Sci.* **2015**, *98*, 6597–6608. [CrossRef]
7. Anzuino, K.; Bell, N.; Bazeley, K.; Nicol, C. Assessment of welfare on 24 commercial UK dairy goat farms based on direct observations. *Vet. Rec.* **2010**, *167*, 774–780. [CrossRef] [PubMed]
8. Pares-Casanova, P.M.; Sinfreu, I.; Villalba, D. Application of varimax rotated principal component analysis in quantifying some zoometrical traits of a relict cow. *Korean J. Vet. Res.* **2013**, *53*, 7–10. [CrossRef]
9. Vincent, S.; Araku, J.; Ayongu, F.; Chia, S.; Momoh, O.; Yakubu, A. Redundancy Elimination from Morpho-Stuctures of Nigerian Uda Rams Using Principal Component Analysis. *J. Anim. Prod. Adv.* **2014**, *14*, 520–526. [CrossRef]

10. Manfredi, E.; Piacere, A.; Lahaye, P.; Ducrocq, V. Genetic parameters of type appraisal in Saanen and Alpine goats. *Livest. Prod. Sci.* **2001**, *70*, 183–189. [CrossRef]
11. Wiggans, G.R.; Hubbard, S.M. Genetic Evaluation of Yield and Type Traits of Dairy Goats in the United States. *J. Dairy Sci.* **2001**, *84*, E69–E73. [CrossRef]
12. Bishara, A.J.; Hittner, J.B. Testing the significance of a correlation with nonnormal data: Comparison of Pearson, Spearman, transformation, and resampling approaches. *Psychol. Methods* **2012**, *17*, 399. [CrossRef]
13. Walde, J. Principal Components Analysis (PCA). In *Advanced Statistics*; Universität Innsbruck: Innsbruck, Austria, 2020.
14. IBM Knowledge Center. *KMO and Bartlett's Test*; IBM Corp: Armonk, NY, USA, 2019.
15. Field, A. *Discovering Statistics Using IBM SPSS Statistics*, 3rd ed.; Sage: Thousand Oaks, CA, USA, 2013.
16. George, D.; Mallery, M. *Using SPSS for Windows Step by Step: A Simple Guide and Reference*; Allyn & Bacon, Inc.: Boston, MA, USA, 2003.
17. IBM Corp. *IBM SPSS Statistics for Windows, 25.0*; IBM Corp: Armonk, NY, USA, 2017.
18. Hébert, J.R.; Miller, D.R. The inappropriateness of conventional use of the correlation coefficient in assessing validity and reliability of dietary assessment methods. *Eur. J. Epidemiol.* **1991**, *7*, 339–343. [CrossRef]
19. Bland, J.; Altman, D. A note on the use of the intraclass correlation coefficient in the evaluation of agreement between two methods of measurement. *Comput. Biol. Med.* **1990**, *20*, 337–340. [CrossRef]
20. Boateng, G.O.; Neilands, T.B.; Frongillo, E.A.; Melgar-Quiñonez, H.R.; Young, S.L. Best Practices for Developing and Validating Scales for Health, Social, and Behavioral Research: A Primer. *Front. Public Health* **2018**, *6*, 149. [CrossRef]
21. Mevik, B.H.; Cederkvist, H.R. Mean squared error of prediction (MSEP) estimates for principal component regression (PCR) and partial least squares regression (PLSR). *J. Chemom.* **2004**, *18*, 422–429. [CrossRef]
22. Asherson, R.; Walker, S.; Jara, L.J. *Endocrine Manifestations of Systemic Autoimmune Diseases*; Elsevier: Amsterdam, The Netehrlands, 2008.
23. Karangeli, M.; Abas, Z.; Koutroumanidis, T.; Malesios, C.; Giannakopoulos, C. Comparison of Models for Describing the Lactation Curves of Chios Sheep Using Daily Records Obtained from an Automatic Milking System. In Proceedings of the 5th International Conference on Information & Communication Technologies in Agriculture, Food and Environment (HAICTA), Skiathos, Greece, 8–11 September 2019; pp. 571–589.
24. Leonard, T.; Hsu, J.S.J. *Bayesian Methods: An Analysis for Statisticians and Interdisciplinary Researchers (Cambridge Series in Statistical and Probabilistic Mathematics)*; Cambridge University Press: Cambridge, UK, 2001; Volume 5.
25. Reddy, T.A.; Claridge, D. Using synthetic data to evaluate multiple regression and principal component analyses for statistical modeling of daily building energy consumption. *Energy Build.* **1994**, *21*, 35–44. [CrossRef]
26. Tavakol, M.; Dennick, R. Making sense of Cronbach's alpha. *Int. J. Med. Educ.* **2011**, *2*, 53. [CrossRef] [PubMed]
27. Hatcher, L. *A Step-by-Step Approach to Using the SAS(R) System for Factor Analysis and Structural Equation Modeling*; SAS Institute: Cary, NC, USA, 1994.
28. Wang, H.-Y.; Wu, X.-J. Weighted PCA space and its application in face recognition. In Proceedings of the 2005 International Conference on Machine Learning and Cybernetics, Guangzhou, China, 18–21 August 2005; pp. 4522–4527.
29. Jordana, J.; Ribo, O.; Pelegrin, M. Analysis of genetic relationships from morphological characters in Spanish goat breeds. *Small Rumin. Res.* **1993**, *12*, 301–314. [CrossRef]
30. Dyce, K.; Sack, W.; Wensing, C. The hindlimb of the horse. In *Dyce, Sack, and Wensing's Textbook of Veterinary Anatomy*; Saunders: Philadelphia, PA, USA, 1996.
31. Jeffcott, L. Back problems in the horse—A look at past, present and future progress. *Equine Vet. J.* **1979**, *11*, 129–136. [CrossRef]
32. Di Grigoli, A.; Bonanno, A.; Alabiso, M.; Brecchia, G.; Russo, G.; Leto, G. Effects of housing system on welfare and milk yield and quality of Girgentana goats. *Ital. J. Anim. Sci.* **2003**, *2*, 542–544.
33. Trukhachev, V.; Oliinyk, S.; Zlidnev, N. Directions to improvement selection-technological features of cattle Ayrshire breed. In Proceedings of the 16th International Scientific Conference "Engineering for Rural Development", Jelgava, Latvia, 24–26 May 2017.
34. Merkhan, K.; Alkass, J. Influence of udder and teat size on milk yield in Black and Meriz goats. *Res. Opin. Anim. Vet. Sci* **2011**, *1*, 601–605.
35. El-Gendy, M.; Youssef, H.F.; Saifelnasr, E.; El-Sanafawy, H.A.; Saba, F.E. Relationship between udder characteristics and each of reproductive performance and milk production and milk composition in Zaraibi and Damascus dairy goats. *Egypt. J. Sheep Goat Sci.* **2014**, *9*, 95–104.

36. Upadhyay, D.; Patel, B.; Kerketta, S.; Kaswan, S.; Sahu, S.; Bhushan, B.; Dutt, T. Study on udder morphology and its relationship with production parameters in local goats of Rohilkhand region of India. *Indian J. Anim. Res.* **2014**, *48*, 615–619. [CrossRef]
37. Wagay, M.A.; Tomar, A.; Lone, S.; Singh, A.K.; Carolina, P. Association of milk quality parameters with teat and udder traits in Tharparkar cows. *Indian J. Anim. Res.* **2018**, *52*, 1368–1372. [CrossRef]
38. Eyduran, E.; Yılmaz, İ.; Kaygısız, A.; Aktaş, Z. An investigation on relationship between lactation milk yield, somatic cell count and udder traits in first lactation turkish saanen goat usıng different statistical techniques. *J. Anim. Plant Sci.* **2013**, *23*, 956–963.
39. Bölling, D.; Pollott, G. Locomotion, lameness, hoof and leg traits in cattle I.: Phenotypic influences and relationships. *Livest. Prod. Sci.* **1998**, *54*, 193–203.
40. Greenough, P.R. *Bovine Laminitis and Lameness: A Hands on Approach*; Elsevier Health Sciences: Amsterdam, The Netherlands, 2007.
41. Greenough, P.R.; MacCallum, F.J.; Weaver, A.D. *Lameness in Cattle*, 2nd ed.; Weaver, A.D., Ed.; Wright's Scientechnica: Bristol, UK, 1981; pp. 1–97.
42. Blowey, R.W. *A Veterinary Book for Dairy Farmers*; Farming Press—Old Pond Publishing Ltd.: Chichester, UK, 1999.
43. Yao, D.; Luo, J.; He, Q.; Wu, M.; Shi, H.; Wang, H.; Wang, M.; Xu, H.; Loor, J.J. Thyroid hormone responsive (THRSP) promotes the synthesis of medium-chain fatty acids in goat mammary epithelial cells. *J. Dairy Sci.* **2016**, *99*, 3124–3133. [CrossRef] [PubMed]
44. An, X.; Zhao, H.; Bai, L.; Hou, J.; Peng, J.; Wang, J.; Song, Y.; Cao, B. Polymorphism identification in the goat THRSP gene and association analysis with growth traits. *Arch. Anim. Breed.* **2012**, *55*, 78–83. [CrossRef]
45. Waheed, A.; Khan, M.; Eyduran, E.; Khan, M.; Faraz, A.; Mirza, R. Genetic evaluation of linear type traits and their association with milk production traits in beetal goats in Pakistan. *JAPS J. Anim. Plant Sci.* **2019**, *29*, 425–430.
46. Akpa, G.; Ambali, A.; Suleiman, I. Body conformation, testicular and semen characteristics as influenced by age, hair type and body condition of Red Sokoto goat. *N. Y. Sci. J.* **2013**, *6*, 44–58.
47. Liesegang, A.; Risteli, J.; Wanner, M. Bone metabolism of milk goats and sheep during second pregnancy and lactation in comparison to first lactation. *J. Anim. Physiol. Anim. Nutr.* **2007**, *91*, 217–225. [CrossRef]
48. Guo, B.; Jiao, Y.; He, C.; Wei, L.; Chang, Z.; Yue, X.; Lan, X.; Chen, H.; Lei, C. A novel polymorphism of the lactoferrin gene and its association with milk composition and body traits in dairy goats. *Genet. Mol. Res.* **2010**, *9*, 2199–2206. [CrossRef]
49. Cornish, J. Lactoferrin promotes bone growth. *Biometals* **2004**, *17*, 331–335. [CrossRef]

© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).

Archivos de Zootecnia
Journal website: https://www.uco.es/ucopress/az/index.php/az/

CAPRIGRAN Linear Appraisal Evidences Dairy Selection Signs in Murciano-Granadina Goats and Bucks: Presentation of the New Linear Appraisal Scale

Fernández Álvarez, J.[1]; León Jurado, J.M.[2], Navas González, F.J.[3,4@], Iglesias Pastrana, C.[3] and Delgado Bermejo, J.V.[3]

[1]National Association of Breeders of Murciano-Granadina Goat Breed, Fuente Vaqueros, Granada.
[2]Centro Agropecuario Provincial de Córdoba, Diputación Provincial de Córdoba, Córdoba, Spain.
[3]Institute of Agricultural Research and Training (IFAPA), Alameda del Obispo, Córdoba, Spain.
[4]Department of Genetics, Faculty of Veterinary Sciences, University of Córdoba, Spain.

SUMMARY

Selection for zoometrics defines individuals' productive longevity, endurance, enhanced productive abilities and consequently, its long-term profitability. When zoometrics analysis is aimed at in large selected or in terms of selection populations, linear appraisal systems (LAS) provide a timely re-sponse. The particular analysis of each variable permits determining specific strategies for each trait and serve as a model for other breeds. Among the strategies proposed the reduction/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. Murciano-Granadina has drifted towards better dairy linked conformation traits but without losing the grounds of the zoometric basis which confers it with an enhanced adaptability to the environment. Hence, such strategies 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 effi-ciency of breeding plans.

Additional keywords
Local breed.
Conservation.
Adaptability.
Zoometry.
Optimization and Validation.
Scale adjustment.

El Sistema de Calificación Lineal de CAPRIGRAN Evidencia los Signos de Selección para la Aptitud Lechera en Cabras y Machos Cabríos de Raza Murciano-Granadina

RESUMEN

La selección para la zoometría define la longevidad productiva, la resistencia, las capacidades productivas mejoradas de los individuos y, en consecuencia, su rentabilidad a largo plazo. Cuando el análisis zoométrico está dirigido a grandes poblaciones seleccionadas o en vías de selección, los sistemas de calificación lineal (LAS) brindan una respuesta oportuna. El análisis particular de cada variable permite determinar estrategias específicas para cada rasgo y servir de modelo para otras razas. Entre las estrategias propuestas la reducción/reajuste de los niveles en la escala como ocurre con los rasgos relacionados con las extremidades, la ampliación de la escala como ocurre en la estatura de los machos, o la subdivisión de la escala utilizada en los machos en dos categorías, machos menores de dos años y machos de dos años en adelante. Murciano-Granadina ha derivado hacia mejores rasgos morfológicos ligados a la aptitud lechera pero sin perder el fundamento de la base zoométrica que le confiere una mayor adaptabilidad al medio. Por lo tanto, tales estrategias pueden ayudar a lograr una mejor comprensión del impulso de selección de caracteres zoométricos ligados a la aptitud lechera en la población murciano-granadina y su evolución futura para mejorar la rentabilidad y eficiencia de los planes de mejora.

Palabras clave adicionales
Raza local.
Conservación.
Adaptabilidad.
Zoometría.
Optimización y Validación.
Ajuste de escala.

Information

Cronología del artículo.
Recibido/Received: 12.04.2021
Aceptado/Accepted: 30.06.2021
On-line: 15.07.2021
Correspondencia a los autores/Contact e-mail:
fjng87@hotmail.com

INTRODUCTION

The overall visual evaluation of animals has been used since specialization in animal production began, but this assessment has the disadvantage that it is subjective and scarcely predictive of the productive capacity of an animal (Kouri et al., 2019). In the search for more predictive and objective methods, in 1993 the American Dairy Goat Association published the Linear Appraisal System for dairy goats. In French goats, the combined Goat Index (BCI) and Morphological Index began to be applied in October 1999. In the Murciano-Granadina breed, the first animals began to be qualified in 2010 (Fernández Álvarez et al., 2020).

The application of linear morphological qualification in dairy goats breeding programs is to take into account morphology as a criterion when selecting animals., in addition to selecting for productive characteristics, we will also select for type. However, caution must be taken since some type characters may be negatively correlated with milk production (Mellado et al., 2008).

The challenge starts as if a metric character is determined by an effectively infinite number of loci, selection cannot cause any permanent change in the genetic variance but will cause a temporary change which is rapidly reversed when selection ceases. This is due entirely to the correlation between pairs of loci induced by selection. When the correlation is negative it may lead to a reduction in the genetic variance under stabilizing or directional selection. However, when it is positive, it may lead to an increase in the variance under disruptive selection (Bulmer, 1971). Such term is also a synonim of diversifying selection, which describes changes in population genetics in which extreme values for a trait are favoured over intermediate values. Hence, the variance of the trait increases and the population is divided into two distinct groups where more individuals acquire peripheral character value at both ends of the distribution curve (West-Eberhard, 2005).

When selection ceases, the correlation rapidly disappears as joint equilibrium at pairs of loci is reestablished, and the variance returns to its original value. An expression is derived for the predicted amount of change in the genetic variance due to disequilibrium in the absence of linkage. The change is likely to be small under selection intensities found under natural conditions, but it may be appreciable under intense artificial selection. This limiting result shows that the magnitude of any permanent change in the variance due to selection must decrease as the number of loci involved increases and that, when the number of loci is large, it is likely to be much less than the temporary change due to disequilibrium.

In these regards, the ideal morphotype would be equivalent to that structure on which the greatest dairy potential of a breed would be based. What we do is compare the morphology of a specific animal with the ideal dairy morphotype (Assan, 2020).

Linear Appraisal enables to evaluate each characteristic of the animal independently of the rest. The rater translates biological variability on a point scale, ranging from 1 to 9. However, the adaptation of a highly selected breed linear appraisal system may not appropriately fit the reality found for zoometrics in local populations which account with a strong rusticity, thus adaptability potential (Fernández Álvarez et al., 2020) (Figure 1).

In this regard, the analysis of the symmetry on the distribution curve of linear appraisal traits revealed 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 as a result of the progress of selection practices. This has also been reported for similar traits

Figure 1. Zoometric evaluation of a Murciano-Granadina buck (Evaluación zoométrica de un macho cabrío de raza Murciano-Granadina).

in other species (Lomillos Pérez and Alonso de la Varga, 2020).

Indeed, 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 an enhanced adaptability to the environment (Delgado et al., 2017; Luigi-Sierra et al., 2020; Guan et al., 2021).

The aim of this paper is to present the new linear appraisal scale to be applied in Murciano Granadina goats and bucks basing on previous research progresses in regards the application of statistical tools for scale optimization and validation and the analysis of the biological representativity of the scale for zoometric traits observed in the current population.

OPTIMIZATION AND VALIDATION OF PREVIOUS SCALE

The first attempt to validate the linear appraisal scale being applied were implemented in 2005 (Sánchez et al., 2005). The combination of principal component analysis and categorical regression (CATREG) resulted successful for the optimization and validation of the reduction of zoometric evaluation procedures and linear appraisal scoring systems such that they are not only able to describe the status of a certain population but can also be used to predict the future evolution of parameters based on their linear correlations.

FICHA DE CALIFICACIÓN POR TIPO

GANADERÍA				NIF		
ID. ANIMAL		FECHA NACIMIENTO	/ /	Nº PARTOS	FECHA ÚLTIMO PARTO	/ /

ESTRUCTURA Y CAPACIDAD	ESTATURA	MUY BAJA	1 2 3 4 5 6 7 8 9	MUY ALTA
	ANCHURA DE PECHO	MUY ESTRECHA	1 2 3 4 5 6 7 8 9	MUY ANCHA
	PROFUNDIDAD CORPORAL	POCO PROFUNDA	1 2 3 4 5 6 7 8 9	MUY PROFUNDA
	ANCHURA DE GRUPA	MUY ESTRECHA	1 2 3 4 5 6 7 8 9	MUY ANCHA
	ÁNGULO DE GRUPA	MUY DERRIBADA	1 2 3 4 5 6 7 8 9	MUY CORREGIDA
	CALIFICACIÓN			
ESTR. LECHERA	ANGULOSIDAD	REDONDEADA	1 2 3 4 5 6 7 8 9	MUY ANGULOSA
	CALIDAD HUESO	BASTO Y REDONDEADO	1 2 3 4 5 6 7 8 9	PLANO Y NÍTIDO
	CALIFICACIÓN			
SISTEMA MAMARIO	INSERCIÓN ANTERIOR	INEXISTENTE	1 2 3 4 5 6 7 8 9	MUY FUERTE
	ALTURA INSERCIÓN POSTERIOR	MUY BAJA	1 2 3 4 5 6 7 8 9	MUY ALTA
	LIGAMENTO SUSPENSOR MEDIO	MUY DÉBIL	1 2 3 4 5 6 7 8 9	MUY PROFUNDO
	ANCHURA POSTERIOR DE UBRE	MUY ESTRECHA	1 2 3 4 5 6 7 8 9	MUY ANCHA
	PROFUNDIDAD DE UBRE	MUY ALTA	1 2 3 4 5 6 7 8 9	MUY DESCENDIDA
	COLOCACIÓN DE PEZONES	MUY LATERALES	1 2 3 4 5 6 7 8 9	VERTICALES
	DIAMETRO DE PEZONES	MUY ESTRECHOS	1 2 3 4 5 6 7 8 9	MUY ANCHOS
	CALIFICACIÓN			
PATAS Y PIES	PATAS TRASERAS (*VISTA POSTERIOR*)	MUY JUNTAS	1 2 3 4 5 6 7 8 9	PARALELAS
	PATAS TRASERAS (*VISTA LATERAL*)	RECTAS	1 2 3 4 5 6 7 8 9	MUY CURVADAS
	MOVILIDAD	MUY DEFICIENTE	1 2 3 4 5 6 7 8 9	MUY EFICIENTE
	CALIFICACIÓN			

REGIONES	%
Estructura y capacidad	25
Estructura lechera	15
Sistema mamario	40
Patas y pies	20

DEFECTOS	
CALIFICACIÓN FINAL	

FECHA	/ /
CALIFICADOR	GANADERO
Fdo.	Fdo.

Figure 2. Zoometric evaluation sheet for Murciano-Granadina does and bucks (Ficha para evaluación zoométrica para machos y hembras de raza Murciano-Granadina).

Table 1. Zoometric traits, former LAS scale and new LAS scale proposal in Murciano-Granadina primipara/multipara does (Caracteres zoométricos, escala tradicional de calificación lineal y nueva propuesta de escala de calificación lineal en cabras primiparas/multiparas de la raza Murciano-Granadina).

Gender/ Status	Major area	Linear trait	Zoometric Scale/ Categorical Scale	Zoometric Optimum Scoring	Reference/Middle point	LAS Extrapolation	LAS Optimum scoring	New LAS Proposal
Primipara/Multipara does	Structure and capacity	Stature (Height to withers)	62-78 cm	72 cm (primipara) and 74 cm (multipara)	5 (70 cm)	1-9 points	6 (primipara) and 7 (multipara)	1-9 points
		Chest Width	15-23 cm	20 cm (primipara) and 21 cm (multipara)	5 (19 cm)	1-9 points	6 (primipara) and 7 (multipara)	1-9 points
		Body Depth	Shallow-Extremely deep	Intermediate	5 (elbow end matches rib depth)	1-9 points	7 (primipara and multipara)	1-8 points
		Rump Width	13-21 cm	18 cm (primipara) and 19 (multipara)	5 (17 cm)	1-9 points	6 (primipara) and 7 (multipara)	1-7 points
	Dairy structure	Rump Angle	55º-31º	31º	5 (43º)	1-9 points	9	1-7 points (Not relevant)
		Angulosity	Angulous extremity-Rough extremity	Angulous extremity	5 (Intermediate)	1-9 points	9	1-10 points
		Bone Quality	Round and rough bones-flat and neat bones	Flat and neat bones	5 (Intermediate)	1-9 points	9	1-5 points
	Mammary system	Anterior insertion	Weak-Strong	120º	5 (90º)	1-9 points	9	1-5 points
		Rear Insertion Height	11-3 cm	3 cm	5 (7 cm)	1-9 points	9	1-5 points
		Median Suspensor Ligament	1-9 cm	5 cm	5 (5 cm)	1-9 points	5	1-6 points
		Udder width	3-11 cm	11 cm	5 (7 cm)	1-9 points	9	1-5 points
		Udder Depth	-10-10 cm	-5 cm (5 cm over hock level) and 0 cm (udder bottom at hock level)	5 (0 cm/at hock level)	1-9 points	3 (primipara) and 5 (multipara)	1-9 points
		Nipple placement	90º-0º	0º	5 (45º)	1-9 points	9	1-6 points
		Nipple Diameter	0.5 cm to 4.5cm	2 cm	5 (2.5 cm)	1-9 points	4	1-9 points
	Legs aplomb	Rear Legs Rear View	Very close-Parallel and separated	Parallel and separated	5 (slightly close)	1-9 points	9	1-7 points
		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	1-7 points
		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	1-5 points

Principal component analyses determined that CAPRIGAN linear appraisal system (Figure 2) was solid and internally consistent for the measurement and capture of the variability of zoometric parameters related to dairy performance. However, the resulting models were quite conservative, as only one variable from the whole zoometric panel was discarded for bucks and does. The outputs of linear regression demonstrate that an optimal fit, variability explanatory power and predictive potential can be achieved by modeling a reduced number of variables from the entire linear appraisal scoring system and traditional zoometric evaluation for Murciano-

Granadina does (Figure 1) and bucks. Conclusively, our results suggest that the combination of PCA and categorical regression (CATREG) may be successful for the optimization and validation of the reduction of zoometric evaluation procedures and linear appraisal scoring systems such that they are not only able to describe the status of a certain population but can also be used to predict the future evolution of parameters based on their linear correlations.

THE ANALYSIS OF DISTRIBUTION AND SKEWNESS

After symmetry analysis was performed, scale readjustment proposal suggested specific strategies should be implemented such as scale reduction of lower or upper levels, determination of a set up moment to evaluate and collect information from young (up to 2 years) and adult bucks (over 2 years), addition of upper categories in males due to upper values in the scale being incorrectly clustered together. The new scale proposal shows Murciano-Granadina goats' zoometric traits and by extension LAS, may not particularly fit the scales used for other standardized highly selected breeds (Tables 1 and 2).

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 the reduction/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

Table 1. Zoometric traits, former LAS scale and new LAS scale proposal in Murciano-Granadina bucks (Caracteres zoométricos, escala tradicional de calificación lineal y nueva propuesta de escala de calificación lineal en machos cabríos de la raza Murciano-Granadina).

Gender/Status	Major area	Linear trait	Zoometric Scale/ Categorical Scale	Zoometric Optimum Scoring	Reference/Middle point	LAS Extrapolation	LAS Optimum scoring	New LAS Proposal
Bucks	Structure and capacity	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)	1-10 points
		Chest Width	15-31 cm	25 cm (young) and 27 cm (adult)	5 (23 cm)	1-9 points	6 (young) and 7 (adult)	1-11 points
		Body Depth[a]	Shallow-Extremely deep	Intermediate	5 (elbow end matches rib depth)	1-9 points	7 (young and adult)	1-7 points
		Rump Width	14-22 cm	19 cm (young) and 20 cm (adult)	5 (18 cm)	1-9 points	6 (young) and 7 (adult)	1-5 points
	Dairy structure	Rump Angle	55-31º	31º	5 (43º)	1-9 points	9	1-6 points
		Angulosity[a]	Angulous extremity-Rough extremity	Angulous extremity	5 (Intermediate)	1-9 points	9	1-9 points
		Bone Quality[a]	Round and rough bones-flat and neat bones	Flat and neat bones	5 (Intermediate)	1-9 points	9	1-5 points
	Legs aplomb	Rear Legs Rear View[a]	Very close-Parallel and separated	Parallel and separated	5 (slightly close)	1-9 points	9	1-6 points
		Rear Legs Side View[a]	Straight-Very curved	Desirable curvature. Short distance from an imaginary line to anterior curvature of hock	5 (desirable curvature)	1-9 points	5	1-7 points
		Mobility[a]	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	1-5 points

[a]Same criteria for males and females.

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.

PRELIMINARY REPORTS ON THE GENETIC EVALUATION FOR LINEAR APPRAISAL

The first attempt to perform an estimation of genetic parameters was carried out in 2012. Six hundred and fifty-four goats belonging to six herd of the top breeding nucleus were evaluated using a kinship matrix of 890 animals. A total of 17 traits were considered: Stature, chest width, body depth, rump width, rump angle, angularity, bone quality, anterior and posterior attachment height, half superior ligament, udder width, udder depth, nipple placement, nipple diameter, rear legs view, lateral legs view and movements. The genetic evaluation was carried out using a Animal Model through MTDFRML package (Gómez et al., 2012). Heritabilities ranged bwtween 0.12 for anterior insertion and 0.28 for median suspensor ligament (Gómez-Carpio et al., 2012).

CONCLUSSIONS

After the validation of CAPRIGAN LAS system was confirmed, the analysis of optimization suggests the removal of rump angle from the panel of zoometric traits implemented. The evaluation of measurement distribution in the population suggested the adaptation of former LAS scales and the separation of bucks (currently evaluated with independence of their age) into two groups with 2 years old being the turn point. The new LAS scale appears in the context of Murciano-Granadina breed being a highly selected breed for milk production and quality attributes, which still maintains its proficient adaptability to harsh environments which is the basis for its international competitiveness.

ACKNOWLEDGMENTS

This work would not have been possible if it had not been for the support and assistance of the National Association of Breeders of Murciano-Granadina Goat Breed, Fuente Vaqueros (Spain) and the PAIDI AGR 218 research group.

BIBLIOGRAPHY

Assan, N 2020, 'Morphology and its relationship with reproduction and milk production in goat and sheep', *Scientific Journal of Zoology*, vol. 9, no. 2, pp. 123-37.

Bulmer, M 1971, 'The effect of selection on genetic variability', *The American Naturalist*, vol. 105, no. 943, pp. 201-11.

Delgado, JV, Landi, V, Barba, CJ, Fernández, J, Gómez, MM, Camacho, ME, Martínez, MA, Navas, FJ & León, JM 2017, 'Murciano-Granadina goat: A Spanish local breed ready for the challenges of the twenty-first century', in *Sustainable goat production in adverse environments: Volume II*, Springer, pp. 205-19.

Fernández Álvarez, J, León Jurado, JM, Navas González, FJ, Iglesias Pastrana, C & Delgado Bermejo, JV 2020, 'Optimization and Validation of a Linear Appraisal Scoring System for Milk Production-Linked Zoometric Traits in Murciano-Granadina Dairy Goats and Bucks', *Applied Sciences*, vol. 10, no. 16, p. 5502.

Gómez-Carpio, M, Miranda, J, León, JM, Pleguezulos, J & Delgado, JV 2012, 'Análisis preliminar de la estimación de parámetros genéticos para caracteres morfológicos lineales en la raza caprina Murciano Granadina', in *"Congresso Ibérico sobre Recursos Genéticos Animais"*, Évora (Portugal).

Gómez, M, Miranda, J, León, JM & Pleguezulos, J 2012, First results of the genetic evaluation of linear morphological traits in the murciano-granadina breed, *Actas Iberoamericanas de Conservación Animal-AICA*. 2, 339-342

Guan, D, Martínez, A, Luigi-Sierra, MG, Delgado, JV, Landi, V, Castelló, A, Fernández Álvarez, J, Such, X, Jordana, J & Amills, M 2021, 'Detecting the footprint of selection on the genomes of Murciano-Granadina goats', *Animal Genetics*, vol. 52, no. 5, pp. 683-93.

Kouri, F, Charallah, S, Kouri, A, Amirat, Z & Khammar, F 2019, 'Milk production and its relationship with milk composition, body and udder morphological traits in Bedouin goat reared under arid conditions', *Acta Scientiarum. Animal Sciences*, vol. 41.

Lomillos Pérez, JM & Alonso de la Varga, ME 2020, 'Morphometric characterization of the Lidia cattle breed', *Animals, vol. 10, n. 7.*

Luigi-Sierra, MG, Landi, V, Guan, D, Delgado, JV, Castelló, A, Cabrera, B, Mármol-Sánchez, E, Alvarez, JF, Gómez-Carpio, M & Martínez, A 2020, 'A genome-wide association analysis for body, udder, and leg conformation traits recorded in Murciano-Granadina goats', *Journal of Dairy Science*, vol. 103, no. 12, pp. 11605-17.

Mellado, M, Mellado, J, Valencia, M & Pittroff, W 2008, 'The Relationship between Linear Type Traits and Fertility Traits in High-yielding Dairy Goats', *Reproduction in domestic animals*, vol. 43, no. 5, pp. 599-605.

Sánchez, M, Martín, D, Fernandez, E & Muñoz-Gutiérrez, E 2005, 'Validación en campo de la metodología de calificación morfológica lineal en las razas caprinas lecheras españolas'.

West-Eberhard, MJ 2005, 'Phenotypic accommodation: adaptive innovation due to developmental plasticity', *Journal of Experimental Zoology Part B: Molecular and Developmental Evolution*, vol. 304B, no. 6, pp. 610-8.

Chapter 2.

Genetic Parameters for Zoometric/Linear Appraisal Traits in the Murciano-Granadina goat

- *Javier Fernández Álvarez, J. M. León Jurado, F. J. Navas González, C. Iglesias Pastrana and J. V. Delgado Bermejo.* ***A decade of progress of linear appraisal traits heritabilities in Murciano-Granadina goats.***
- *Javier Fernández Álvarez, J. M. León Jurado, F. J. Navas González, C. Iglesias Pastrana and J. V. Delgado Bermejo.* ***Analysis of the genetic parameters for dairy linear appraisal and zoometric traits: A tool to enhance the applicability of Murciano-Granadina goats major areas evaluation system****.*

Archivos de Zootecnia
Journal website: https://www.uco.es/ucopress/az/index.php/az/

A decade of progress of linear appraisal traits heritabilities in Murciano-Granadina goats

Fernández Álvarez, J.[1]; Navas González, F.J.[2,3@], León Jurado, J.M.[4], Iglesias Pastrana, C.[3] and Delgado Bermejo, J.V.[3]

[1]National Association of Breeders of Murciano-Granadina Goat Breed, Fuente Vaqueros, Granada.
[2]Institute of Agricultural Research and Training (IFAPA), Alameda del Obispo, Córdoba, Spain.
[3]Department of Genetics, Faculty of Veterinary Sciences, University of Córdoba, Spain.
[4]Centro Agropecuario Provincial de Córdoba, Diputación Provincial de Córdoba, Córdoba, Spain.

Additional keywords
Breeding.
Heritability.
Dairy Conformation.
Trends.
Razas locales.
Standard error.

SUMMARY

The objective of this study was to evaluate the progress of heritabilities of the traits comprising the linear appraisal system in the Murciano-Granadina breed during the complete decade from December 2011 to December 2021. The estimated values for heritability were obtained from multivariate analyzes using the BLUP methodology and MTDFREML software. For 2021 heritabilities, a simple animal model was applied to records collected from 22,727 primiparous goats and 17,111 multiparous goats belonging to 85 herds. The model included the linear and quadratic and linear components of the covariates age and days in milk, respectively. The fixed effects considered in the model were herd, reproductive status, calving month and herd/year interaction. The animal was considered as a random effect. The variables studied included five characteristics related to Structure and capacity; Height at withers (EST), Body Depth (PC), Chest Width (AP), Rump Width (AG) and Rump Angle (ANG). Two traits related to dairy Structure; Angularity (ANGUL), Bone quality (HUESO). Six related to the mammary system; Anterior Insertion (IA), Rear Insertion Height (AIP), Median Suspensor Ligament (LSM), Udder Depth (PU), Nipple Placement (CP) and Nipple Diameter (DP). Finally, three related to legs and feet; Rear and lateral views of the rear legs (VPPT and VLPT) and Mobility (MOV). The heritabilities for structure and capacity characters progressed from 0.22 to 0.28 including non-convergent variables (PC and ANG) in June 2012 to values between 0.10 and 0.41 with all variables converging in June 2011. 2021. Heritabilities for dairy structure progressed from 0.18 with non-convergent variables (HUESO) in 2011 to 0.17 to 0.25 in 2021. Heritabilities for mammary system traits progressed from 0.12 to 0, 27 with non-convergent variables (AU) in 2012 to between 0.10 and 0.41 in 2021. For legs and feet, heritabilities progressed from 0.16 to 0.17 with non-convergent variables (VLPT) to 0.09 a 0.22. Genetic progress is not only evident in heritability values, but there has been a notable reduction in the standard error of heritabilities from 0.1000 (0.080-0.120) to 0.000 (0.000-0.001) from 2011 to 2021. These results provide evidence of the enhancement in the effectiveness and precision of the linear qualification system applied during the past decade and its successful integration in the breeding program of the Murciano-Granadina breed.

Una década de progreso de la heredabilidad de los caracteres relacionados con la calificación lineal en cabras Murciano-Granadina

Palabras clave adicionales
Mejora genética.
Heredabilidad.
Conformación lechera.
Tendencias.
Razas Locales.
Error standard.

RESUMEN

El objetivo de este estudio fue evaluar el progreso de la heredabilidad para los caracteres considerados dentro del sistema de calificación lineal en la raza Murciano-Granadina durante la década completa desde diciembre de 2011 hasta diciembre de 2021. Los valores estimados para la heredabilidad fueron obtenidos a partir de análisis multivariados utilizando la metodología BLUP y el software MTDFREML. Para el cálculo de las heredabilidades de 2021, se aplicó un modelo animal simple sobre los registros recogidos en 22727 cabras primíparas y 17111 cabras multíparas, pertenecientes a 85 ganaderías. El modelo induyó los componentes lineal y cuadrático y lineal de las covariables edad y días en leche, respectivamente. Los efectos fijos considerados en el modelo fueron el rebaño, status reproductivo, el mes de parto y la interacción rebaño/año. Por su parte se consideró el animal como efecto aleatorio. Las variables estudiadas incluyeron cinco características relacionadas con la Estructura y capacidad; Altura a la cruz (EST), Profundidad corporal (PC), Anchura de pecho (AP), Anchura de grupa (AG) y Ángulo de la Grupa (ANG). Dos rasgos relacionados con la Estructura lechera; Angulosidad (ANGUL), Calidad de hueso (HUESO). Seis relacionados con el Sistema mamario; Inserción anterior (IA), Altura inserción posterior (AIP), Ligamento suspensorio medio (LSM), Profundidad de la ubre (PU), Colocación de pezones (CP) and Diámetro de pezones (DP). Finalmente, tres relacionados con Patas y pies; Vistas posterior y lateral de las patas traseras (VPPT y VLPT) y Movilidad (MOV). Las heredabilidades para los caracteres de estructura y capacidad progresaron desde 0,22 a 0,28 incluyendo variables no convergentes (PC y ANG) en junio de 2011 a valores de entre 0,10 a 0,41 con todas las variables convergiendo en junio de 2021. Las heredabilidades para la estructura lechera progresaron desde 0,18 con variables no convergentes (HUESO) en 2012 hasta 0,17 a 0,25 en 2021. Las heredabilidades para los caracteres del sistema mamario progresaron de entre 0,12 a 0,27 con variables no convergentes (AU) en 2011 a entre 0,10 y 0,41 en 2021. Para las patas y pies las heredabilidades progresaron de 0,16 a 0,17 con variables no convergentes (VLPT) a 0,09 a 0,22. El progreso genético no sólo es patente en los valores de la heredabilidad, sino que se ha dado una reducción notable en el error estándar de las heredabilidades desde 0,1000 (0,080-0,120) hasta 0,000 (0,000-0,001) desde 2011 a 2021. Estos resultados proporcionan evidencias de la efectividad y precisión del sistema de Calificación lineal aplicado y de su integración en el esquema de selección de la raza Murciano-Granadina.

Information
Cronología del artículo.
Recibido/Received: 19.01.2021
Aceptado/Accepted: 03.02.2021
On-line: 15.10.2021
Correspondencia a los autores/Contact e-mail:
franciscoj.navas@juntadeandalucia.es

INTRODUCTION

The global visual assessment of an animal has been used since specialization in animal production began, but this assessment has the drawback that it is subjective and poorly predictive of the productive capacity of an animal. In the search for more predictive and objective methods, in 1993 the American Dairy Goat Association published the Linear Classification System for dairy goats.

In French goats, the Combined Goat Index (ICC) and Morphological Index began to be applied in October 1999. In the Murciano-Granadina breed, the first animals began to be qualified in 2010 (Fernández Álvarez, et al. (2020), due to the efforts of the National Association of Murciano-Granadina Goat Breeders (CAPRIGRAN).

CAPRIGRAN started implementing its linear appraisal system in the selection scheme of the Murciano-Granadina experimentally, beginning to qualify animals from farms belonging to its selective nucleus in 2010.

Even if data registration and the integration of the linear morphological appraisal system in the dairy goat improvement genetic program of Murciano-Granadina breed had started two years ealier (Martinez, et al. 2010), the genetic background of linear appraisal traits of Murciano-Granadina goats would not be preliminarily approached until 2011, with the first evaluation of genetic parameters and breeding values (Gómez-Carpio et al., 2012a,b).

Still the system was strongly subjetive in nature and as recently revealed, may not represent the variability found within the population of the Murciano-Granadina breed (Fernández Álvarez et al., 2021).

As a consequence, CAPRIGRAN and the AGR218 PAIDI reasearch group from the University of Córdoba set up a project with the aim to evaluate the disribution properties of zoometric linear appriasal traits within Murciano-Granadina population, to define the scales which better represent the variability for zoometric traits present in the population, to optimize and validate such scales, and to perform a comprbensive genetic evaluation of the heritable component and correlations among linear appraisal traits (Fernández Álvarez, et al. (2021).

In this context, the aim of this study is the comparative evaluation of the heritabilities of the seventeen linear traits that comprise Murciano-Granadina linear appraisal system, a decade after the first preliminary results were issued. The comparison of this value may help inferring the success of the integration and implementation of the linear appraisal system in Murciano-Granadina breeding program.

MATERIAL AND METHODS

2011's Genetic evaluation

Sample

A total of 890 animals were evaluated in the kinship matrix. Out of these, 328 animals had complete DNA-certified father and mother information, 72 had a DNA-confirmed father and 26 had a DNA-confirmed mother. In cases in which there was no genealogical information checked with DNA, the data of the parent, father or mother, was indicated as not controlled. Thus, for this genetic evaluation, a quality kinship matrix, fully certified with DNA microsatellites was used. For the genetic evaluation, a file was used productive constituted by 654 qualifications developed all of them by the same rater. Six herds that were genetically connected and that are part of the selective nucleus of the breed selection scheme were included in the analysis.

Traits

Seventeen linear characters have been experimentally scored; Height at withers (EST), Chest Width (AP), Body Depth (PC), Rump Width (AG), Rump Angle (ANG), Angularity (ANGUL), Bone Quality (HUESO), Anterior Attachment (IA), Posterior Insertion Height (ALTIP), Median Superior Ligament (LSM), Udder Width (AU), Udder Depth (PU), Teat Placement (CP), Teat Diameter (DP), Rear legs rear view (VPPT), Rear legs side view (VLPT) and Mobility (MOV).

Model

The BLUP (Best Linear Unbiased Predictors) methodology was used, applying a Simple Animal Model, using the genetic evaluation software MTDFREML (Boldman et al., 1995). The animal model used was the following:

$$y_{ijkl} = \mu + R_i + NP_j + A_k + (bE + b2E)_l + e_{ijkl}$$

where: y_{ijkl} = dependent variable; μ = population mean; R_i = herd fixed effect (6 levels); NP_j = fixed effect of the parturition number (5 levels); A_k = random additive effect of the animal; $(bE + b2E)_l$ = linear and quadratic components of the age of the goat as a covariate and e_{ijkl} = effect of random residuals.

2021's Genetic evaluation

Sample

A total of 279,768 animals were evaluated in the kinship matrix. Routine father and mother information DNA-certification is implemented. In cases in which there was no genealogical information checked with DNA, the data of the parent, father or mother, was indicated as not controlled. DNA certification of kinship matrix ensured the genealogical basis integrity. All of the zoometric analyses were performed by the same rater. Zoometric records belonged to 39,823 animals. Eighty-five genetically connected herds were included in the analysis.

Traits

Seventeen linear characters have been experimentally scored; Height at withers (EST), Chest Width (AP), Body Depth (PC), Rump Width (AG), Rump Angle (ANG), Angularity (ANGUL), Bone Quality (HUESO), Anterior Attachment (IA), Posterior Insertion Height

(ALTIP), Median Superior Ligament (LSM), Udder Width (AU), Udder Depth (PU), Teat Placement (CP), Teat Diameter (DP), Rear legs rear view (VPPT), Rear legs side view (VLPT) and Mobility (MOV).

Model

The BLUP (Best Linear Unbiased Predictors) methodology was used, applying a Simple Animal Model, using the genetic evaluation software MTDFREML (Boldman et al., 1995). The animal model used was the following:

$$y_{ijklmnop} = \mu + ST_i + R_j + PM_k + IRA_l + A_m + (bE + b2E)_n + DEL_o + e_{ijklmno}$$

where: $y_{ijklmno}$ = dependent variable; μ = population mean; ST_i = status fixed effect (2 levels); R_j= herd fixed effect (85 levels); PM_k = fixed effect of the parturition month (12 levels); IRA_l = interaction between the herd and parturition year; A_m = random additive effect of the animal; $(bE + b2E)_n$ = linear and quadratic components of the age of the goat as a covariate; DEL_o = linear component of the days in milk as a covariate and $e_{ijklmno}$ = effect of random residuals.

RESULTS

Table I presents heritabilities for the seventeen linear appraisal zoometic traits derived from the evaluations perfomed in 2011, published by Gómez-Carpio et al. (2012) and 2021.

DISCUSSION

The Murciano-Granadina goat is a very widespread autochthonous Spanish breed which is linked to those regions with dry and warm climates. Due to its rusticity, it is very suitable for dairy production in especially arid and hot countries of America and Africa, which is the basis for its international competitiveness within the dairy goat panorama (Delgado et al., 2017).

This remarkable rusticity, strongly conditions productive performance in the Murciano-Granadina breed as suggested by Sanchez et al. (2005). Indeed, Delgado et al., (2017), would inquire that to determine and obtain a good productive capacity in this breed, zoometric traits must be evaluated, since the productive quality or excellence of animals will strongly be linked to the adscription of goats to the dairy morphotype, but without losing the grounds of adaptability that the breed inherently has. In these regards, angular animals, with wide chests, lightly fat covered, with a strong bone structure, and a lively expression are sought after.

The outcomes of the first genetic evaluations for linear morphological traits in the Murciano-Granadina goat breed were described as very satisfactory, due to the high frequency of males and females with from average to high breeding values (Gómez-Carpio et al., 2012). However, the lack of convergence attained for some of these traits such as body depth, rump angle, bone quality, udder width and rear legs side view, rendered the evaluation inefficient.

Table I. Heritability and standard error progress from 2011 to 2021 for linear appraisal traits in Murciano-Granadina goats (Progreso desde 2012 a 2021 de las heredabilidades y errores estándar para los caracteres relacionados con la calificación lineal en cabras Murciano-Granadina).

	$h^2_{2011\ (1)}$	$SE_{2011\ (1)}$	h^2_{2021}	SE_{2021}
Stature (Height to withers)	0.220	0.110	0.430	0.000
Chest Width	0.280	0.110	0.291	0.001
Body Depth	NC	NC	0.100	0.000
Rump Width	0.260	0.110	0.310	0.000
Rump Angle	NC	NC	0.171	0.001
Angulosity	0.180	0.090	0.251	0.001
Bone Quality	NC	NC	0.310	0.000
Anterior insertion	0.120	0.080	0.211	0.001
Rear Insertion Height	0.160	0.090	0.259	0.001
Median Suspensor Ligament	0.120	0.090	0.330	0.000
Udder width	NC	NC	0.100	0.000
Udder Depth	0.170	0.100	0.290	0.000
Nipple placement	0.200	0.120	0.270	0.000
Nipple Diameter	0.270	0.110	0.410	0.000
Rear Legs Rear View	0.170	0.090	0.221	0.001
Rear Legs Side View	NC	NC	0.091	0.001
Mobility	0.160	0.100	0.110	0.000

NC: Non-convergent variables; h^2: Heritabilities; SE: Standard error.
(1) Gómez-Carpio, et al. (2012).

In line with these results, Gómez-Carpio et al. (2012) would suggest the need for readjustments of the analysis model, as well as an increase in the volume of the database, both genealogical and zoometric records. The variety of traits, the differences in the scales used to score them and their mere biological nature compelled the implementation of rather complex models than those that had traditionally been implemented. For example, apart from the effect of the herd, the strong adaptability of the breed suggested adding terms to control the effect of seasonality in the breed (through the inclusion of parturition month) but also on the particular handling of herds along time, through the inclusion of the interaction between parturition year and herd. Additionally, rather than the number of parturitions that each goat had had up to the moment when it was zoometrically evaluated, as considered in 2011, the marked dairy aptitude of the breed suggested approaching alternative methods to control for the productive status of each goat.

In these regards, apart from determining whether goats were either primipara or multipara, the effect od days in milk was included in the model as a covariate. Days in milk (DEL) is related closely to dry period length and is a good indicator of reproductive efficiency and herd management. Drying period was suggested to be an important factor to account for in the productive evaluation in Murciano-Granadina seeking the improvement of both milk quantity and nutritional quality (Pizarro et al., 2019a,b; 2020a,b,c,d,e,f). The rest of the model remained the same.

The modifications together with the vast increase in the number of animals comprising the kinship matrix and those for which actual zoometric records were present, translated into the drastic reduction of standard errors of prediction as reported in Table I, but also evidence the increased quality of information with which 2021 genetic evaluation has been carried out.

Heritabilities were in the range of those found in literature for Alpines, LaManchas, Nubians, Oberhaslis, Saanens, and Toggenburgs (Luo et al., 1997). All variables converged at the genetic evaluation performed in 2021. Heritability estimates increased 1.52 times on average with higher increase values being reported for height at withers with 1.95 higher heritabilities in 2021than in 2011 and mobility, which was the only trait for which a reduction in the value of heritability of 0.69 was reported. Such a reduction may be ascribed to the drastic reduction occurring in the standard error of prediction which was 10 times higher on average.

These results encourage us to continue working and improving these methods for their general integration in the breeding program of the Murciano-Granadina breed. Getting deeper in the study of the connections between linear appraisal derived traits and productive traits such as milk yield or protein, fat, lactose, dry matter, somatic cells contents may mark a significant step towards a rather efficient and accurate dairy goat selection and thus ensure that in the future the information offered to breeders accounts with quality enough as for the breed to consolidate its prominent position in the international dairy goat panorama.

CONCLUSIONS

In conclusion, the progress reported for the heritabilities of the seventeen traits studied in this paper enable breeders to select animals that either improve or correct certain undesirable conditions or which adscribe to a desirable zoometric standard. Even if linear appraisal derived morphofunctional traits are often not considered by breeders, our results suggest selection is feasible and may in turn make the animals more suitable for the productive demands, since selection for linear appraisal may indirectly improve the performance of the animals of the breed in question; for instance, aplombs, bone structure, muscle development or mammary conformation.

ACKOWLEDGMENT

The authors of this paper would like to give special thanks for the support and assistance provided by the National Association of Breeders of Murciano-Granadina Goat Breed, Fuente Vaqueros (Spain) and the members of the PAIDI AGR 218 research group of the University of Córdoba.

BIBLIOGRAPHY

Boldman KG, Kriese LA, Van Vleck LD, Kachman SD. A set programs to obtain estimates of variances and covariance. A manual for use of MTDFREML. Lincoln: Departament of Agriculture, Agricultural Research Service. 1995.

Delgado JV, Landi V, Barba CJ, Fernández J, Gómez MM, Camacho ME, Martinez MA, Navas FJ, León JM Murciano-Granadina goat: A Spanish local breed ready for the challenges of the twenty-first century. In Sustainable goat production in adverse environments: volume II. 2017. (pp. 205-219). Springer, Cham.

Fernández Álvarez J, León Jurado JM, Navas González FJ, Iglesias Pastrana C, Delgado Bermejo JV. Optimization and Validation of a Linear Appraisal Scoring System for Milk Production-Linked Zoometric Traits in Murciano-Granadina Dairy Goats and Bucks. *Applied Sciences*. 2020 Aug 9;10(16):5502.

Fernández Álvarez J, León JM, Navas González FJ, Iglesias Pastrana C, Delgado Bermejo JV. CAPRIGRAN Linear Appraisal Evidences Dairy Selection Signs in Murciano-Granadina Goats and Bucks: Presentation of the New Linear Appraisal Scale. *Archivos de zootecnia*. 2021;70(271):239-45.

Gómez M, Miranda J, León JM, Pleguezuelos J, Delgado JV. First results of the genetic evaluation of linear morphological traits in the murciano-granadina breed. *Actas Iberoamericanas de Conservación Animal,* AICA. 2 (2012) 339 339-34.

Gómez-Carpio M, Miranda J, León JM, Pleguezulos J, Delgado JV. Análisis preliminar de la estimación de parámetros genéticos para caracteres morfológicos lineales en la raza caprina Murciano Granadina. In VIII Congresso Ibérico sobre Recursos Genéticos Animais 2012.

Luo MF, Wiggans GR, Hubbard SM. Variance component estimation and multitrait genetic evaluation for type traits of dairy goats. Journal of Dairy Science. 1997 Mar 1;80(3):594-600.

Martinez B, Vicente C, Picchioni M, Sanchez M, Gómez EA, Peris C. Integration of the linear morphological appraisal system in the dairy goat improvement genetic program of Murciano-Granadina breed. InXXXV Congreso de la Sociedad Española de Ovinotecnia y Caprinotecnia (SEOC), Valladolid, España, 22-24 de septiembre de 2010 2010 (pp. 470-474). Sociedad Española de Ovinotecnia y Caprinotecnia (SEOC).

Pizarro MG, Landi V, Navas González FJ, León JM, Delgado JV. Non-parametric analysis of the effects of αS1-casein genotype and parturition non-genetic factors on milk yield and composition in Murciano-Granadina goats. Italian Journal of Animal Science. 2019 Jan 2;18(1):1021-34.

Pizarro Inostroza MG, Landi V, Navas González FJ, León Jurado JM, Martínez Martínez A, Fernández Álvarez J, Delgado Bermejo JV. Does the acknowledgement of αS1-casein genotype affect the estimation of genetic parameters and prediction of breeding values for milk yield and composition quality-related traits in Murciano-Granadina?. Animals. 2019 Sep 13;9(9):679.

Pizarro Inostroza MG, Landi V, Navas González FJ, León Jurado JM, Martínez Martínez MD, Fernández Álvarez J, Delgado Bermejo JV. Non-parametric association analysis of additive and dominance effects of casein complex SNPs on milk content and quality in Murciano-Granadina goats. Journal of Animal Breeding and Genetics. 2020 Jul;137(4):407-22.

Pizarro MG, Landi V, Navas FJ, León JM, Martínez A, Fernández J, Delgado JV. Nonparametric analysis of casein complex genes' epistasis and their effects on phenotypic expression of milk yield and composition in Murciano-Granadina goats. Journal of dairy science. 2020 Sep 1;103(9):8274-91.

Pizarro Inostroza MG, Landi V, Navas González FJ, León Jurado JM, Delgado Bermejo JV, Fernández Álvarez J, Martínez Martínez MD. Integrating casein complex SNPs additive, dominance and epistatic effects on genetic parameters and breeding values estimation for murciano-granadina goat milk yield and components. Genes. 2020 Mar 14;11(3):309.

Pizarro Inostroza MG, Navas González FJ, Landi V, León Jurado JM, Delgado Bermejo JV, Fernández Álvarez J, Martínez Martínez MD. Goat milk nutritional quality software-automatized individual curve model fitting, shape parameters calculation and Bayesian flexibility criteria comparison. Animals. 2020 Sep 18;10(9):1693.

Pizarro Inostroza MG, Navas González FJ, Landi V, León Jurado JM, Delgado Bermejo JV, Fernández Álvarez J, Martínez Martínez MD. Software-automatized individual lactation model fitting, peak and persistence and Bayesian criteria comparison for milk yield genetic studies in Murciano-Granadina goats. Mathematics. 2020 Sep 4;8(9):1505.

Pizarro Inostroza MG, Navas González FJ, Landi V, León Jurado JM, Delgado Bermejo JV, Fernández Álvarez J, Martínez Martínez MA. Bayesian Analysis of the Association between Casein Complex Haplotype Variants and Milk Yield, Composition, and Curve Shape Parameters in Murciano-Granadina Goats. Animals. 2020 Oct 10;10(10):1845.

Sánchez M, Martín D, Fernandez E, Muñoz-Gutiérrez E. Validación en campo de la metodología de calificación morfológica lineal en las razas caprinas lecheras españolas. Feagas 2005, 28, 97-103.

animals

MDPI

Article

Analysis of the Genetic Parameters for Dairy Linear Appraisal and Zoometric Traits: A Tool to Enhance the Applicability of Murciano-Granadina goats Major Areas Evaluation System

Javier Fernández Álvarez [1], Francisco Javier Navas González [2,3,*], Jose Manuel León Jurado [4], Carlos Iglesias Pastrana [3] and Juan Vicente Delgado Bermejo [3]

[1] National Association of Breeders of Murciano-Granadina Goat Breed, Fuente Vaqueros, Granada; j.fernandez@caprigran.com (J.F.Á.)

[2] Institute of Agricultural Research and Training (IFAPA), Alameda del Obispo, 14004 Córdoba, Spain; fjng87@hotmail.com (F.J.N.G.)

[3] Department of Genetics, Faculty of Veterinary Sciences, University of Córdoba, Spain; juanviagr218@gmail.com (J.V.D.B.); ciglesiaspastrana@gmail.com (C.I.P.)

[4] Centro Agropecuario Provincial de Córdoba, Diputación Provincial de Córdoba, Córdoba, Spain; jomalejur@yahoo.es (J.M.L.J.)

* Correspondence: fjng87@hotmail.com; Tel.: + 34−638535046 (ext. 621262)

Simple Summary: Murciano-Granadina has drifted towards better dairy linked conformation traits but without losing the grounds of the zoometric basis which confers it with an enhanced adaptability to the environment. Consequently, international LAS systems may not fit the zoometric variability reality of autochthonous breeds, such as the Murciano-Granadina goat. LAS panels comprise large number of traits which makes selection for dairy conformation a complex and time costly task, hence selection practices focusing on major areas is often suggested. The evaluation of genetic, phenotypic and environmental parameters for each zoometric/LAS trait individually and of the pairwise relationships among traits may permit to design a solid selection strategy towards the maximization of dairy potential while making selection tasks time and resource efficient. Results suggest zoometrics and LAS derived genetic and phenotypic parameters are translatable as long as the process of collection is performed objectively by trained operators. Major areas selection is feasible but may be conditioned to the restructuration and modification of the scales that are currently used for dairy goats. The strategies that were designed help to evaluate the momentum of selection for dairy-linked zoometric traits of the Murciano-Granadina population and its future evolution to enhance the profitability and efficiency of breeding plans.

Abstract: Selection for zoometrics defines individuals' productive longevity, endurance, enhanced productive abilities and consequently, their long-term profitability. When zoometrics analysis is aimed at in large selected or in terms of selection populations, linear appraisal systems (LAS) provide a timely response. The present study estimates genetic and phenotypic parameters for zoometric/LAS traits in Murciano-Granadina goats, estimate genetic and phenotypic correlations among all traits, and to determine whether major area selection would be appropriate of if adaptability strategies may need to be followed. Heritability estimates for the zoometric/LAS traits were low to high, ranging from 0.09 to 0.43 and the accuracy of estimation has improved after decades rendering standard errors negligible. Scale inversion of specific traits may need to be performed before major areas selection strategies are implemented. Genetic and phenotypic correlations suggests that negative selection against thicker bones and higher rear insertion heights, indirectly results in the optimization of selection practices in the rest of traits, specially of those in the structure and capacity and mammary system major areas. The integration and implementation of the strategies proposed within Murciano-Granadina breeding program maximizes selection opportunities and the sustainable international competitiveness of the Murciano-Granadina goat in the dairy goat breed panorama.

Citation: Álvarez, J.F.; González, F.J.N.; Jurado, J.M.L.; Pastrana, C.I.; Bermejo, J.V.D. Analysis of the Genetic Parameters for Dairy Linear Appraisal and Zoometric Traits: A Tool to Enhance the Applicability of Murciano-Granadina goats Major Areas Evaluation System. *Animals* **2022**, *12*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s):

Received: date
Accepted: date
Published: date

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

Keywords: does; local breed; conservation; adaptability; variance components; heritability; genetic and phenotypic correlations

1. Introduction

Linear Appraisal Systems (LAS) were developed as time cost-effective alternatives to provide a timely relatively accurate response to the need to perform large scale zoometric evaluations. The biggest problem associated with in vivo zoometry is the difficulty to restrain animals in a natural position long enough to make an accurate measurement, especially when the differences being measured are small [1].

Objectivity is one of the main points to address when implementing LAS, as these systems must base on observations by trained appraisers, rather than on actual zoometric measurements. In time, not only experienced appraisers achieve equal or greater accuracy and consistency while evaluating LAS traits than when performing routine zoometric evaluations, but also, they do it much more rapidly and less expensively.

In this context, the complementarity between LAS and zoometry must be performed at an acceptable repeatability level across appraisers. This means that it must be possible to define the trait and all its components and the associated evaluation criteria precisely enough as for the trait to be evaluated by appraisers with acceptable repeatability.

Despite earlier few preliminary applications [2], the National Association of Breeders of the Murciano-Granadina goat breed (CAPRIGRAN) started routinely implementing its LAS in 2010[3]. Since then, CAPRIGRAN LAS has assisted Murciano-Granadina goat breed breeders in the evaluation of their individual animals based on type traits that affect dairy structural and functional durability [4]. This translated into a ten-times higher increase in the number of Murciano-Granadina LAS evaluations than those implemented in other breeds over the past decade. The efficiency of implementation of CAPRIGRAN LAS, has been maximized through the integration of the association within "Cabrandalucía", the Andalusian Federation of Purebred Goat Associations, set up on February 24th , 2005 as an initiative to share the projects that, until that moment, each association of goat breeders in Andalusia had implemented.

In these regards, Cabrandalucía Federation has recently implemented the concept of smart farming relying on a PLF platform (Web-App RUMIA). Web-App RUMIA incorporates PLF-like principles based on the integration of individual animal data to optimize decision making through a smart phone-based terminal and substitutes the previous "Escardillo" software used by CAPRIGRAN [3]. The improvements achieved in the collection of zoometric/LAS information rely on the axioma which lays the basis for Web-App RUMIA platform, that is the systematic remote on-farm individual data recording and acquisition, storage processing and interpretation by a supercomputer placed at Cabrandalucía headquarters, and provides interactive feedback of processed data to the farmer for farm management tasks optimization [5].

The productive levels that Murciano-Granadina breed has reached nowadays, provides it with a prominent position within the international dairy goat breed panorama [6]. In this sense, Murciano-Granadina consideration among the most highly productive dairy goat breeds explains the strong roots of CAPRIGRAN LAS being found in The American Dairy Goat Association (ADGA) and U.S. Department of Agriculture (USDA)'s LAS [7].

CAPRIGRAN LAS routinely comprises the numerical description of 17 zoometric linear traits (10 in the case of bucks as the mammary system major category is not evaluated) on a one to nine-point scale to represent the zoometric linear biological range for each particular trait [3]. The term "linear" in a linear appraisal system refers to the fact that traits are rated on a linear scale that goes from one biological extreme for that trait to the other. For primipara and multipara does, the 17 zoometric traits are sorted into four major categories (structure and capacity, dairy structure, mammary system and legs aplomb). Parallelly, for bucks, young males and goats that have not yet given birth, thus have not freshened, the mammary system is not evaluated, hence, only three major categories are considered into which 10 zoometric linear traits are sorted. The same scale is used in males and females for the body depth trait from the structure and capacity major category and the major categories of dairy structure and legs and feet. Afterwards, linear trait data is comprehensively used to build individual reports for every doe and buck.

One of the main drawbacks derived from the extrapolation of ADGA LAS to build CAPRIGRAN LAS, relies on the scarce amount of information which exists on the heritability of structural traits in dairy goats. Indeed, although genetic parameters may be similar, according to relative indications and experience, the absolute heritability of traits is not known or expected to be the same for dairy cattle and dairy goats. For example, the heritabilities used in the selection of traits for ADGA LAS based on 4 years of dairy cattle linear data, hence, they were inferred in other species, and specifically barely any information is present in regards the genetic correlations across zoometric or LAS traits.

Consequently, the specific computation of genetic parameters and the study of the relationship between zoometric and LAS traits must be performed. However, for this to occur, sufficient data has to be gathered to perform the calculations so as for information to be enough to issue valid and replicable conclusions.

Selection for zoometrics defines individuals' productive longevity, endurance, enhanced productive abilities and consequently, its long-term profitability [8,9]. When zoometric analysis is aimed at in large highly selected populations or in those at different selection momentums, LAS may provide a timely selection response. However, the particular selective context of the breed must be evaluated. The particular analysis of each variable permits tailoring specific strategies for each trait and serve as a model for other breeds, either selected or in terms of selection. For CAPRIGRAN LAS to be deemed effective, zoometric and LAS computed genetic parameters must be comparable, but also, they must be heritable (genetically-controlled) enough (heritability of 0.15 or higher is accepted as indicating at least moderate heritability of a trait) so that progress or improvement can be made at an acceptable rate through the selection of sires. Traits that are not at least moderately heritable are more effectively handled through herd management practices (such as culling) and are no suitable for inclusion in LAS.

Despite the breed's dairy potential, recent studies have suggested Murciano-Granadina inherent highly rustic nature, may make CAPRIGRAN LAS not to optimally meet the ADGA and USDA's LAS standards (upon which CAPRIGRAN LAS formerly based) [10]. Contextually, this may hinder the efficiency of selection practices focused towards the enhancement of dairy linked conformation in Murciano-Granadina goats, while sustainably maintaining its increased productivity under the harsh conditions in which the breed originated and was traditionally bred.

In this context, CAPRIGRAN international disagreement compelled the evaluation, optimization, validation and suggestion of restructuration measurements for CAPRIGRAN LAS [3,4,10]. The most recent studies validated CARIGRAN LAS to be solid and internally consistent for the measurement and capture of the variability of dairy related zoometric parameters [4]. However, optimization was limited given resulting models were quite conservative, with only rump angle lacking representativeness in the explanation of milk yield and milk quality-related traits [3]. Among other proposals, researchers suggested a limb-related traits scale levels reduction/readjustment, bucks' stature extension and male category age group subdivision (bucklings younger than two years and bucks of two years old and older) as the most relevant modifications to be implemented.

After shaping CAPRIGRAN LAS for it to capture the biological reality of Murciano-Granadina goats, a better understanding of the particular momentum of selection of the breed for dairy-linked zoometric traits can be achieved. This may permit understanding the future evolution of Murciano-Granadina breed population, while enhancing the profitability and efficiency of breeding plans. The value of CAPRIGRAN LAS relies in the possibility of dairy goat breeders using the information provided by these animal evaluation programs as guidance in making their management decisions such as mating plans that involve the selection of sires or dams used in their breeding programme. In turn, these management decisions may not only influence the structural correctness and genetic potential of individual animals, which determines their lifetime in the herd and their overall production level, but also may help to understand how the condition of type traits affects the structural durability and the reproductive and production efficiency of an animal is critical to effective herd management. This means dairy goat herds evaluated with the LAS will be instrumental in helping develop the data base needed to determine the heritability of structural traits in dairy goats and, eventually, their relationship to longevity and production, thus, their economic value.

To this aim, the present paper seeks to determine whether phenotypic, genotypic and environmental parameters for traditional zoometric analysis and CAPRIGRAN LAS are translatable and comparable. Afterwards, the zoometric or LAS items comprising each mayor category will be tested to determine the categorization system is appropriate or to propose enhancement measures to ensure the potential of selection strategies is maximized. This may help to evaluate the viability of selection strategies based on the relationship across zoometric and LAS traits as a base for future studies evaluating potential benefits linked to an increased productive longevity.

2. Materials and Methods

2.1. Animal Sample and Linear Appraisal Records

Murciano-Granadina whole pedigree datafile comprised 279264 animals (266793 does and 12971 bucks) and was used as the pedigree matrix for genetic analyses. Animals had been born from June 1966 to November 2019. The linear appraisal had been performed in 41418 animals across the year. Animal records were collected in 76 farms in the South of Spain from 09/06/2010 to 18/12/2019. All the farms considered in the study had received official National and International Sanitary Certificates. All farms were controlled and officially declared tuberculosis-free (C3), brucellosis-free (M4) (Order of 22 June 2018 and Directive 91/68/EEC), and SCRAPIE RC (Regulation (EC) No 999/2001 of the European Parliament and the Council). These farms also followed voluntary control plans for Caprine Contagious Agalactia (CCA) (National CCA Surveillance, Control, and Eradication Programme 2018–2020) and Caprine arthritis encephalitis (CAEV) (Order AYG/287/2019 of 28 of February of 2019). Goats were clinically examined by an official veterinarian and individuals presenting signs of illness or disease conditions were officially declared and removed from the herds, hence, discarded from the analyses. Permanent stabling practices were followed by all farms considered, *ad libitum* water, forage and supplemental concentrate were provided. A detailed description of the analytical composition of the diet supplied to the animals is reported in Table S1.

Records from 95 individuals were discarded due to their zoometric and linear appraisal observations being missing or incomplete. A total of 41323 records, belonging to 22727 herdbook registered primipara does, 17111 multipara does and 1485 bucks were considered in the analysis. Average ages for primipara, multipara 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.

2.2. Murciano-Granadina Linear Appraisal System (LAS)

Each observation comprises each animal's rater' score in the following four major categories for primipara and multipara does (three for bucks, young males and yet-to-give-birth goats); structure and capacity, dairy structure, mammary system (except in males) and legs and aplomb. In primipara and multipara does, each record comprised information on 17 linear traits rated on a 9-points scale. Given bucks were not scored for the mammary system major category, only 10 traits were scored for them following the aforementioned 9-points scale. Body depth from the structure and capacity major category and the dairy structure and legs and feet major categories followed the same criteria with independence of sex and sexual status. The same trained rater scored all animals in the study.

Once all major categories are scored, 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 mammary system for primipara and multipara does (any doe which has ever begun producing milk). In bucks and young males, such percentages change to 50% for structure and capacity, 20% for dairy structure, and 30% for legs and feet, respectively.

Rater's scores are assigned one of the six category qualifications considered by CAPRIGRAN as follows; insufficient (IN) for animals which display less than 69% of the optimal standard for Murciano-Granadina dairy goats (a final score of 69 points or less), mediocre (R), 70 to 74% of optimal standard (a final score between 70 and 74 points), good (B) from 75 to 79% of optimal standard (a final score from 75 to 79 points), quite good (BB) from 80 to 84% of optimal standard (a final score from 80 to 84 points), very good (MB) from 85 to 89% of optimal standard (a final score from 85 to 89 points), or excellent (E) when at least 90% of optimal standard is displayed (higher than 90 points final score). The scales used and the translation process from zoometric traits to LAS traits is detailedly described in Sánchez Rodríguez, et al. [11], Table 1, and Figures S1 to S27.

Age elements, for instance, the age of does or lactation order condition dairy linear or type appraisal-related traits [12]. Hence, these elements, often considered and registered for does at appraisal, permit to adjust models for the outputs of linear or type appraisal records [13]. Pearson product-moment correlation coefficient between lactation stage and age in years was 0.705 ($P < 0.01$), hence redundancies could be presumed for the outputs of linear or type appraisal if both age components were simultaneously considered. Thus, the lactation stage was considered and results for primipara and multipara goats were reported separately.

Table 1. Detailed description of the scales used and the translation process from zoometric traits to LAS scores in Murciano-Granadina goat and bucks.

Gender/ Status	Major area	Linear trait	Zoometric Scale/ Categorical Scale	Zoometric Optimum Scoring	Reference/Middle point	LAS Extrapolation	LAS Optimum scoring	New Scale Proposal [14]
Primipara/ Multipara does	Structure and capacity	Stature (Height to withers)	62–78 cm	72 cm (primipara) and 74 cm (multipara)	5 (70 cm)	1–9 points	6 (primipara) and 7 (multipara)	1–9 points
		Chest Width	15–23 cm	20 cm (primipara) and 21 cm (multipara)	5 (19 cm)	1–9 points	6 (primipara) and 7 (multipara)	1–9 points
		Body Depth	Shallow-Extremely deep	Intermediate	5 (elbow end matches rib depth)	1–9 points	7 (primipara and multipara)	1–8 points
		Rump Width	13–21 cm	18 cm (primipara) and 19 (multipara)	5 (17 cm)	1–9 points	6 (primipara) and 7 (multipara)	1–7 points
		Rump Angle	55º–31º	31º	5 (43º)	1–9 points	9	1–7 points (Not relevant) [3]
	Dairy structure	Angulosity	Angulous extremity-Rough extremity	Angulous extremity	5 (Intermediate)	1–9 points	9	1–10 points
		Bone Quality	Round and rough bones-flat and neat bones	Flat and neat bones	5 (Intermediate)	1–9 points	9	1–5 points
	Mammary system	Anterior insertion	Weak-Strong	120º	5 (90º)	1–9 points	9	1–5 points
		Rear Insertion Height	11–3 cm	3 cm	5 (7 cm)	1–9 points	9	1–5 points
		Median Suspensor Ligament	1–9 cm	5 cm	5 (5 cm)	1–9 points	5	1–6 points
		Udder width	3–11 cm	11 cm	5 (7 cm)	1–9 points	9	1–5 points
		Udder Depth	− 10–10 cm	-5 cm (5 cm over hock level) and 0 cm (udder bottom at hock level)	5 (0 cm/at hock level)	1–9 points	3 (primipara) and 5 (multipara)	1–9 points
		Nipple placement	90º–0º	0º	5 (45º)	1–9 points	9	1–6 points
		Nipple Diameter	0.5º to 4.5º	2 cm	5 (2.5 cm)	1–9 points	4	1–9 points
	Legs aplomb	Rear Legs Rear View	Very close-Parallel and separated	Parallel and separated	5 (slightly close)	1–9 points	9	1–7 points

		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	1–7 points
		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	1–5 points
Bucks	Structure and capacity	Stature (Height to withers)	68–92 cm	83 cm (young) and 86 cm (adult)	5 (80 cm)	1–9 points	6 (bucklings) and 7 (bucks)	1–10 points
		Chest Width	15–31 cm	25 cm (young) and 27 cm (adult)	5 (23 cm)	1–9 points	6 (bucklings) and 7 (bucks)	1–11 points
		Body Depth [a]	Shallow-Extremely deep	Intermediate	5 (elbow end matches rib depth)	1–9 points	7 (bucklings and bucks)	1–7 points
		Rump Width	14–22 cm	19 cm (young) and 20 cm (adult)	5 (18 cm)	1–9 points	6 (bucklings) and 7 (bucks)	1–5 points
		Rump Angle	55–31º	31º	5 (43º)	1–9 points	9	1–6 points
	Dairy structure	Angulosity [a]	Angulous extremity-Rough extremity	Angulous extremity	5 (Intermediate)	1–9 points	9	1–9 points
		Bone Quality [a]	Round and rough bones-flat and neat bones	Flat and neat bones	5 (Intermediate)	1–9 points	9	1–5 points
	Legs aplomb	Rear Legs Rear View [a]	Very close-Parallel and separated	Parallel and separated	5 (slightly close)	1–9 points	9	1–6 points
		Rear Legs Side View [a]	Straight-Very curved	Desirable curvature. Short distance from an imaginary line to anterior curvature of hock	5 (desirable curvature)	1–9 points	5	1–7 points
		Mobility [a]	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	1–5 points

[a]Same criteria for bucks and does.

2.3. Preliminary Assumption Testing in Zoometric and LAS Traits

Common parametric assumptions were tested in Murciano-Granadina goat breed zoometric and LAS historical records collected until December 2019. Kolmogórov-Smirnov and Levene tests were used to evaluate normality and homoscedasticity, respectively using SPSS Statistics for Windows statistical software, Version 25.0. Given the large sample size used in this study, the nonparametric method to test for the independence of two random variables with continuous distribution function (df) proposed by Hoeffding [15] which uses joint ranks was chosen. To this aim, the *Hmisc* package's *hoeffd* function [16] of RStudio 1.1.463 by the R Studio Team [17] was used. P-values are approximated by linear interpolation on the table in Hollander and Wolfe [18], which uses the asymptotically equivalent Blum-Kiefer-Rosenblatt statistic. For $P < 0.0001$ or >0.5, P values are computed using a well-fitting linear regression function in log P against the test statistic.

2.4. Multicollinearity Testing of Fixed Effects (Factors) and Covariates

To determine the environmental background affecting zoometric and LAS traits, we chose the following set of independent factors (kidding month and season, farm, sex, lactation stage) and covariates of age at kidding (in years) and days in milk following the premises that are commonly found in literature for the same purpose [12,19,20] . Additionally, we considered the effect of the interaction between farm/kidding year and farm/kidding year/kidding season to verify whether using a linear model to evaluate environmental effects would be appropriate. Redundancies in the variables used were identified after performing the multicollinearity assumption prior to further analyses. Multicollinearity analysis seeks to avoid the overinflation of the explanatory potential of variance due to the inclusion of an unnecessarily large number of variables. As an indicator of multicollinearity, the variance inflation factor was calculated using the following formula:

$$VIF = 1/(1-R^2) \quad (1)$$

where R^2 is the coefficient of determination.

A recommended maximum VIF value of 5 was used in the study, as suggested by Rogerson [21]. Tolerance $(1 - R^2)$ is the amount of variability in a certain independent variable that is not explained by the rest [22]. When tolerance values are lower than 0 and, simultaneously, VIF values ≥10, multicollinearity must be considered troublesome. VIF was computed using the *Multicollinearity statistics* routine of the *Describing data* package of XLSTAT 2014 (Pearson Edition).

2.4. Analysis of Covariance (ANCOVA) Test for Fixed and Random Effects

After multicollinearity testing, we used the ANCOVA from the family of Generalized Linear Models to determine how zoometric and LAS traits vary across independent factors, covariates and interactions. ANCOVA was performed using the *ANCOVA* routine of the *Modelling data* package of XLSTAT 2014 (Pearson Edition). The independent factors considered were as follows; parturition month and season, farm, sex, lactation stage (all qualitative variables that take value form). The covariates of age (in years) and days in milk and the interaction between farm/kidding year were alos considered. ANCOVA was run to verify the appropriateness of a linear model comprising the aforementioned environmental effects to explain the variability in zoometric and LAS traits in Murciano-Granadina does and bucks.

A Spearman's rho (ϱ) correlation test must be performed to rule out monotonic redundancies. The Spearman correlation between two variables is equal to the Pearson correlation between the rank values of those two variables; except for the fact that while Pearson's correlation assesses linear relationships, Spearman's correlation assesses monotonic relationships (whether linear or not). Hence, Spearman's rho (ϱ) explains how well the relationship between two variables can be described using a monotonic function.

When an independent variable is related to other independent variable at a correlation of ≥|0.5|, statistical redundancies are detected, hence a model comprising both will not adjust the dependent variable over the relationship between both independent variables. Hence, one or the other should be removed. Decision on which to discard must be carried considering the relationship of each independent variable in the pair with the rest of independent variables considered in the model.

2.4.1. Fisher's F test

The Fisher's F test was used to examine the results of the analysis of variance (Table 3). This test's outputs permit to determine whether the explanatory variables bring significant information (null hypothesis H_0) to the model or not, that is, if the mean reports valid information to describe the complete zoometric or LAS dataset, or if explanatory variables satisfactorily explain the behaviour of zoometric or LAS traits. Lower than 0.0001 P-values imply there is a lower than 0.01% risk in assuming that the null hypothesis is wrong (this is no effect of the explanatory variables).

2.4.2. Goodness of fit

The R^2 (coefficient of determination) indicates the percentage of the variability of the dependent variable which is explained by the explanatory variables that remained after multicollinearity analyses. The closer to 1 the R^2 is, the better the fit of the set of explicative variables is to describe the variability in the respective dependent zoometric trait. The Predicted R-squared decreases when insignificant or redundant terms are added to a particular model (Adjusted R^2). As a rule of thumb, adjusted and predicted R-squared values should not differed in more than 0.2. According to StatEase [23], there is not a commonly used reference value for R-squared. When a model is significant ($P < 0.05$), there is no evidence for an insignificant lack of fit ($P > 0.05$), and good agreement between adjusted and predicted R^2. When agreement between Predicted and Adjusted-R^2 exists, precision is adequate (> 4) and the residuals could be presumed to statistically behave well. Hence, the model being tested provides good predictions for outcomes on average. In these regards, low R-squared values are indicative of a certain fraction of individual variation not being explained by the model tested.

2.4.3. Type III Sum of Squares Analysis and Model Predictive Potential

To determine the amount of information provided by each fixed effect and covariate we evaluated the Type III Sum of Squares SS tables (Table 4). This choice was made upon the fact that the Type I SS table adds each factor and covariate to the model one by one, and evaluates the impact of each of them on the model sum of squares (Model SS). For this reason, in Type I SS, the order in which the variables are chosen influences the outputs. The lower the F probability of a given factor or covariate, the stronger its impact on the model as it is before such factor or covariate is added.

Contrarily, the Type III SS table is computed by removing one factor or covariate of the model at a time to evaluate its impact on the model's quality. As a result, the order in which the factors or covariates are chosen and taken out does not have any effect on the values in the Type III SS. For this reason, the Type III SS is the preferable method to use to interpret results when an interaction or interactions are part of the model, as it occurs in our case. In these regards, the lower the F probability of a given factor or covariate, the stronger its impact on the model will be as well.

In regards the evaluation of model predictive potential, the significance level and confidence intervals for each level of each parameter were evaluated. Confidence intervals including zero and significance levels $P > 0.05$ are indicative of a statistically non-significant weak impact of such factor on the specific zoometric or LAS traits tested.

2.4.5. Analysis of Residuals

Given the assumptions of the linear regression model evaluated in ANCOVA, standardized residuals should normally distribute, which implies 95% of the residuals should be in the interval [-1.96, 1.96], with all the observations falling outside this interval potentially being outliers, or indicative of the normality assumption not being met. *DataFlagger* routine of the *Tools* package in of XLSTAT 2014 (Pearson Edition) was used to graphically represent residuals. When the percentage off the residuals that are not in the [-1.96, 1.96] interval exceeds 5% ($P > 0.05$), the analysis could lead to rejecting the hypothesis of normality of residuals, which would render ANCOVA outputs invalid for conclusions to be issued.

2.5. Genetic Analyses

2.5.1. Model and Genetic Parameter Estimation for Zoometric and LAS Traits

The complete kinship matrix used for genetic analyses comprised all the 279,264 animals (266793 does and 12971 bucks) in Murciano-Granadina goat breed pedigree. As literature suggests, when bucks start rutting, that is when male goats display the behaviors associated with the urge to breed, they go through physical changes which even make specific variables such as rump angle decrease 3 degrees [24]. Most of goat breeds breeding season extends from August to January and go into rut during Autumn. The rut is characterized in bucks and the males of other species by an increase in testosterone, exacerbated sexual dimorphisms and increased aggression and interest in does [25]. This cyclic changes along the year are the source for natural discrepancies in the definition and specific characteristics of zoometric traits between bucks and does, whose body changes are rather progressive along their lives across lactation stages. This in turn may lead to statistical biases, hence, we decided phenotype data set to only comprise those observations belonging to does, either primipara or multipara to estimate genetic and phenotypic parameters. As a result, a total of 39838 records, belonging to 22727 herdbook registered primipara does and 17111 multipara does were considered in the genetic analysis. Animals were only scored once in their lifetime. Therefore, a multitrait animal mixed model with single measures was used to estimate (co) variance components, and the corresponding heritability, repeatability, phenotypic and genetic correlations and standard errors of such correlations for the traits under examination. In matrix notation, the following multitrait animal model with single measures was used;

$Y_{ijklmn} = \mu + Far_i \cdot A_i + LacStat_j \cdot B_j + KMon_k \cdot C_k + IntFarm/KYear_l \cdot D_l + b_1DIM_m \cdot E_m + b_2A_n \cdot F_n + b_3^2A_n \cdot F_n + e_{ijklmn}$, where Y_{ijklmn} is the vector of observations for each separate measure of each zoometric or LAS trait (Table 1) for a given animal; μ is the overall mean; Far_i is the vector for the fixed effect of the i[th] farm/herd (i = 76 farms); LacStatj is the vector for the fixed effect of the jth lactation stage (j = primipara/multipara does); $KMon_k$ is the vector for the fixed effect of the kth kidding month (k = January to December); $IntFarm/KYear_l$ is the vector for the fixed effect of the lth level of interaction between farm/herd and kidding year (l = 400 interaction levels possibilities combining the 76 farms and kidding years from 2005 to 2019); days in milk was considered a linear covariate, hence b_1 is the linear regression coefficient on days in milk (DIM_m), age in years was considered a linear and quadratic covariate, hence b_2 and b_3^2 are the linear and quadratic regression coefficients on the age of evaluation (A_n), e_{ijklmn} is vector of random residual effects and A_i, B_j, C_k and D_l are incidence matrices relating records to their respective fixed while E_m and F_n are incidence matrices relating records to their respective random effects. Only the direct genetic effect (animal) was fitted in each model due to zoometrics/LAS scores were recorded only once on each individual animal.

MTDFREML software package [26] was used to perform Restricted maximum likelihood approach-based univariate analyses in order to compute heritabilities and variance components. The same software was used to carry out bivariate analyses to estimate covariates and genetic and phenotypic correlation. Genetic and phenotypic correlations between each individual conformation trait were estimated using a multivariate analysis including all traits. The iteration process used sought a convergence criterion level of 10^{-12}. Link functions can be found in Boldman, et al. [26]. The standard errors for heritability and genetic and phenotypic correlations were computed using the same software.

As suggested by Navas González, et al. [27], we used the phenotypical variance of each character and the existing phenotypical correlations between each possible pair combination for the estimation of the starting point to seek for the convergence of additive genetic variance component (multiplying them by 0.2). Then, we did the same for environmental variances (multiplying them by 0.8) and genetic and phenotypic correlations to obtain specific variance components and estimates of fixed and random effects for each trait in multivariate analyses. To build the matrix of covariates among zoometric and LAS traits, respectively, the *Bivariate* routine of the *Correlate* procedure of the *Analyze* package in SPSS Statistics for Windows statistical software, Version 25.0. was used. For this, users need to check the box next to Cross-product deviations and covariances in the menu. Afterwards, to obtain the covariance for each pairwise combination of variables, you must divide the Sum of Squares and Cross-products by sample size (N). Starting values for genetic, phenotypic and environmental variates and covariates are shown in Table S2.

2.5.2. Non-Genetic Factors Estimation (BLUES)

After convergence was reached, we directly estimated non-genetic factors estimators through best linear unbiased estimators for fixed effects (BLUES) using the MTDFREML software [27].

3. Results

3.1. Preliminary Assumption Testing in Zoometric and LAS Traits

After the study of the distribution and symmetry properties of zoometric traits and the scale readjustment proposal suggested in Fernández Álvarez, et al. [14]. Parametric assumptions were met (normality, heteroscedasticity and sample independence, $P > 0.001$) which was supported by the values for skewness statistics ranging from - ½ to ½, which evidenced the symmetry of the profile of the curve described by the distribution of the data for all the variables evaluated. According to the evaluation of kurtosis, 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.

3.2. Multicollinearity Testing of Fixed Effects (Factors) and Covariates

Variance inflation factor evaluation suggested the model was free from redundancies after two rounds of multicollinearity analyses were performed (Table S1). Multicollinearity evaluation suggested the need to discard kidding year and the interaction between farm-kidding year-kidding season from further analyses (VIF > 5). Additionally, Spearman's rho correlation ($\varrho \geq |0.5|$), denoted a strong monotonic relationship between sex and kidding season with the rest of variables, hence, XLSTAT 2014 (Pearson Edition) automatically discarded them the set of environmental factors and covariates used for the following ANCOVA procedure.

3.3. Analysis of Covariance (ANCOVA) Test for Fixed and Random Effects

As suggested in Table 2, we can therefore conclude that all the factors and covariates explain a significant amount of the information contained in zoometric and LAS traits (Table 2).

Table 2. Type III Sum of Squares analysis for zoometric traits to LAS scores in Murciano-Granadina primipara and multipara does (41323) and bucks (1485).

Major area	Linear trait	Degrees of freedom (df)	Sum of squares (SS)	Mean squares (MS)	F	Pr > F	Error DF	Residual Sum of squares (RSS)	Residual Mean squares (RMS)
Structure and capacity	Stature (Height to withers)	490	499732.77	1019.86	186.36	< 0.0001	40832	223454.22	5.47
	Chest Width	490	123786.00	252.62	194.49	< 0.0001	40832	53037.59	1.30
	Body Depth	490	29629.31	60.47	86.68	< 0.0001	40832	28484.34	0.70
	Rump Width	490	16323.73	33.31	73.71	< 0.0001	40832	18454.07	0.45
	Rump Angle	490	65656.15	133.99	22.39	< 0.0001	40832	244385.19	5.99
Dairy structure	Angulosity	490	2355485.16	4807.11	54.49	< 0.0001	40832	3602289.62	88.22
	Bone Quality	490	15032.88	30.68	64.25	< 0.0001	40832	19497.63	0.48
Mammary system	Anterior insertion	418	4658.34	11.14	20.36	< 0.0001	39419	21571.54	0.55
	Rear Insertion Height	418	13155.42	31.47	45.46	< 0.0001	39419	27288.45	0.69
	Median Suspensor Ligament	418	19956.34	47.74	35.96	< 0.0001	39419	52341.04	1.33
	Udder width	418	17626.29	42.17	59.41	< 0.0001	39419	27976.58	0.71
	Udder Depth	418	248845.63	595.32	68.59	< 0.0001	39419	342127.71	8.68
	Nipple placement	418	391367.34	936.29	12.86	< 0.0001	39419	2869493.07	72.79
	Nipple Diameter	418	2365.73	5.66	10.71	< 0.0001	39419	20827.55	0.53
Legs aplomb	Rear Legs Rear View	490	15298.02	31.22	77.71	< 0.0001	40832	16404.11	0.40
	Rear Legs Side View	490	17773.05	36.27	83.17	< 0.0001	40832	17808.44	0.44
	Mobility	490	3622.40	7.39	20.94	< 0.0001	40832	14415.85	0.35

Table 3 presents the goodness of fit coefficients of the model. In this particular case, from 10.2 to 70% (9.2 to 69.6% when adjusted) of the variability across zoometric/LAS traits is explained by the independent factors of kidding month and season, farm, sex, lactation stage, the covariates of age at kidding (in years) and days in milk and the interaction between kidding year and farm. The remainder of the variability may be ascribed to additional effects (other explanatory variables) not considered during this experiment, for instance, genetic or those related to the nutritional status of the animals as suggested in literature [28,29].

Significance levels over 0.05 were reached and 0 was not contained in the confidence interval for almost all the levels within all fixed effects and covariates considered in the model. This denoted all the elements brought relevant information to the explanation of the behaviour of zoometric and LAS traits. The particular values for each element and level can be consulted in Table S3.

The comparison between predicted values and observed values suggested 5% standardized residuals ((35196x100)/692096) could be identified as potential outliers. Hence residual normality assumption was met and ANCOVA outputs can be used to draw valid conclusions.

Table 3. Goodness of fit coefficients of the model testing for zoometric traits to LAS scores in Murciano-Granadina primipara and multipara does (41323) and bucks (1485).

Major area	Linear traits	Degrees of freedom (df)	Predicted R^2	Adjusted R^2	Mean Squared Error (MSE)	Root Mean Squared Error (RMSE)	Durbin Watson (DW)
Structure and capacity	Stature (Height to withers)	40832	0.691	0.687	5.473	2.339	1.691
	Chest Width	40832	0.700	0.696	1.299	1.140	1.575
	Body Depth	40832	0.510	0.504	0.698	0.835	1.446
	Rump Width	40832	0.469	0.463	0.452	0.672	1.857
	Rump Angle	40832	0.212	0.202	5.985	2.446	1.787
Dairy structure	Angulosity	40832	0.395	0.388	88.222	9.393	1.742
	Bone Quality	40832	0.435	0.429	0.478	0.691	1.747
Mammary system	Anterior insertion	39419	0.178	0.169	0.547	0.740	1.911
	Rear Insertion Height	39419	0.325	0.318	0.692	0.832	1.805
	Median Suspensor Ligament	39419	0.276	0.268	1.328	1.152	1.901
	Udder width	39419	0.387	0.380	0.710	0.842	1.564
	Udder Depth	39419	0.421	0.415	8.679	2.946	1.890
	Nipple placement	39419	0.120	0.111	72.795	8.532	1.926
	Nipple Diameter	39419	0.102	0.092	0.528	0.727	1.924
Legs aplomb	Rear Legs Rear View	40832	0.483	0.476	0.402	0.634	1.888
	Rear Legs Side View	40832	0.500	0.493	0.436	0.660	1.747
	Mobility	40832	0.201	0.191	0.353	0.594	1.902

3.2. Genetic Analyses

3.2.1. Genetic Model Comparison, Phenotypic and Genetic Parameters Estimation

Estimates of non-genetic fixed effects (BLUES) obtained from the REML quantitative genetic analysis, including days in milk as a linear covariate and age as a linear and quadratic covariate, the fixed effects of farm/herd, lactation stage, kidding month, and the interaction between farm/herd and kidding year are shown in Supplementary Table S4. The estimates for heritability, genetic, phenotypic and environmental variance obtained through REML methods for zoometric and LAS traits are shown in Table 4. The genetic (r_G) and phenotypic correlations (r_P) estimated are shown in Table 5.

Table 4. Estimated components of variance, heritability (h^2) and standard error of the mean (SEM) for zoometric and LAS traits obtained from multivariate analyses through REML methods. Results for zoometric and LAS traits were exactly the same.

Major area	Zoometric/LAS Trait	σ_a^2 ± SEM	σ_p^2 ± SEM	σ_e^2 ± SEM	h^2 ± SEM
Structure and capacity	Stature (Height to withers)	0.4986 ± 0.0002	1.15511 ± 0.00006	0.6565 ± 0.0002	0.4300 ± 0.0001
	Chest Width	0.3094 ± 0.0003	1.05539 ± 0.00006	0.7460 ± 0.0002	0.2906 ± 0.0025
	Body Depth	0.0666 ± 0.0002	0.67957 ± 0.00002	0.6130 ± 0.0002	0.1000 ± 0.0001
	Rump Width	0.1370 ± 0.0001	0.43747 ± 0.00003	0.3005 ± 0.0001	0.3100 ± 0.0001
	Rump Angle	0.1096 ± 0.0001	0.63168 ± 0.00003	0.5221 ± 0.0001	0.1706 ± 0.0025
Dairy structure	Angulosity	0.2699 ± 0.0001	1.06034 ± 0.00002	0.7904 ± 0.0001	0.2513 ± 0.0034
	Bone Quality	0.1479 ± 0.0001	0.47679 ± 0.00002	0.3289 ± 0.0001	0.3100 ± 0.0001
Mammary system	Anterior insertion	0.1176 ± 0.0002	0.54863 ± 0.00007	0.4310 ± 0.0002	0.2106 ± 0.0025
	Rear Insertion Height	0.1691 ± 0.0003	0.65676 ± 0.00005	0.4877 ± 0.0002	0.2588 ± 0.0034
	Median Suspensor Ligament	0.3758 ± 0.0003	1.13703 ± 0.00006	0.7612 ± 0.0002	0.3300 ± 0.0001
	Udder width	0.0515 ± 0.0001	0.52287 ± 0.00002	0.4714 ± 0.0001	0.1000 ± 0.0001
	Udder Depth	0.4014 ± 0.0002	1.37782 ± 0.00004	0.9764 ± 0.0002	0.2900 ± 0.0001
	Nipple placement	0.1533 ± 0.0002	0.56946 ± 0.00003	0.4162 ± 0.0001	0.2700 ± 0.0001
	Nipple Diameter	0.8757 ± 0.0002	2.13335 ± 0.00006	12576 ± 0.0002	0.4100 ± 0.0001
Legs aplomb	Rear Legs Rear View	0.0883 ± 0.0005	0.40271 ± 0.00012	0.3144 ± 0.0004	0.2213 ± 0.0050
	Rear Legs Side View	0.0379 ± 0.0004	0.42775 ± 0.00012	0.3899 ± 0.0004	0.0906 ± 0.0025
	Mobility	0.0393 ± 0.0001	0.35306 ± 0.00001	0.3138 ± 0.0001	0.1100 ± 0.0001

Table 5. Estimated genetic (rG) (above diagonal) and phenotypic (rP) (below diagonal) correlations for zoometric and LAS traits obtained in bivariate analyses through REML.

	Major area	Structure and capacity					Dairy structure		Mammary system							Legs aplomb		
Major area	Linear traits	Stature (Height to withers)	Chest Width	Body Depth	Rump Width	Rump Angle	Angulosity	Bone Quality	Anterior insertion	Rear Insertion Height	Median Suspensor Ligament	Udder width	Udder Depth	Nipple placement	Nipple Diameter	Rear Legs Rear View	Rear Legs Side View	Mobility
	Stature (Height to withers)		0.530	0.220	0.610	0.050	0.320	-0.460	-0.230	-0.400	0.150	0.120	0.080	-0.160	0.070	-0.340	-0.130	-0.360
	Chest Width	0.340		0.620	0.790	0.280	0.700	-0.490	0.070	-0.500	0.140	0.230	0.070	0.040	0.090	-0.120	-0.110	-0.150
Structure and capacity	Body Depth	-0.030	0.260		0.530	0.150	0.420	-0.420	0.100	-0.370	0.050	0.090	0.110	-0.040	0.000	-0.210	0.160	-0.130
	Rump Width	0.290	0.450	0.210		0.260	0.560	-0.530	0.070	-0.440	0.130	0.260	0.000	-0.010	0.080	-0.140	-0.030	-0.200
	Rump Angle	0.050	0.140	0.050	0.140		0.300	0.010	0.230	-0.320	0.030	0.160	-0.060	0.090	0.040	0.250	0.080	0.150
Dairy structure	Angulosity	0.160	0.430	0.250	0.370	0.150		-0.320	0.210	-0.390	0.100	0.320	0.090	0.130	0.060	-0.030	-0.290	-0.110
	Bone Quality	-0.120	-0.180	-0.070	-0.150	-0.040	-0.120		0.140	0.420	-0.110	-0.040	-0.120	0.110	-0.060	0.380	0.050	0.440
	Anterior insertion	0.060	0.120	0.070	0.120	0.120	0.150	-0.030		0.240	-0.110	0.160	-0.570	0.210	-0.120	0.300	0.020	0.350
	Rear Insertion Height	-0.110	-0.210	-0.040	-0.160	-0.150	-0.160	0.070	-0.070		-0.050	0.150	-0.190	0.150	-0.020	0.280	0.030	0.350
	Median Suspensor Ligament	0.040	0.060	0.030	0.040	0.010	0.060	0.020	-0.090	-0.060		0.130	0.360	0.370	0.320	-0.050	-0.100	-0.100
Mammary system	Udder width	0.090	0.160	0.170	0.190	-0.040	0.150	-0.020	0.010	0.090	0.050		-0.090	0.320	0.060	0.280	-0.130	0.260
	Udder Depth	0.030	0.100	0.050	0.060	0.000	0.080	-0.010	-0.230	-0.030	0.320	0.130		-0.170	0.240	-0.220	-0.100	-0.370
	Nipple placement	0.010	0.020	0.040	0.050	0.020	0.050	-0.020	0.080	0.030	0.180	0.100	0.050		0.380	0.290	0.090	0.290
	Nipple Diameter	0.080	0.080	0.030	0.080	0.000	0.040	-0.050	-0.060	0.010	0.120	0.100	0.160	0.140		0.020	-0.040	-0.010
	Rear Legs Rear View	0.040	0.020	0.010	0.030	0.020	-0.030	0.020	0.020	0.040	0.020	0.130	-0.010	0.080	0.050		0.370	0.870
Legs aplomb	Rear Legs Side View	-0.070	-0.090	0.010	-0.060	0.000	-0.070	0.050	0.010	0.050	0.010	-0.030	0.000	0.000	0.010	0.030		0.200
	Mobility	0.000	0.000	0.040	0.040	0.050	0.010	0.010	0.070	-0.010	-0.020	0.050	-0.080	0.050	-0.020	0.200	0.130	

Average standard error for estimated genetic (rG) (above diagonal) and phenotypic (rP) (below diagonal) were 0.0001, respectively.

4. Discussion

4.1. Heritabilities for Zoometric/LAS Traits and Their Evolution

The univariate heritability estimates for each trait ranged from 0.0906 to 0.4300 (Table 4) with standard errors ranging from 0.0001 to 0.0050 for all the seventeen zoometric/LAS traits. As reported by Fernández Álvarez, et al. [19], the Murciano-Granadina breed has experienced an average gain in heritability values for zoometrics/LAS of 0.1082 and an average decrease in standard errors of 0.0706 (Table S5) since 2011. Unlike previous genetic evaluations, convergence was attained for all zoometric/LAS traits. Overall, the heritability estimates observed agreed those in literature by Manfredi, et al. [12], Rupp, et al. [30], McLaren, et al. [20] and Luo, et al. [31]. However, estimates observed rather closely resembled those in Manfredi, et al. [12], Rupp, et al. [30] and Luo, et al. [31]. The reason for this may be the fact that McLaren, et al. [20] used mixed breeds individual in the genetic evaluations that the authors performed.

Despite the average heritability of zoometric measures has reportedly been described as higher than the heritability of LAS traits, which also, according to literature usually presents larger standard errors [32], the process of validation and optimization of the scales used and the implementation of the system by trained operators makes both parameters equal [3,14].

Indeed, the dissimilarities that have been described in literature may occur when LAS scale units are not able to represent the same range of units found in the population for a particular zoometric trait, thus LAS is unable to capture all the population's variability for such traits. This normally occurs due to the lack of implementation of a process of scale validation and optimization, and trained score operators are not used to collect the information as it has occurred in the Murciano-Granadina goat breed [3].

The progressive gain in heritability values and reduction in heritability standard errors may be ascribed to the technification and improvement of the efficiency of the methods used to collect either phenotypic or genealogic data in terms of quantity and quality. Relative increases in heritability may evidence faster traits evolution; this means fewer generations may be required for traits to evolve either positively or negatively. According to Haworth, et al. [33], in their studies on cognitive development, heritability increases as more genes come into play as individuals undergo major transitions. Our study suggests some of those increases/decreases may reflect underlying changes in the body of does as they go through their first parity, as they accumulate further parities along their lives [34] or in bucks when these periodically go through rutting [35]. Rutting event occurrence varies along the year depending on the breed, although normally, it occurs around autumn.

When compared to the values in Fernández Álvarez, et al. [19], mobility was the only trait for which a loss in heritability (+ 0.0500) was reported after a decade. Interestingly, such a loss was parallel to the reduction of -0.1000 in heritability standard errors. Indeed, the first may be a consequence of the second as the drastic reduction of standard errors may indeed be an increase in the accuracy of this parameter estimation which may derive from the optimization of the methods used to assess mobility which on a regular basis are not standardized and may rather depend on the degree of objectivity of the criteria and training of operators. Moreover, the study by Fernández Álvarez, et al. [14] reported a reduction in the scale for mobility from 1 to 9 points to 1 to 5 which may have stemmed from the fact that Murciano-Granadina does and bucks mobility may not describe such a diverse range of mobility values as to cover all the levels in the scale that was formerly applied, which in turn adds to the reduction in heritability for the mobility trait. Furthermore, the value of heritability can change if the impact of environment (or of genes) in the population is substantially altered, for example as farms implement improvement in their management or systems of phenotypic productive data collection [36]. In this context, If the environmental variation encountered by different individuals increases, then the heritability figure decreases.

Changes in heritability must be regarded with caution given heritability does not measure the proportion of a trait caused by genes, but the proportion of variation in a trait that can be attributed to genes. As a result, when the environment relevant to a given trait, uniformly changes affecting all members of the population, that is the variation or differences among individuals in the population remains the same, the mean value of the trait will change without any change in its heritability. This not only becomes evident for traits for which convergence had not been reached at previous evaluations (body depth, rump angle, bone quality, udder width and rear legs side view), but for those, such as stature, which accounts with a high heritability of 0.4300, even if average stature continues to increase through the years to reach the international optimal standard for the dairy goat type [19]. This means high heritabilities may not necessarily mean that average group differences may ascribe to genes, but to the relationship of those genes with environment, which is of extreme relevance in locally adapted breeds following a process of selection towards a particular productive outcome, such as Murciano-Granadina.

Total phenotypic variance is the denominator of heritability and it is estimated as the variance of the trait being evaluated after correcting for known fixed effects such as sex and covariates such as age as it occurred in this study. As extended among animal breeders, the best prediction of future performance is obtained by considering the amount of variation that is not accounted for by known environmental effects. The lack of knowledge in regards these factors increases the estimates of phenotypic variance thus reduces the estimate of heritabilities. However, zoometry needs to follow a rather evolutionary perspective and focus on the total variation between individuals.

According to Visscher, et al. [37], the prediction of the response to selection of specific traits, such as zoometrics/LAS ones depends on whether selection takes place within or across the factors that cause variation, for instance, year-to year fluctuations within and among herds. Even if the thorough consideration of other factors such as climate, diet among others, that presumably have a large effect on mean zoometrics has not been considered. This is due to the fact that selection practices operate at a farm/herd level and within years. Consequently, the best prediction of response would be based on a heritability that is estimated by adjusting for farm between-year variation rather than other factors which may initially be stronger conditioners of zoometrics.

The highest estimates were generally associated with the udder- and teat-related traits, whereas those estimated for the legs and feet were lower. The highest estimates were generally associated with the stature, the udder (nipple-related traits) and those traits involved in teat suspensory system. whereas those estimated for mobility, legs, feet and other body areas which are involved in movement development were the lowest ones. The individual traits with the overall highest and lowest heritability estimates were stature (0.4300) and rear legs side view (0.0906), respectively. Other authors [12,20] have also reported higher estimates for the udder and teat traits compared with the legs and feet in general even if despite using a similar scale and scoring system, some of the traits considered were not the same as those in the present study.

The evaluation of legs aplomb related traits in Murciano-Granadina goats (rear legs side and rear views and mobility) reported heritability values ranging from 0.0906 to 0.2213. This range comprised the values reported for standardized breeds (0.16 and 0.12 for the Alpine and Saanen breeds, respectively) and was also reasonably similar to those of 0.13 reported by McLaren, et al. [20] for random crossings between British Alpine, Saanen, and Toggenburg. However, heritability values were centered around the middle of the range and were neither as high or low as any of the range limits in the present study.

This situation may be ascribed to zoometric/LAS criteria differing in terms of the methods that were implemented for their collection (different scales or even different trait definition). Furthermore, the rather advanced level of standardization of the breeds that were evaluated may be a source for reduction in the variability for specific zoometric/LAS traits.

When the same or similar scoring methods is used, values closely resemble those in our study (0.2213), as shown by the 0.21 heritability values presented by Luo, et al. [31] for a multiracial evaluation involving Alpine, LaMancha, Nubian, Oberhasli, Saanen and Toggenburg goat breeds, respectively. The higher heritability reported for rear legs seen from the rear than from the side may derive from the fact that visualization of the area is easier hence, the ability of operator to detect representative animals for a wider range of the scale is feasible. As suggested by McLaren, et al. [20] on-farm previous selection criteria may have only selected animals with better aplomb and mobility patterns to remain in the herd, which determines the relative fixation of traits such as rear legs side view and the reduction in the variability and in turn of the heritability of the trait.

The studies by Fernández Álvarez, et al. [14] and Fernández Álvarez, et al. [19] suggested the fact that the traits comprised within the legs and aplomb major area may have experienced a drastic improvement in terms of the efficiency with which the variability in the scale represents the variability perceived on field, but also of the ability of the operators involved in measure collection to capture such a variability across the levels of the each particular scale for each trait [10].

Considering the Mammary system major area, the estimates observed in the present study were in close agreement with those observed by Manfredi, et al. [12] and Rupp, et al. [30] in Saanen and Alpine breeds, Mavrogenis, et al. [38] in Damascus breed, and Luo, et al. [31] in a multiracial evaluation involving Alpine, LaMancha, Nubian, Oberhasli, Saanen and Toggenburg goat breeds, respectively. Heritabilities for Mammary system major area traits ranged from 0.1000 to 0.4100 for udder width and nipple diameter, respectively. Nipple diameter and location had heritabilities of 0.2700 to 0.4100, respectively. These heritability values are in the range of the aforementioned studies by Mavrogenis, et al. [38] and Luo, et al. [31] who found intermediate heritabilities over 0.35 for udder and teat characteristics (Table 4).

Despite the results in this study are in the range of the studies mentioned above [12,20,30,31,39], noticeable differences are patent. The most of such differences may ascribe to the number of zoometric/LAS data records available for primipara and multipara does (n = 39,838). Furthermore, the Murciano-Granadina breed routinely follows a parentage DNA testing of the animals in the kinship matrix. Kinship matrix comprises a total of 279,264 individuals. The aforediscussed studies performed genetic evaluations using data from slightly lower than 19000 to slightly over 43000 does recorded over several years. Our study considered the information from 39838 multipara and primipara does, which is in the upper limit of data used in previous research experiences.

McLaren, et al. [20], suggested the accuracy of heritability estimates drastically increases as more information is available which is particularly supported by the negligible values for standard errors in this study (Table 4).

However, differences may not only derive from accuracy issues. For instance, selection of specific traits may involve a reduction in variability and in turn this may translate in the progressive reduction of heritability estimates. The implementation of on-farm selection policies tends to remove effectives displaying undesirable conformations from an early age before animals are able to disseminate their genetics and become established in the herd. The optimization of zoometric and LAS systems and of the ability of operators to collect information may be responsible for the increases in heritability experienced by almost all traits, as reported in Fernández Álvarez, et al. [19], as these often translate into an adequation of the scales used to measure or score animals and thus to capture the variability in the population but also in an increased ability by operators to perceive differences. The Murciano-Granadina breed is an autochthonous population whose additive genetic variance remains relatively stable in time as a result of breed standardization, with the need for decades for significant changes in heritability estimate to occur [19].

4.2. Genetic and Phenotypic Correlations among Zoometric/LAS Traits

Genetic correlations ranged from -0.010 to 0.870, with the highest positive genetic correlation occurring between Mobility and Rear Legs Rear View (0.870) and the lowest positive genetic correlation between Udder Depth and Rump Width (0.000). The highest negative genetic correlation (-0.570) occurred between udder depth and anterior insertion while the lowest negative genetic correlation was -0.010 and occurred between nipple placement and rump width and nipple diameter and mobility. The standard errors associated with the genetic correlations were low and negligible (μ = 0.0001), with the highest error associated with rear legs rear view. Similar findings were reported by McLaren, et al. [20], who also found feet and legs related traits to account for the highest standard errors. Phenotypic correlations values were low to high and ranged from -0.230 to 0.450, with standard errors being 0.0001 on average. The highest positive phenotypic correlation (0.450) occurred between rump width and chest width while the lowest positive genetic correlation occurred between rump angle and bone quality (0.010). The only variable pair which did not genetically correlate was that comprising nipple diameter and body depth.

The highest negative phenotypic correlation was -0.210 and occurred between rear insertion height and chest width, while the lowest negative phenotypic correlation was -0.010 and occurred between rear legs rear view and udder depth. Mobility and stature and mobility and chest width, between rear legs side view and nipple placement and rear legs side view and udder depth, and rear legs side view and rump angle, nipple diameter and rump angle, rump angle and udder depth, respectively were neither positively nor negatively phenotypically correlated.

There was a general lack of parallelism in the magnitude of genetic correlations and the respective phenotypic correlations for the same pair of variables. This means that although the moderate to high values of genetic relationship among variable pairs permits the determination of a well-defined relationship between trait pairs on either direction (positive or negative), phenotypic correlations are low to mild. This situation challenges selection if we only consider what we can visually see of zoometric traits, and is typical of breeds which are immersed in a process of standardization such as the Murciano-Granadina [6]. This becomes even more complex when genetic and phenotypic correlations present a different sign, with genetic correlations being positive or negative for a specific pair of traits while the corresponding value for phenotypic correlations describes the opposite trend. As reported in Table 5, this situation occurs in the traits of body depth and less sharply in rear legs rear view and mobility traits. The heritability for these traits is in the lowest end of the range for the heritabilities reported in this study.

In line with this findings, Fernández Álvarez, et al. [3] reported evidences of a common data structure for the aforementioned traits which defined the configuration of the category of the "mobility and propulsion system" at the principal component analysis that the authors performed. The same authors would also recommend discarding the trait of rump angle from the panel of traits due to its redundant nature in regards its data variability explanatory potential. According Dyce, et al. [39], the basis for such dimensionality relies in the continuity of common aponeurosis of the longissimus dorsi muscle given its implication with the development of back motion, and the middle gluteal muscle given its instrumental role in the mechanisms of propulsion.

4.3. Major Area Zoometric/LAS Traits Configuration Assessment

The evaluation of genetic and phenotypic parameters across major areas revealed the set of traits comprised in the structure and capacity major area genetically correlate following a positive pattern, which at the very least duplicates the magnitude of phenotypic correlations. There are only two exceptions to note, which are the low negative phenotypic correlation between stature (height at withers) and body depth against the moderate positive genetic correlation for the same pair of traits, with the latter presenting the lowest heritability of the traits in the structure and capacity major area, hence the more limited range of possibilities for selection to be efficient and the existence of redundancies with their base on the rump angle trait as evidenced by the studies of Fernández Álvarez, et al.

[3], which also presented a low heritability of 0.1706 and a relatively higher standard error of prediction that the rest of traits in the same major area.

The aforedescribed genetic/phenotypic pattern is also shared by the angulosity trait of the dairy structure major area. Contrastingly, angulosity and bone quality, both from the dairy structure major area describe an opposite relationship. This means that at the same time that our focus seeks the improvement in one of them, we also hinder the selection in favour of the other.

As a consequence, the first suggestion is the discard of the rump angle variable from the structure and capacity major area and to include the angulosity trait, which may ensure all traits in the same major area behave similarly, which in turn may enhance the potential of selection strategies. This becomes even more important when these results are compared to those in literature given the same pattern sustain across research experiences in the topic across goat breeds [12,20,30,31]. This may stem from the high values for heritabilities of these traits but also in the objectivity with which such traits can be collected, which configures the solidity of data.

The high negative genetic correlations of bone quality and rear insertion height with almost all of the rest of traits makes of these traits potential candidates to be used as references in negative selection practices. In this sense, quantitatively selecting against thicker bones and higher rear insertion heights, which indirectly means selecting for animals with finer and flatter bones, with shorter rear insertion heights (which is the optimum that breeders seek) may indeed result in the optimization of selection practices in the rest of traits, specially of those in the structure and capacity and mammary system major areas.

Within the mammary system major area, rear insertion height described the exact opposite genetic and phenotypic correlation patterns to the rest of traits in the same major area. This stems from the fact that, while performing the extrapolation of zoometrics to LAS, the optimum in LAS scale (9 points in the former and 5 in the new proposal) corresponds to less centimeters (3 cm) than the minimum level in the scale (1 point and 11 cm). This may need to be considered when implementing selection strategies as although distribution properties and descriptive statistics are equivalent, the direction of the correlations is inversed when compared to the rest of traits in the same major area. The proposal would be to invert the current LAS scale so that upper levels in LAS scale correspond to longer rear insertion heights, hence making LAS system and zoometrics follow the same direction, without the need to remove the trait from the major area in which it has traditionally been comprised.

This has also been described in other breeds as CAPRIGRAN LAS bases upon the system which was traditionally applied in international goat breeds such as Alpine and Saanen breeds, as a direct extrapolation from dairy cows, in respect to the direction of the relationships among trait pairs that were considered a priori. In these regards, Manfredi, et al. [12] indicated that in goats, as the strength of the medial ligament changed, there is a negative knock-on effect on the angle and placement of the nipples. Thus, selection against "baggy" udders (which means udder traits scoring low) would translate into an indirect response towards bigger, close-in and inner oriented teats. This event may also be the source for the high negative correlation between udder depth and anterior insertion. As we go lower in the LAS scale for anterior insertion, we approach wider angles that reach a minimum of 45° and correspond with 1 in the LAS scale, while the optimum was formerly placed in 9 or currently placed at 5 in the new proposal for LAS scale and corresponds with 120°. Wider angles imply shallower udders derived from these implanting more cranially in the body of does. For this, the inversion of the scale would permit correlations to agree with the patterns described by the rest of parameters without impairing the aim of selection for anterior insertion.

In this sense, if sturdy tall thick boned animals presenting sloping rumps are selected against, we may indirectly seek for rather average sized fine boned animals with raised rumps, which is the exact opposite to that recommended in literature for Holstein Friesian dairy cows [40,41], but which in goats maximizes the space between hocks which in turn means goats present broader spaces for the mammary system to be installed.

In regards the legs aplomb major area, all traits considered (rear legs side and rear views and mobility) describe the similar negative genetic correlation trend with the rest of traits in the rest of major areas, which permits the consideration of these traits as a solid cluster in terms of the planification of selection strategies, even if the direction of selection must be the opposite to that to be performed for the structure and capacity and mammary system major areas.

5. Conclusions

The Murciano-Granadina breed has relatively stable additive genetic variances for zoometric/LAS traits derived from breed standardization progress. Selection for zoometrics and LAS is equivalent as long as trained operators are able to distinguish and score for the variability present in the reality of the breed. The progressive gain in heritability values for zoometric and LAS traits and reduction in their heritability standard errors through the years may derive from the technification and enhancement of the methods used to collect either phenotypic or genealogic data quantitively and qualitatively more efficiently. Changes occurring along lactations and during rutting need to be accounted for while measuring individuals due to the zoometric alterations that they promote. Certain traits may not be able to cover for the variability described in international 9-point scoring scales, but a 5-point scale with the consequent reduction of heritability. Total variation across individuals in the multifactorial environmental context in which these are herded and thrive, is of extreme relevance in locally adapted breeds following a process of selection towards a particular productive outcome and is the source for the high estimates for heritabilities found. Highest estimates rather associate to the udder- and teat-related traits than those in the legs and feet major area. A priori on-farm selection criteria may have selected animals with better aplomb and mobility patterns which is the source for their relative fixation in the population, variability and heritability reduction. The increase in the accuracy of estimations derives from the large number of individuals considered in the kinship matrix and to the routine application of DNA parentage testing. Discarding rump angle trait from the structure and capacity major area and including the angulosity trait ensures all traits in the same major area behave similarly which enhances the potential of selection strategies. Scale inversion on specific zoometric traits may help to address disagreement in the patterns of the rest of traits in the same major area without impairing the aim of selection for the trait whose scale has been modified itself. Legs aplomb major area conforms a solid cluster in terms of the planification of selection strategies, even if the direction of selection must be the opposite to that for the structure and capacity and mammary system major areas. Future breeding programs would benefit from modifying the collection system and the manner in which the zoometric traits are managed at a genetic level to ensure that selection for zoometrics/LAS does not translate into any unwanted change in functional fitness, maximizing the outcome of selection strategies to fit the particular reality of the goat species and the diverse range of breeds that it comprises.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Table S1. Multicollinearity Testing Statistics (VIF and Tolerance) for environmental fixed effects and covariates; Table S2. Starting values for convergence iteration of genetic, phenotypic and environmental variates and covariates for zoometric and LAS traits in Murciano-Granadina goats and bucks; Table S3. Fixed Effects and covariates significance and impact within model; Table S4. Best linear estimators (BLUES) for fixed effects and covariates for zoometric and LAS traits in Murciano-Granadina goats and bucks; Table S5. Gain (+)/Loss (-) in heritability and increase (+)/decrease (-) in heritability standard errors for zoometric and LAS traits in Murciano-Granadina goats and bucks from 2011 to 2021.

Author Contributions: Conceptualization, Javier Fernández Álvarez, Francisco Javier Navas González, Jose Manuel León Jurado, Carlos Iglesias Pastrana and Juan Vicente Delgado Bermejo; Data curation, Francisco Javier Navas González and Jose Manuel León Jurado; Formal analysis, Francisco Javier Navas González and Jose Manuel León Jurado; Funding acquisition, Javier Fernández Álvarez and Juan Vicente Delgado Bermejo; Investigation, Javier Fernández Álvarez, Francisco Javier Navas González and Carlos Iglesias Pastrana; Methodology, Francisco Javier Navas González and Jose Manuel León Jurado; Project administration, Francisco Javier Navas González and Juan Vicente Delgado Bermejo; Resources, Javier Fernández Álvarez, Jose Manuel León Jurado, Carlos Iglesias Pastrana and Juan Vicente Delgado Bermejo; Software, Francisco Javier Navas González and Carlos Iglesias Pastrana; Supervision, Francisco Javier Navas González and Juan Vicente Delgado Bermejo; Validation, Francisco Javier Navas González; Visualization, Francisco Javier Navas González and Juan Vicente Delgado Bermejo; Writing—original draft, Javier Fernández Álvarez and Francisco Javier Navas González; Writing—review & editing, Javier Fernández Álvarez, Francisco Javier Navas González, Jose Manuel León Jurado, Carlos Iglesias Pastrana and Juan Vicente Delgado Bermejo.

Funding: The present research was carried during the covering period of a predoctoral contract (FPU Fellowship) funded by the Spanish Ministry of Science and Innovation.

Institutional Review Board Statement: The study followed the premises described in the Declaration of Helsinki. The Spanish Ministry of Economy and Competitivity 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 of 2010. Furthermore, the present study works with records rather than live animals directly, hence no special permission was compulsory.

Data Availability Statement: Data will be made available from corresponding author upon reasonable request.

Acknowledgments: The database used in the present study was supplied by the National Association of Murciano-Granadina Goat Breeders and all the information that the database comprised had been collected in the framework of Murciano-Granadina goat breed breeding programme. This work would not have been possible if it had not been for the support and assistance of the National Association of Breeders of Murciano-Granadina Goat Breed, Fuente Vaqueros (Spain) and the PAIDI AGR 218 research group.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Vieira, A.; Brandão, S.; Monteiro, A.; Ajuda, I.; Stilwell, G. Development and validation of a visual body condition scoring system for dairy goats with picture-based training. *J. Dairy Sci.* **2015**, *98*, 6597–6608.
2. Arrebola, F.; González, B.; Beltrán, N.; Gil, M.; Sánchez, M.; Dueñas, A. Caracterización zoométrica mediante calificación morfológica lineal del caprino lechero de raza Murciano-Granadina en el Valle de los Pedroches. In Proceedings of the XXXI Congreso de la Sociedad Española de Ovinotecnia y Caprinotecnia (SEOC), Zamora, Spain, 10–13th May, 2006; pp. 198–201.
3. Fernández Álvarez, J.; León Jurado, J.M.; Navas González, F.J.; Iglesias Pastrana, C.; Delgado Bermejo, J.V. Optimization and Validation of a Linear Appraisal Scoring System for Milk Production-Linked Zoometric Traits in Murciano-Granadina Dairy Goats and Bucks. *Applied Sci.* **2020**, *10*, 5502.
4. Fernández Álvarez, J.; León, J.M.; Navas González, F.; Iglesias, C.; Delgado Bermejo, J.V. CAPRIGRAN Linear Appraisal Evidences Dairy Selection Signs in Murciano-Granadina Goats and Bucks: Presentation of the New Linear Appraisal Scale. *Arch. Zootecn.* **2021**, *70*, 239–245.
5. Pardo, G.; del Prado, A.; Fernández-Álvarez, J.; Yáñez-Ruiz, D.R.; Belanche, A. Influence of precision livestock farming on the environmental performance of intensive dairy goat farms. *J. Clean. Prod.* **2022**, *351*, 131518.
6. Delgado, J.V.; Landi, V.; Barba, C.J.; Fernández, J.; Gómez, M.M.; Camacho, M.E.; Martínez, M.A.; Navas, F.J.; León, J.M. Murciano-Granadina goat: A Spanish local breed ready for the challenges of the twenty-first century. In *Sustainable Goat Production in Adverse Environments: Volume II.*; Springer: Cham, Switzerland, 2017; pp. 205–219.
7. Sánchez, M.; Muñoz, E.; Pérez, G.; Micheo, J.; González, O.; Canals, A.; Lozano, J.; Díez de Tejada, P.; Bolívar, R. Development of the methodology of linear appraisal system in dairy goat. In Proceedings of the 30th Scientific and 9th International Conference of Spanish Society on Sheep and Goat Breeding, Serie Ganadería Ovino-Caprino-Junta de Andalucía, Granada, Spain, 28th-30th September and 1st October, 2005.

8. Luigi-Sierra, M.G.; Landi, V.; Guan, D.; Delgado, J.V.; Castelló, A.; Cabrera, B.; Mármol-Sánchez, E.; Fernández-Álvarez, J.; Martínez, A.; Such, X. Identification of genomic regions associated with morphological traits in Murciano-Granadina goats. In Proceedings of the 37th International Conference on Animal Genetics, Lleida, Spain, 7–12th July, 2019.
9. Martinez, B.; Vicente, C.; Picchioni, M.; Sanchez, M.; Gómez, E.; Peris, C. Integration of the linear morphological appraisal system in the dairy goat improvement genetic program of Murciano-Granadina breed. In Proceedings of the XXXV Congreso de la Sociedad Española de Ovinotecnia y Caprinotecnia (SEOC), Valladolid, Spain, 22–24th Spetember, 2010; pp. 470–474.
10. Fernández Álvarez, J.; León Jurado, J.M.; Navas González, F.; Iglesias Pastrana, C.; Delgado Bermejo, J.V. CAPRIGRAN Linear Appraisal Evidences Dairy Selection Signs in Murciano-Granadina Goats and Bucks: Presentation of the New Linear Appraisal Scale. *Arch. Zootecn.* **2021**, *70*, 239–245.
11. Sánchez Rodríguez, M.; Cárdenas Baena, J.M.; Blanco del Campo, G. Rasgos descriptivos lineales. In *Valoración Morfológica del Ganado Caprino Lechero*; Federación Cabrandalucía, Ed.; Servet Diseño y Comunicación: Zaragoza, Spain, 2012.
12. Manfredi, E.; Piacere, A.; Lahaye, P.; Ducrocq, V. Genetic parameters of type appraisal in Saanen and Alpine goats. *Livest. Prod. Sci* **2001**, *70*, 183–189.
13. Wiggans, G.R.; Hubbard, S.M. Genetic Evaluation of Yield and Type Traits of Dairy Goats in the United States. *J. Dairy Sci.* **2001**, *84*, E69–E73.
14. Fernández Álvarez, J.; León Jurado, J.M.; Navas González, F.J.; Iglesias Pastrana, C.; Delgado Bermejo, J.V. Applicability of an international linear appraisal system in Murciano-Granadina breed: Fitting, zoometry correspondence inconsistencies, and improving strategies. *Ital. J. Anim. Sci.* **2022**, *21*, 1232–1245.
15. Hoeffding, W. A non-parametric test of independence. In *The Collected Works of Wassily Hoeffding*; Springer: New York, NY 1994; pp. 214–226.
16. Harrell Jr, F.E.; Harrell Jr, M.F.E. Package 'hmisc'. *CRAN2018*, 2019, 235–236.
17. RStudio Team, R. RStudio. *Integrated development for R,* 2015.
18. Hollander, M.; Wolfe, D.A.; Chicken, E. *Nonparametric statistical methods*; John Wiley & Sons: HOboken, NJ, USA, 2013.
19. Fernández Álvarez, J.; León Jurado, J.M.; Navas González, F.J.; Iglesias Pastrana, C.; Delgado Bermejo, J.V. A decade of progress of linear appraisal traits heritabilities in Murciano-Granadina goats. *Arch. Zootecn.* **2021**, *70*, 352–356.
20. McLaren, A.; Mucha, S.; Mrode, R.; Coffey, M.; Conington, J. Genetic parameters of linear conformation type traits and their relationship with milk yield throughout lactation in mixed-breed dairy goats. *J. Dairy Sci.* **2016**, *99*, 5516–5525.
21. Rogerson, P.A. Data reduction: Factor analysis and cluster analysis. *Statistical methods for geography*. Rogeron, P.A. (Ed.), SAGE Publishing: Thousand Oaks, CA, USA, 2001, 192–197.
22. Nanda, M.A.; Seminar, K.B.; Nandika, D.; Maddu, A. Discriminant analysis as a tool for detecting the acoustic signals of termites Coptotermes curvignathus (Isoptera: Rhinotermitidae). *Int. J. Technol.* **2018**, *9*, 840–851.
23. StatEase. Design Expert 11. Interpretation of R-squared. *StatEase*, Minneapolis, MN, USA, 2022.
24. Group, C.M. Linear Appraisal (Update we received an email from ADGA this morning. *The Goat Spot Forum*, Bingham Farms, MI, USA, 2016.
25. Poole, J.H. Rutting Behavior in African Elephants: The Phenomenon of Musth. *Behaviour* **1987**, *102*, 283–316.
26. Boldman, K.G.; Kriese, L.A.; Vleck; Tassell; Kachman, S.D. *A Manual for Use of MTDFREML. A Set of Programs to Obtain Estimates of Variances and Covariances*, 1st ed.; US Department of Agriculture, Agricultural Research Service: Washington, DC, USA, 1995; p. 114.
27. Navas González, F.J.; Jordana Vidal, J.; León Jurado, J.M.; McLean, A.K.; Delgado Bermejo, J.V. Dumb or smart asses? Donkey's (Equus asinus) cognitive capabilities share the heritability and variation patterns of human's (Homo sapiens) cognitive capabilities. *J. Vet. Behav.* **2019**, *33*, 63–74.
28. Nagda, R.; Singh, C. The Effect of Non-Genetic Factors on Body Weight and Zoometric Traits in Sirohi Kids. *J. Anim. Res.* **2021**, *11*, 1031–1038.
29. Santos e Silva, L.; dos Santos, D.; da Silva, E.; da Silva, J.; da Silva, G.; Vieira, G.; Moreno, G. Development and zoometry of young dairy goats from different genetic groups. *PUBVET* **2018**, *12*, 1–9.
30. Rupp, R.; Clément, V.; Piacere, A.; Robert-Granié, C.; Manfredi, E. Genetic parameters for milk somatic cell score and relationship with production and udder type traits in dairy Alpine and Saanen primiparous goats. *J. Dairy Sci.* **2011**, *94*, 3629–3634.
31. Luo, M.; Wiggans, G.; Hubbard, S. Variance component estimation and multitrait genetic evaluation for type traits of dairy goats. *J. Dairy Sci.* **1997**, *80*, 594–600.
32. Gómez, M.; Valera, M.; Cervantes, I.; Vinuesa, M.; Peña, F.; Molina, A. Development of a linear type trait system for Spanish Purebred horses (preliminary analysis). In Proceedings of the Proceedings of the 57th Annual Meeting of the European Association for Animal Production, Antalya, Turkey, 17–20th September 2006; pp. 17–20.
33. Haworth, C.M.; Wright, M.J.; Luciano, M.; Martin, N.G.; de Geus, E.J.; van Beijsterveldt, C.E.; Bartels, M.; Posthuma, D.; Boomsma, D.I.; Davis, O.S.; et al. The heritability of general cognitive ability increases linearly from childhood to young adulthood. *Mol. Psychiatry* **2010**, *15*, 1112–1120,.
34. Gielen, M.; Lindsey, P.J.; Derom, C.; Smeets, H.J.M.; Souren, N.Y.; Paulussen, A.D.C.; Derom, R.; Nijhuis, J.G. Modeling Genetic and Environmental Factors to Increase Heritability and Ease the Identification of Candidate Genes for Birth Weight: A Twin Study. *Behav. J.* **2008**, *38*, 44–54.
35. Shelton, M. Reproduction and breeding of goats. *J. Dairy Sci.* **1978**, *61*, 994–1010.

36. Boykin, A.W.; Brody, N.; Sternberg, R.J. Intelligence: Knowns and unknowns. *Am Psychol.* **1996**, *51*, 77–101.
37. Visscher, P.M.; Hill, W.G.; Wray, N.R. Heritability in the genomics era — concepts and misconceptions. *Nat. Rev. Genet.* **2008**, *9*, 255–266.
38. Mavrogenis, A.; Papachristoforou, C.; Lysandrides, P.; Roushias, A. Environmental and genetic effects on udder characteristics and milk production in Damascus goats. *Small Ruminant Res.* **1989**, *2*, 333–343.
39. Dyce, K.M.; Sack, W.O.; Wensing, C.J.G. *Textbook of veterinary anatomy-E-Book*; Elsevier Health Sciences: Amsterdam, The Netherlands, 2009.
40. Dadati, E.; Kennedy, B.; Burnside, E. Relationships between conformation and reproduction in Holstein cows: Type and calving performance. *J. Dairy Sci.* **1985**, *68*, 2639–2645.
41. Sawa, A.; Bogucki, M.; Krężel-Czopek, S.; Neja, W. Association between rump score and course of parturition in cows. *Arch. Anim. Breed.* **2013**, *56*, 816–822.

Chapter 3.

Relationship of Zoometric/Linear Appraisal Traits with other Functional Traits in the Murciano-Granadina goat

- *Javier Fernández Álvarez, F. J. Navas González, J. M. León Jurado, A. González Ariza, M.A. Martínez Martínez, C. Iglesias Pastrana, M. G. Pizarro Inostroza and J. V. Delgado Bermejo.* ***Discriminant Canonical Tool to Infer the Role of αS1, αS2, β and κ Casein Haplotypes and Haplogroups on Zoometrics/Linear Appraisal Breeding Values in Murciano-Granadina Goats***

Discriminant Canonical Tool to Infer the Role of αS1, αS2, β and κ Casein Haplotypes and Haplogroups on Zoometrics/Linear Appraisal Breeding Values in Murciano-Granadina Goats

Journal:	*Journal of Dairy Science*
Manuscript ID	Draft
Article Type:	Research
Date Submitted by the Author:	n/a

Complete List of Authors:	Fernández-Álvarez, Javier; CAPRIGRAN, Executive Manager Navas González, Francisco Javier; Universidad de Cordoba Facultad de Veterinaria, Genetics León, Jose; University of Cordoba, Genetics González Ariza, Antonio; Centro Agropecuario Provincial de la Diputación de Córdoba Martinez, Amparo; Universidad de Cordoba, Departamento de Genética Iglesias Pastrana, Carlos; University of Cordoba, Genetics Pizarro Inostroza, Gabriela; Universidad de Córdoba, Genetics Delgado, Juan; University of Cordoba, Genetics

Key Words:	Data Mining, SNPs, Caprine, Discriminant Canonical Analysis

SCHOLARONE™
Manuscripts

ScholarOne support: (434) 964 4100

INTERPRETIVE SUMMARY

Selection of breeding animals requires the accurate estimation of genetic parameters for economically important traits, given dairy livestock have evolved in response to the needs of producers and consumers. These traits comprise milk yield and composition but also, those zoometric/linear appraisal traits which confer the animals a better dairy type, or that promoting the capacity of does to provide high quantities of prominent quality milk. The relationship between breeding values and the casein gene complex has not been explored in literature, however, the consideration of the haplotypic variants of β casein while selecting the bucks that will be used as sires in future generations may assist in the choice for animals presenting a better ability to genetically transmit a desirable dairy type. In turn, genomic tools considering the β Casein genetic background of animals, which is not routinely performed, may help to enhance the accuracy and efficiency for selection in a time and resources effective manner.

LINEAR APPRAISAL/ZOOMETRIC BREEDING VALUES DISCRIMINANT ANALYSIS ON CASEIN HAPLOTYPES AND HAPLOGROUPS

Discriminant Canonical Tool to Infer the Role of αS1, αS2, β and κ Casein Haplotypes and Haplogroups on Zoometrics/Linear Appraisal Breeding Values in Murciano-Granadina Goats

J. Fernández Álvarez[1], F. J. Navas-González[2,3*], J. M. León Jurado[4], A. González Ariza[3,4*], M.A. Martínez Martínez[3], C. Iglesias Pastrana[3], M. G. Pizarro Inostroza[3,5] and J. V. Delgado Bermejo[3]

[1]National Association of Caprine of Murciano-Granadina Breed (CAPRIGRAN), Fuente Vaqueros, Granada 18340

[2]Institute of Agricultural Research and Training (IFAPA), Alameda del Obispo, Córdoba 14004

[3]Department of Genetics, University of Córdoba, Córdoba 14071

[4]Centro Agropecuario Provincial de Córdoba, Diputación Provincial de Córdoba, Córdoba 14071

[5]Animal Breeding Consulting, S.L., Córdoba Science and Technology Park Rabanales 21, Córdoba 14071

[*]Corresponding authors: franciscoj.navas@juntadeandalucia.es (F.J.N.-G.) and aga07@dipucordoba.es (A.G.A.)

ABSTRACT

The objective of the present research was to develop a discriminant canonical analysis (DCA) tool that permits outlining the role of the individual haplotypes of each component of the casein complex (αS1, β, αS2, and κ-casein) on zoometrics/linear appraisal breeding values. The relationship of the predicted breeding value for 17 zoometric/Linear appraisal traits and αS1, β, αS2, and κ-casein genes haplotypic sequences was assessed. Results suggest that, although a lack of significant differences ($P>0.05$) was reported across the predictive breeding values of zoometric/linear appraisal traits for αS1, αS2 and κ casein, significant differences were found for β Casein ($P<0.05$), respectively. The presence of β Casein haplotypic

For Peer Review

sequences GAGACCCC, GGAACCCC, GGAACCTC, GGAATCTC, GGGACCCC, GGGATCTC and GGGGCCCC, linked to differential combinations of increased quantities of greater quality milk in terms of its composition, may also be connected to increased zoometric/linear appraisal predicted breeding values. Selection must be performed carefully, given the fact that the consideration of apparently desirable animals that present the haplotypic sequence GGGATCCC in the β Casein gene, due to their positive predicted breeding values for certain zoometric/linear appraisal traits such as rear insertion height, bone quality, anterior insertion, udder depth, rear legs side view and rear legs rear view may lead to an indirect selection against the rest of zoometric/linear appraisal traits and in turn lead to an inefficient selection towards an optimal dairy morphological type in Murciano-Granadina goats. Contrastingly, the consideration of animals presenting the GGAACCCC haplotypic sequence involves also considering animals which increase the genetic potential for all zoometric/linear appraisal traits, thus making them recommendable as breeding animals. The information derived from the present analyses will enhance the selection of breeding individuals seeking a rather desirable dairy type, through the determination of the haplotypic sequences that they present in the β Casein locus. The routine consideration of β casein haplotypes in breeding catalogues to join the determination of αS1 and κ genotypes which are already routinely implemented strategies will not only support the standardization and improvement of the productive capacity and dairy morphotype of Murciano-Granadina goat breed but also will help to reach its competitive consolidation in the international dairy goat panorama.

KEYWORDS

Data Mining; SNPs; Caprine; Discriminant Canonical Analysis; Zoometrics.

INTRODUCTION

Goat farming now extends to almost all the countries around the world, due to the competitive prices and the high nutritional value of products (especially milk) derived from this species, which attracts new investment companies and farmers (Miller and Lu, 2019).

Developing countries account with the largest fraction of the world goat census due to the great adaptability potential of the species to marginal territories, ability to thrive under adverse climatic conditions and within low-tech farming systems (Gama and Bressan, 2011).

Such a scenario contrasts with that of Europe and North American countries, where highly developed and intensive conditions rule the goat industry. This defines a highly focused on milk production industry supported on the exploitation of high-yielding breeds genetically managed under the scope of breeding schemes (Amills et al., 2017).

Still, the development of the areas of genetics, nutrition, and animal management in the goat is rather limited compared to the level of integration and technification that these methods reach in other ruminant species (Salgado Pardo et al., 2022).

Best Linear Unbiased Prediction (BLUP) methods and the Animal Model application in livestock, including the caprine sector occurred during the mid-1980s (Wiggans et al., 1984, Wiggans et al., 1988). This would

For Peer Review

lead to the increase in the complexity of the methodologies that breeding schemes could implement, especially for genetic parameter estimations and breeding value calculations.

This in turn enabled the access to reliable, structured, and complete genealogical information and to its integration into genetic evaluations, but also marked the moment when animals phenotypically controlled under widely different environmental conditions were evaluated altogether. BLUP model permitted disentangling and isolating the effect of environmental (non-genetic) factors from genetic ones, thus permitted the estimation of the heritable fraction of functional traits (Pizarro Inostroza et al., 2020a).

Microsatellites were the first markers to be used in the 'Genomic Era'. The genomic information obtained from goat microsatellite studies allowed the development of research based on the relationship between Quantitative Trait Loci (QTL), which are regions of the genome for which an association with the phenotypic variation of a certain trait has been demonstrated (Gebreselassie et al., 2019), with certain desirable production traits (Gipson, 2019).

This association was supported by the theory that the QTL regions may contain genes that code for the specific regulation of the expression of a certain functional characteristic. Early on, many QTLs were described using microsatellite genetic markers (Sugimoto et al., 2020).

Although microsatellites still constitute and are indeed preferable as a valid analysis tool when economic resources for research are scarce, the large size of some QTL makes their mapping resolution and confidence intervals limited, which therefore, led to the development of other more efficient techniques (Zhang et al., 2012).

In this regard, Single Nucleotide Polymorphisms (SNPs) studies were developed since these markers offer a higher degree of polymorphism and genome coverage (Li et al., 2006). This caused the SNPs to replace microsatellites as the most widespread genetic marker in research studies. As a result, geneticists became able to identify and select individuals with superior genetic potential but with an improved accuracy which was not possible with microsatellites (Caravaca et al., 2011, Rychtářová et al., 2014).

Casein complex comprises a series of genes located on the goat's chromosome 6. Specifically, casein genes are encoded by four loci (CSN1S1, CSN1S2, CSN2, CSN3) clustered within the 250kb segment of this chromosome (Martin et al., 2002). Casein SNPs act as genetic units that are closely linked through epistatic relationships (Pizarro Inostroza et al., 2020b). These markers are transmitted as haplotypes (Yahyaoui et al., 2001). The genetic polymorphism of the casein complex (αS1, β, αS2, and κ-casein genes), either in form of SNPs, haplotypes or haplogroups, associates to specific productive traits (milk yield, components and lactation curve parameters) of interest from an economic and research point of view (Martin et al., 2010, Pizarro Inostroza et al., 2020c).

The consideration of casein haplotypes rather than the use of a single gene or genetic marker has been suggested to maximize the comprehension of heritable mechanisms and how they affect the expression of functional traits related to milk yield, its different components (protein, fat, dry extract and/or lactose) production, the cumulative milk production, and the greater or lesser presence of somatic cells (Caroli et al., 2006, Pizarro Inostroza et al., 2020c). Although SNPs, haplotype or haplogroup associations across

For Peer Review

casein genes and casein variants with milk production traits has been previously reported (Pizarro Inostroza et al., 2020c), the relationship of casein haplotype variants with morphometry and linear appraisal has not been investigated in depth.

Zoometrics and linear appraisal traits have also been developed in the caprine specie since 1993, when the American Dairy Goat Association published the Linear Appraisal System for dairy goats, in search of higher production yields (Fernández Álvarez et al., 2020). However, National Association of the Murciano-Granadina goat breeders (CAPRIGRAN) would not start the implementation of the Combined Goat Index and the Morphological Index in its selective nucleus until 2010 (Fernández Álvarez et al., 2021a).

Murciano-Granadina goat is a rustic breed whose morphology has evolved towards a dairy type which permits to sustain quality milk production. This evolution in turn makes the breed to depart from zoometric international dairy standards, hence the need to tailor specific methods is compulsory in order to correctly represent the variability present in the Murciano-Granadina breed population. This brought about the optimization and validation of a specific zoometric/linear appraisal scale and was the starting point to perform a comprehensive genetic evaluation of the hereditary component and the correlations across zoometric the linear appraisal traits (Fernández Álvarez et al., 2021b, Fernández Álvarez et al., 2022).

Despite the phenotypic relationship between zoometrics and dairy production (either milk yield, components or even transformed products such as cheese) has been investigated (Benyoub et al., 2018, Jena et al., 2019, Erduran and Dag, 2021) and tools seeking the optimal dairy goat type have been developed (Fernández Álvarez et al., 2020, Fernández Álvarez et al., 2021a, Fernández Álvarez et al., 2022), the role that traditionally dairy linked genes, such as those in the casein complex, play on growth or zoometrics remains unexplored.

In this context, the present research aims to develop a discriminant canonical analysis (DCA) tool that permits outlining the role of the individual haplotypes of each component of the casein complex (αS1, β, αS2, and κ-casein) on zoometrics/linear appraisal breeding values. The information derived from the present analyses will help to plan strategies that support the standardization and improvement of the productive capacity of this native goat breed to seek for the consolidation of the breed in the international dairy goat panorama.

MATERIAL AND METHODS

Zoometric and Linear Appraisal Breeding Value Prediction

Pedigree matrix and linear appraisal records

Murciano-Granadina whole pedigree datafile comprised 279264 animals (266793 does and 12971 bucks) and was used as the pedigree matrix for genetic analyses. Animals had been born from June 1966 to November 2019. The linear appraisal had been performed in 41418 animals across the year. Animal records were collected in 76 farms in the South of Spain from 09/06/2010 to 18/12/2019. All the farms considered in the study had received official National and International Sanitary Certificates. All farms were controlled and officially declared tuberculosis-free (C3), brucellosis-free (M4) (Order of 22 June 2018 and Directive 91/68/EEC), and SCRAPIE RC (Regulation (EC) No 999/2001 of the European Parliament and the Council). These farms also followed voluntary control plans for Caprine Contagious Agalactia (CCA) (National CCA Surveillance, Control, and Eradication Programme 2018-2020) and Caprine arthritis encephalitis (CAEV) (Order AYG/287/2019 of 28 of February of 2019). Goats were clinically examined by an official veterinarian and individuals presenting signs of illness or disease conditions were officially declared and removed from the herds, hence, discarded from the analyses. Permanent stabling practices were followed by all farms considered, ad libitum water, forage and supplemental concentrate were provided.

Records from 95 individuals were discarded due to their zoometric and linear appraisal observations being missing or incomplete. A total of 41323 records, belonging to 22727 herdbook registered primipara does, 17111 multipara does and 1485 bucks were considered in the analysis. Average ages for primipara, multipara 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.

For Peer Review

Murciano-Granadina Linear appraisal system (LAS)

Each observation comprises each animal's rater' score in the following four major categories for primipara and multipara does (three for bucks, young males and yet-to-give-birth goats); structure and capacity, dairy structure, mammary system (except in males) and legs and aplomb. In primipara and multipara does, each record comprised information on 17 linear traits rated on a 9-points scale. Given bucks were not scored for the mammary system major category, only 10 traits were scored for them following the aforementioned 9-points scale. Body depth from the structure and capacity major category and the dairy structure and legs and feet major categories followed the same criteria with independence of sex and sexual status. The same trained rater scored all animals in the study.

Once all major categories are scored, 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 mammary system for primipara and multipara does (any doe which has ever begun producing milk). In bucks and young males, such percentages change to 50% for structure and capacity, 20% for dairy structure, and 30% for legs and feet, respectively.

Rater's scores are assigned one of the six category qualifications considered by CAPRIGRAN as follows; insufficient (IN) for animals which display less than 69% of the optimal standard for Murciano-Granadina dairy goats (a final score of 69 points or less), mediocre (R), 70 to 74% of optimal standard (a final score between 70 and 74 points), good (B) from 75 to 79% of optimal standard (a final score from 75 to 79 points), quite good (BB) from 80 to 84% of optimal standard (a final score from 80 to 84 points), very good (MB) from 85 to 89% of optimal standard (a final score from 85 to 89 points), or excellent (E) when at least 90% of optimal standard is displayed (higher than 90 points final score). The scales used and the translation process from zoometric traits to LAS traits is detailedly described in Sánchez Rodríguez et al. (2012), Table S1.

Age elements, for instance, the age of does or lactation order condition dairy linear or type appraisal-related traits (Manfredi et al., 2001). Hence, these elements, often considered and registered for does at appraisal, permit to adjust models for the outputs of linear or type appraisal records (Wiggans and Hubbard, 2001). Pearson product-moment correlation coefficient between lactation stage and age in years was 0.705 ($P<0.01$), hence redundancies could be presumed for the outputs of linear or type appraisal if both age components were simultaneously considered. Thus, the lactation stage was considered and results for primipara and multipara goats were reported separately.

Preliminary Assumption Testing in Zoometric and LAS Traits

Common parametric assumptions were tested in Murciano-Granadina goat breed zoometric and LAS historical records collected until December 2019. Kolmogórov-Smirnov and Levene tests were used to evaluate normality and homoscedasticity, respectively using SPSS Statistics for Windows statistical software, Version 25.0. Given the large sample size used in this study, the nonparametric method to test for the independence of two random variables with continuous distribution function (df) proposed by Hoeffding (1994) which uses joint ranks was chosen. To this aim, the Hmisc package's hoeffd function (Harrell Jr and Harrell Jr, 2019) of RStudio 1.1.463 by the R Studio Team (RStudio Team, 2015) was used. P-values are approximated by linear interpolation on the table in Hollander et al. (2013), which uses the asymptotically equivalent Blum-Kiefer-Rosenblatt statistic. For $P<0.0001$ or >0.5, P values are computed using a well-fitting linear regression function in log P against the test statistic.

For Peer Review

Genetic Analyses

Model and Genetic Parameter Estimation for Zoometric and LAS Traits

The complete kinship matrix used for genetic analyses comprised all the 279,264 animals (266793 does and 12971 bucks) in Murciano-Granadina goat breed pedigree. As literature suggests, when bucks start rutting, that is when male goats display the behaviors associated with the urge to breed, they go through physical changes which even make specific variables such as rump angle decrease 3 degrees (Group, 2016). Most of goat breeds breeding season extends from August to January and go into rut during Autumn. The rut is characterized in bucks and the males of other species by an increase in testosterone, exacerbated sexual dimorphisms and increased aggression and interest in does (Poole, 1987). This cyclic changes along the year are the source for natural discrepancies in the definition and specific characteristics of zoometric traits between bucks and does, whose body changes are rather progressive along their lives across lactation stages. This in turn may lead to statistical biases, hence, we decided phenotype data set to only comprise those observations belonging to does, either primipara or multipara to estimate genetic and phenotypic parameters.

As a result, a total of 39838 records, belonging to 22727 herdbook registered primipara does and 17111 multipara does were considered in the genetic analysis. Animals were only scored once in their lifetime. Therefore, a multitrait animal mixed model with single measures was used to estimate (co) variance components, and the corresponding heritability, repeatability, phenotypic and genetic correlations and standard errors of such correlations for the traits under examination. In matrix notation, the following multitrait animal model with single measures was used;

$Y_{ijklmn} = \mu + Far_i \cdot A_i + LacStat_j \cdot B_j + KMon_k \cdot C_k + IntFarm/KYear_l \cdot D_l + b_1DIM_m \cdot E_m + b_2A_n \cdot F_n + b_3^2A_n \cdot F_n + e_{ijklmn}$, where Y_{ijklmn} is the vector of observations for each separate measure of each zoometric or LAS trait (Table S1) for a given animal; μ is the overall mean; Far_i is the vector for the fixed effect of the ith farm/herd (i = 76 farms); LacStatj is the vector for the fixed effect of the jth lactation stage (j = primipara/multipara does); $KMon_k$ is the vector for the fixed effect of the kth kidding month (k = January to December); $IntFarm/KYear_l$ is the vector for the fixed effect of the lth level of interaction between farm/herd and kidding year (l = 400 interaction levels possibilities combining the 76 farms and kidding years from 2005 to 2019); days in milk was considered a linear covariate, hence b_l is the linear regression coefficient on days in milk (DIM_m), age in years was considered a linear and quadratic covariate, hence b_2 and b_3^2 are the linear and quadratic regression coefficients on the age of evaluation (A_n), e_{ijklmn} is vector of random residual effects and A_i, B_j, C_k and D_l are incidence matrices relating records to their respective fixed while E_m and F_n are incidence matrices relating records to their respective random effects. Only the direct genetic effect (animal) was fitted in each model due to zoometrics/LAS scores were recorded only once on each individual animal.

MTDFREML software package (Boldman et al., 1995) was used to perform Restricted maximum likelihood approach-based univariate analyses in order to compute heritabilities and variance components. The same software was used to carry out bivariate analyses to estimate covariates and genetic and phenotypic correlation. Genetic and phenotypic correlations between each individual conformation trait were estimated using a multivariate analysis including all traits. The iteration process used sought a convergence criterion level of 10^{-12}. Link functions can be found in Boldman et al. (1995). The standard errors for heritability and genetic and phenotypic correlations were computed using the same software.

As suggested by Navas González et al. (2019), we used the phenotypical variance of each character and the existing phenotypical correlations between each possible pair combination for the estimation of the starting point to seek for the convergence of additive genetic variance component (multiplying them by 0.2). Then, we did the same for environmental variances (multiplying them by 0.8) and genetic and phenotypic correlations to obtain specific variance components and estimates of fixed and random effects for each trait in multivariate analyses. To build the matrix of covariates among zoometric and LAS traits, respectively, the Bivariate routine of the Correlate procedure of the Analyze package in SPSS Statistics for Windows statistical software, Version 25.0. was used. For this, users need to check the box next to Cross-product deviations and covariances in the menu. Afterwards, to obtain the covariance for each pairwise combination of variables, you must divide the Sum of Squares and Cross-products by sample size (N).

For Peer Review

Breeding Value Prediction (BLUPS, PBVs)

After convergence was reached, predicted breeding values were calculated through best linear unbiased predictors for random effects (BLUPs, PBVs), their accuracies and reliabilities for zoometric and LAS traits for each animal in the matrix, using the MTDFREML software [27]. The standard errors for heritability and genetic and phenotypic correlations were computed by the same software. The fact that bucks were not considered for genetic evaluations and genetic parameter estimation must be considered. As a result, bucks' breeding values were estimated from the female individuals connected with them through their genealogy. When the average difference in zoometric parameters between males and females is ignored, the estimate of heritability has been reported to reduce (Visscher et al., 2008) as well, which may have also contributed to a reduction in BLUPs/PBVs.

This in turn may lead to statistical biases, hence, we decided phenotype data set to only comprise those observations belonging to does, either primipara or multipara to predict bucks breeding values from the information of their females relatives.

BLUPs Standard error of prediction (SEP), reliability (R_{AP}) and accuracy (RTi)

Standard error of prediction (SEP), reliability (R_{AP}) and accuracy (RTi) were calculated. The aforementioned parameters relate to each other through their definition and equation determination (R_{AP} = $RTi^2 = (1–SEP^2/Va)^2$, from which Va is genetic additive variance.

First, reliability is the likeliness of someone repeating the experiment and getting the same result (repeatability), while accuracy measures how close a certain estimated value is to the real value. Their interpretation is therefore, different. For example, for the evaluation of accuracy (RTi) Scheme (2015), suggests that less than 50% RTis mean PBVs are preliminary, thus calculated basing on little information and hence very prone to change substantially as more direct information on the animal becomes available. RTis which range from 50%–74% accuracy (medium) suggest that PBVs may have been calculated based on the animal direct information and some limited indirect pedigree information. Medium/high RTis denoted by 75%–90% and may be calculated considering the animal's direct information together with the performance of a small number of its offspring. RTi values over 90%, report estimates of the animal's true breeding value, as it unlikely that PBVs will change considerably even if additional information from offspring is added.

When reliability (R_{AP}) is considered, the rule of thumb proposed by Horse) (2016) enquires that; lower R_{AP} values than 30% are generally unreliable, 30–55% poor R_{AP}, 55%–65% sufficient R_{AP}, 65%–75% more than sufficient R_{AP}, 75%–90% good R_{AP}, >90% very reliable and repeatable with values around 60% meaning the information strongly relies on offspring information, what would be undesirable.

Last but not least, the standard error of prediction (SEP) measures how large prediction errors (residuals) are for your data set measured in the same unit each of the zoometric or LAS traits measured, hence provides a direct measure of possible change, that is the risk of the true breeding value of animal (TBV) not to be alligned on the PBV.

Van Vleck (2016), suggested that possible change is the risk in units of the trait breeding value not being true and can be 'positive' or 'negative'. This means the likelihood of true BV being higher than PBV by a certain amount (possible gain) is the same as the likelihood of true BV being lower than PBV by the same amount (possible loss). Contextually, confidence intervals are normally used to determine likelihoods of possible change assuming a normal distribution of TBV around the PBV.

The first half of TBV would be expected to be higher than the PBV while the second would be expected to be lower than the PBV. The interval range from PBV–(1)SEP to PBV + (1)SEP corresponds to 68% of probability that the TBV for an animal is centered on the PBV for the animal. Such an interval can be narrowed or widened corresponding to the probability of TBV in the interval. For instance, one could expect the interval from PBV–(2)SEP to PBV + (2)SEP to contain 95% of TBV. Units of SEP other than (1) or

(2) would correspond to other confidence intervals. With a 68% confidence interval, 32% would be half over and half below the interval' ends, while with the 95% interval, the percentage placed out of the interval would be 5% (again half over and half below each end, respectively). Ranges for many combinations of PBV and SEP may overlap considerably. Then, by observing which PBV centers the interval and comparing intervals, a rather direct measure of risk than that from accuracy (RTi) is obtained.

Descriptive statistics and differences in Zoometric/Linear Appraisal PBVs across Casein Haplotypes

Maximum and Minimum for zoometric/linear appraisal traits predicted breeding values (PBVs), standard error of prediction (SEP). accuracy (RTi) and reliability (R_{AP}) were calculated using the *Descriptive statsitics* routine of the *Analyze* set of SPSS version 26.0 software. Afterwards, Kruskal–Wallis H test was performed to study the potentially existing differences between predicted breeding values for zoometric/linear appraisal traits across haplotypes of the same casein gene as three or more possibilities were available using the *independent samples* routine of the *Nonparametric tests* package within the *Analyze* set of SPSS version 26.0 software.

Casein Haplotyping

Haplotyping Animal sample and selection process

Given the costs involved in genotyping, a selection process of goats which had been considered for milk yield standardization and composition analysis was implemented. This sample selection process aimed at genotyping a representative sample of animals for 48 SNPs in the casein complex from which complete records for several lactations existed. Hence, animals present in the herdbook of the National Association of Breeders of Goats of Murciano-Granadina breed (CAPRIGRAN) were ranked considering the most recent and updated official breeding values for milk yield and composition reported for all the animals published in 2015. Provided multiple traits are considered, we developed combined selection index (ICO) procedures following the premises in Van Vleck (1993) to summarize the value of each individual comprising each of its partial values for milk yield and composition and these were computed for each animal using MatLab r2015a (Inc., 2015). We decided not to include dry matter in the ICO, as redundancies may occur deriving from the relationship of this trait and fat or protein content. To determine the weights to apply to each trait, we considered the phenotypic relationship across milk yield and composition traits (except for dry matter) scoring their relevance as selection criteria when the breeding goal was milk yield and quality. In matrix notation, the weights to be applied on the selection index combining the partial scores of each modality were obtained as, $b = P^{-1}g$, where b is the vector of weights to be applied to each production or content trait, P is the phenotypic (co) variance matrix, and g is the vector of genetic (co)variances of every trait with each other. As a result and considering the market demands, the weights for milk yield, fat, protein and lactose followed the proportion of 1 : 1 : 1 : 1 , respectively. The combined index used (ICO)was as follows; $ICO = \frac{PBV_{milkyield}W_1}{\mu_{milkyield}} + \frac{PBV_{fat}W_2}{\mu_{fat}} + \frac{PBV_{protein}W_3}{\mu_{protein}} + \frac{PBV_{lactose}W_4}{\mu_{lactose}}$, where PBV is the predicted breeding value for each of the traits and animals included in the matrix; W_1 is the weight for milk yield, W_2 for fat, W_3 for protein and W_4 for lactose in kg and normalized at 210 days; and μ the mean for each of the traits included in the ICO computed in kg and at 210 days. After ICO was computed for each of the animals included in the matrix, we sorted a total of 200 animals from the whole routine milk recording of Murciano-Granadina goat breed in a ranking considering their ICO value obtained at the previous genetic evaluation. Animals with extreme PBVs may be less efficient and less balanced than we could expect at first. Furthermore, not all traits are affected to the same degree by selection for these extremes. For these reasons, 200 animals were ranked as follows: we chose 67 females presenting the lowest ICO values in the rank, 66 females with values around percentile 50, and the 67 females presenting the highest ICO values in the rank, so as to perform an adjusted representative sampling of the genotype distribution in the population. The samples belonging to animals with missing or incomplete phenotype registries were discarded, hence the final set for genotyping consisted of blood samples from 108 stud book registered goats out of the 200 animals that were initially considered. The records were collected from 28 Southern Spanish farms, whose records were collected in random periods, from October, 2006 to June, 2018. Mean age of the animals in the sample was 1.39 years old (from 1 year to 9.15 years).

Genotyping and Linkage disequilibrium (LD)

A modification of the procedure described in Miller et al. (1988) was performed for DNA isolation. To this aim sixteen nonrelated does were randomely chosen from the herdbook of the breed. Oligonucleotide sequences and SNPs promoters, UTRH3' regions, and polymorphic exons are described in Pizarro Inostroza et al. (2019). Platinium High Fidelity (LifeTechnology, CA) PCR kit was used to amplify polymorphic regions. MACROGEN sequencing service (Macrogen Inc., Korea) sequenced the PCR product and MEGA7 software and Ensembl Genome Browser 97 database were used to analyze pherograms and evaluate previous annotations for SNPs (Hubbard et al., 2002). Genotyping was performed using the KASP assay (LGC Limited, Fordham, UK) and KlusterCaller software (LGC Limited, Fordham, UK). Heterozygosity values of around 40%, suggested the number of SNPs to be used as genomic controls was enough (Hao et al., 2004) so as to prevent the effects from population stratification.

Minor allele frequency (MAF) was calculated to differentiate between common and rare variants (MAF<0.05) using PLINK v1.90 (Purcell et al., 2007). Casein complex SNPs' Linkage disequilibrium extent (LD) was calculated using HaploView software [19], scoring LD through D' (normalized linkage disequilibrium coefficient) and r^2 (linkage disequilibrium coefficient of determination) (Table S2). The total length of casein loci and distances between adjacent loci were determined following the premises presented by Dagnachew et al. (2011).

Haplotyping

Phasing (or haplotyping) describes the process of determining haplotypes from the genotype data (Glusman et al., 2014). As suggested by Glusman et al. (2014), haplotypes are more specific than less complex variants such as single nucleotide variants (SNP variants). An haplotype-based empirical model inherited from a SNP-based method was followed a suggested by Chen et al. (2018). We identified 48 single nucleotide polymorphisms (SNPs) present in the casein complex of 159 unrelated individuals of diverse ancestry, which were organized the SNPs into 86 different haplotypes. Haplotype sequences and the maximum and minum value for the predicted breeding values of each zoometric/Linear appraisal trait that they reached can be consulted in Table S3. The results from the analyses of epistatic relationships in Pizarro Inostroza et al. (2020b), were also considered to validate haplotyping.

ScholarOne support: (434) 964 4100

For Peer Review

Canonical Discriminant Analysis

Canonical discriminant analyses (CDAs) were performed to design a tool that enables the classification of goats while determining whether linear combinations of predicted breeding values for zoometrics/linear appraisal traits (Stature (Height to withers), Rump Width, Rear Insertion Height, Rump Angle, Angulosity, Chest Width, Udder Width, Nipple Placement, Nipple Diameter, Bone Quality, Anterior Insertion, Median Suspensor Ligament, Mobility, Body Depth, Udder Depth, Rear Legs Side View, Rear Legs Rear View describe within- and between-population αS1, αS2, β and κ Casein Haplotypes and Haplogroups clustering patterns. The explanatory variables used for the present analyses were the predicted breeding value for each of the zoometric/linear appraisal related traits presented in Table S1. The Haplotype and haplogroups for each of the four caseins (αS1, αS2, β and κ) were considered the clustering criterion.

Canonical relationships with traits were plotted to depict the group differences into an easily interpretable territorial map. Regularized forward stepwise multinomial logistic regression algorithms were used to perform the variable selection. Priors were regularized according to the group sizes calculated using the prior probability of commercial software (SPSS Version 26.0 for Windows, SPSS, Inc., Chicago, IL) instead of considering them the same to avoid groups with different sample sizes affecting the quality of the classification(Marín Navas et al., 2021).

The same sample size contexts as those used in this study across groups have been reported to be robust. In this regard, some authors have reported a minimum sample size of at least 20 observations for every 4 or 5 predictors, and the maximum number of independent variables should be n-2, where n is the sample size, to palliate possible distortion effects(Poulsen and French, 2008, Marín Navas et al., 2021).

Consequently, the present study used a 4 or 5 times higher ratio between observations and independent variables than those described above, which renders discriminant approaches efficient. Multicollinearity analysis was run to ensure independence and a strong linear relationship across predictors. Variables chosen by the forward or backward stepwise selection methods were the same. Finally, the progressive forward selection method was performed since it requires less time than the backward selection method.

The discriminant routine of the Classify package of SPSS version 26.0 software and the canonical discriminant analysis routine of the Analyzing Data package of XLSTAT software (Addinsoft Pearson Edition 2014, Addinsoft, Paris, France) were used to perform canonical discriminant analysis.

Multicollinearity Preliminary Testing

Multicollinearity refers to the linear relationship among two or more variables, which also means a lack of orthogonality among them. Different methods are available to detect multicollinearity, and the most widely used are variance inflation factor (VIF) and tolerance(Handhal et al., 2019). VIF is a ratio of variance in a regression model with multiple attributes divided by the variance of a model with only one attribute(James et al., 2013). Explained more technically and exactly, multicollinearity occurs when k vectors lie in a subspace of dimension less than k. Multicollinearity can explain a data-poor condition, which frequently is found in observational studies in which the researchers do not interfere with the study. Thus, many investigators often confuse multicollinearity with correlation. Whereas correlation is the linear relationship

For Peer Review

between just two variables, multicollinearity can exist between two variables or between one variable and the linear combination of the others. Therefore, correlation is considered a special case of multicollinearity. A high correlation implies multicollinearity, but not the other way around. Before performing the statistical analyses per se, a multicollinearity analysis was run to discard potential strong linear relationships across explanatory variables and ensure data independence. In this way, before data manipulation, redundancy problems can be detected, which limits the effects of data noise and reduces the error term of discriminant models. The multicollinearity preliminary test helps to identify unnecessary variables which should be excluded, preventing the overinflation of variance explanatory potential and type II error increase (González Ariza et al., 2021).The variance inflation factor (VIF) was used to determine the occurrence of multicollinearity issues. The literature reports a recommended maximum VIF value of 5 (Rogerson, 2001). On the other hand, tolerance $(1 - R^2)$ concerns the amount of variability in a certain independent variable which is not explained by the rest of the dependent variables considered (tolerance > 0.20) (Nanda et al., 2018). The multicollinearity statistics routine of the describing data package of XLSTAT software (Addinsoft Pearson Edition 2021, Addinsoft, Paris, France) was used. The following formula was used to calculate the VIF:

$$\mathrm{VIF} = 1/(1 - R^2), \qquad (1)$$

where R^2 is the coefficient of determination of the regression equation.

Canonical Correlation Dimension Determination

The maximum number of canonical correlations between two sets of variables is the number of variables in the smaller set. The first canonical correlation usually explains most of the relationships between different sets. In any case, attention should be given to all canonical correlations, despite reporting of only the first dimension being common in previous research (Toalombo Vargas et al., 2020). When canonical correlation values are 0.30 or higher, they correspond to approximately 10% of the variance explained.

Canonical Discriminant Analysis Efficiency

Wilks' lambda test evaluates which variables may significantly contribute to the discriminant function. When Wilks' lambda approximates 0, the contribution of that variable to the discriminant function increases. $\chi 2$ tests the Wilks' Lambda significance. If significance is below 0.05, the function can be concluded to explain the group adscription well (Anuthama et al., 2011). Discriminant loadings for predicted breeding values for zoometrics/linear appraisal traits determining the relative weight of each trait on each canonical discriminant function can be consulted in Figure 1.

Canonical Discriminant Analysis Model Reliability

Pillai's trace criterion, as the only acceptable test to be used in cases of unequal sample sizes, was used to test the assumption of equal covariance matrices in the discriminant function analysis(Zhang et al., 2020). Pillai's trace criterion was computed as a subroutine of the Canonical Discriminant Analysis routine of the Analyzing Data package of XLSTAT software (Addinsoft Pearson Edition 2014, Addinsoft, Paris, France). A significance of ≤ 0.05 is indicative of the set of predictors considered in the discriminant model being

For Peer Review

statistically significant. Pillai's trace criterion is argued to be the most robust statistic for general protection against departures from the multivariate residuals' normality and homogeneity of variance. The higher the observed value for Pillai's trace is, the stronger the evidence that the set of predictors has a statistically significant effect on the values of the response variable. That is, the Pillai trace criterion shows potential linear differences in the predicted breeding values for zoometric/linear appraisal traits across β Casein haplotype clustering groups (Pieruccini-Faria et al., 2021).

Canonical Coefficients and Loading Interpretation and Spatial Representation

When CDA is implemented, a preliminary principal component analysis is used to reduce the overall variables into a few meaningful variables that contributed most to variations between eggs from different genotypes. The use of the CDA determined the percentage assignment of eggs within its own group. Variables with a discriminant loading of ≥|0.40| were considered substantive, indicating substantive discriminating variables. By the use of the stepwise procedure technique, nonsignificant variables were prevented from entering the function. Coefficients with large absolute values correspond to variables with greater discriminating ability. Data were standardized following procedures reported by Manly and Alberto (2016). Then, squared Mahalanobis distances and principal component analysis were computed using the following formula:

$$D_{ij}^2 = (\bar{Y}_i - \bar{Y}_j)\ COV^{-1}(\bar{Y}_i - \bar{Y}_j)\ ,$$

where D_{ij}^2: distance between population i and j; COV^{-1}: inverse of the covariance matrix of measured variable x; $\bar{Y}_i$ and $\bar{Y}_j$: means of variable x in the ith and jth populations, respectively.

The squared Mahalanobis distance matrix was converted into a Euclidean distance matrix, and a dendrogram was built using the underweighted pair-group method arithmetic averages (UPGMA; Rovira i Virgili University, Tarragona, Spain) and the Phylogeny procedure of MEGA X 10.0.5 (Institute of Molecular Evolutionary Genetics, The Pennsylvania State University, State College, PA, USA).

Discriminant Function Cross Validation

Afterwards, to determine the probability that an egg of an unknown background belongs to a particular classification group (Hair et al., 2010), the hit ratio parameter was computed. For this, the relative distance of the problem observation to the centroid of its closest group was used. The hit ratio is the percentage of correctly classified goats that is correctly ascribed to the casein haplotype form that they present. The leave-one-out cross-validation procedure is used as a form of significance to consider if the discriminant functions can be validated. Classification accuracy is achieved when the classification rate is at least 25% higher than that obtained by chance.

Press' Q statistic can support these results, since it can be used to compare the discriminating power of the cross-validated function, as follows:

$$\text{Press } Q' = \frac{[n - (n'K)]^2}{n(K-1)},$$

For Peer Review

where n: number of observations in the sample; n': number of observations correctly classified; K: number of groups.

The value of Press' Q statistic must be compared with the critical value of 6.63 for χ^2 with a degree of freedom at a significance of 0.01. When Press' Q exceeds the critical value of χ^2 = 6.63, the cross-validated classification can be regarded as significantly better than chance.

RESULTS

Breeding Value Prediction and Comparative Descriptive Analysis

A summary of the maximum and minimum predicted breeding values (PBV), standard error of prediction (SEP), accuracy (RTi) and reliability (R_{AP}) for zoometrics and LAS traits sorted by sex and lactation stage is shown in Table 1. Maximum and minimum PBVs for almost all traits were slightly to moderately higher in bucks, except for stature (height to withers, anterior insertion, and nipple diameter, which otherwise reported the broadest ranges for R_{AP} in bucks (0.000 to 0.980) when compared to primipara does (0.000 to 0.672) or multipara does (0.000 to 0.740). The lowest R_{AP} was reported for the PBVs for zoometric or LAS traits in either multipara or primipara does while the highest was again reported by stature (height to withers, anterior insertion, and nipple diameter in bucks. The ame trend was described by RTi scores. Pearson product-moment correlation analysis between the predicted breeding values (PBV) for zoometric and LAS traits was around Pearson's product moment correlation was ≈1 and highly statistically significant (P<0.001), which suggested the consistency of genetic parameters after zoometry to LAS translation was almost perfect.

Differences for Zoometric/Linear Appraisal Traits Predicted Breeding Value Across Casein Haplotypes

The only significant differences revealed after the performance of the Kruskall-Wallis H test (P<0.05) were found across the haplotypes of the β-Casein gene for the predicted breeding values of Stature (Height to Whithers), Rump Width, Rump Angle, Median Suspensor Ligament and Body Depth.

Canonical Discriminant Analysis Model Reliability

Predicted Breeding Values for Stature (Height to withers) and Rump Width were discarded from the analyses because they presented VIF values over 5 (Table 2). Significant Pillai´s trace criterion determined

ScholarOne support: (434) 964 4100

For Peer Review

that discriminant canonical analysis was only feasible in β Casein (Table 3). As reported in Table 4, only one out of the nine discriminant functions designed after the analyses presented a significant discriminant ability. The discriminatory power of the F1 function was high (eigenvalue of 0.5773; Figure 2), with ≈50% of the variance being explained by F1 and F2.

Canonical Coefficients, Loading Interpretation, and Spatial Representation

Variables were ranked depending on their discriminating properties. For this, a test of equality of group means across β Casein haplotypes was used (Table 5). Lower values of Wilks' lambda and greater values of F indicate a better discriminating power, which translates into a better position in the rank. The analyses revealed that yolk and white pH did not significantly contribute ($P<0.05$) to the discriminant ability of significant discriminant functions.

For Peer Review

Standardized discriminant coefficients measure the relative weight of each predicted breeding value for zoometrics/linear appraisal traits in the discriminant functions (Figures 1 and 3). Out of the nine significant discriminant functions (Table 4), only the two most relevant functions were used to build a standardized discriminant coefficient biplot, capturing the highest fraction of variance (Figure 1). In this regard, those variables whose vector extends further apart from the origin most relevantly contributed to the first (F1) and second (F2) discriminant functions. Figures 3 and 4 suggest clear differentiation among Murciano-Granadina goats across the β Casein haplotypes considered in the analyses. The relative position of centroids was determined through the substitution of the mean value for observations in each term of the first two discriminant functions (F1 and F2). The larger the distance between centroids, the better the predictive power of the canonical discriminant function in classifying observations. Supplementary Tables S2 and S3 report the results obtained in the classification and leave-one-out cross-validation. A Press' Q value of 210.19 (N=108; n=56; K=10) was obtained. Therefore, it can be considered that predictions were significantly better than chance at 95%(Chan, 2005).

Additionally, to evaluate the proximity between β Casein haplotypes, Mahalanobis distances were represented (Figure 4). Two main clusters are formed, the first represented by GAAACCCC, which was the most distant haplotype from the rest (Mahalanobis distance of 10.5620) when zoometrics/linear appraisal predicted breeding values are considered and the second subcluster comprising the nine remaining β Casein haplotypes. A progressive seggregation of haplotypes occurs within the second cluster, first derived from the change from G→A and from T→C at the third and fifth SNP positions in the β Casein haplotype, second derived from the change back to the fomer position of C→T at the fifth SNP in the β Casein haplotype. The third segregation step undoes the change from G→A and from T→C at the third and fifth SNP positions in the β Casein haplotype.

Afterwards, a complex fourth cluster is formed which presents two main branches. The first one developed around the presence of GGG at first, second and third positions in the β Casein haplotype and the second one based upon the alternating change from G→A at second and third SNPs within the β Casein haplotype and the change of C→T, even if the later does not seem to be a source for β Casein haplotype differences.

DISCUSSION

The casein haplotype structure highly varies across breeds. However, its study is still scarce, even more in species other than the cow. This translates into the patent lack of documents to compare to. Our study suggest no differential effect may be ascribed to the different haplotypic forms of the αS1, αS2 and κ Casein gene (Table S2). Particularly, some authors such as Pizarro Inostroza et al. (2020c), reported the expression of certain β-casein haplotypes together with specific haplotypes from the rest of casein loci may indeed be linked to differential expressions of milk yields and composition and somatic cells counts. For example, if the αS1-casein sequence GAGAAATCGAGAAAGCAA was present in an animal at the same time that the sequence GGGATCTC of the β-casein locus, higher milk yields were reported (2.45 kg) when compared to the sequence GGGACCCC (2.34 kg).

This was also regarded in terms of fat percentage. For example, for the following haplotypic sequences fat percentage was GGGACCCC (5.48%), GGAACCCC (5.45%) and GGGATCTC (5.29%), respectively, while average protein percentages were GGGACCCC (3.61%), GGAACCCC (3.56%) and GGGATCTC (3.78%), respectively. Average percentages of dry matter were GGAACCCC (14.85%), GGGATCTC (14.46%) and GGGACCCC (14.77%), respectively. For lactose percentage, the sequence GGGACCCC presented 4.88% which contrasts the slightly lower value of 4.80% described for GGGATCTC. For somatic cells count, the values for GGGACCCC and GGGATCTC were 760.15x103 sc/mL and 645.96x10^3 sc/mL, respectively.

For Peer Review

If the αS1-casein sequence GAGAAATCGAGAGAGCGA was associated to β-casein locus sequence GGGATCTC (2.63 kg), an increase in milk yield and a paralel reduction in average fat/protein/dry matter percentages was reported when compared to the individuals in which the aformentioned αS1-casein sequence was followed by the β-casein locus sequence GGGGCCCC (2.03 kg). , which parallelly decreased with the increase in milk yield as follows GGGATCTC (4.91% fat/ 3.50% protein/13.95% dry matter/4.86% lactose/1148.89x10^3 sc/mL), GGGGCCCC (5.56% fat/ 3.97% protein/15.19% dry matter/4.59% lactose/959.09x10^3 sc/mL) and GGAATCTC (5.82% fat/3.63% protein/15.13% dry matter), respectively.

The same authors (Pizarro Inostroza et al., 2020c), would also inquire that the combination of the αS1-casein sequence GAGGAATTAAAAGAGCAA with the β-casein sequences GGGACCCC characterized by an average milk yield of 3.73 Kg and followed by GGGGCCCC (2.96 Kg), GGGATCTC (2.90 Kg) and GAGACCCC (3.31 Kg) A negative correlation was found between milk yields and fat/protein/dry matter percentages, which parallelly decreased with the increase in milk yield as follows GGGATCTC (6.21% fat/3.43% protein/14.90% dry matter) GGGACCCC (5.02% fat/3.35% protein/14.02% dry matter/744.33x10^3 sc/mL), GGGGCCCC (5.44 % fat/ 3.50% protein/13.96% dry matter/1255.74x10^3 sc/mL) and GAGACCCC (5.13% fat/3.52% protein/14.25% dry matter/788.10x10^3 sc/mL), respectively. The sequence GGAATCTC would be associated with an increased average lactose percentage of 4.88% in comparison to the rest. The aforementioned sequences differed in the change of the alleles A → G, A → G, T→ C and T→ C at SNPs 34, 35, 36 and 37.

The different haplotype combinations that can be determined when the β-casein locus is considered exert a strong favourable effect on milk yield and composition, where the presence of the alleles A, G, T and C is related to higher production and composition percentages. Contrastingly, G and T alleles may imply a reduction in somatic cells counts. However, this contrasts the finding by Baltrėnaitė et al. (2013), who did not find statistically significant differences for milk performance across the different allelic combinations within the β-casein locus. In this context, Chessa et al. (2005), reported C may be the most frequent allele to appear within the β-casein locus.

ScholarOne support: (434) 964 4100

For Peer Review

Pizarro Inostroza et al. (2020c) reported the effect of β-casein haplotypes of milk yield and composition, rather than an isolated effect should be considered in combination with the haplotypic sequences of other casein genes. In these regards, conjoined actions seem to be exerted which in turn, not only modifies the expression for milk performance and composition as it was also suggested by other authors (Vallas et al., 2012), but also may condition dairy morphology type.

Up to the date to the knowledge of authors, no study has approached the relationship between casein haplotype and zoometric/linear appraisal traits from a genetic perspective. Our results suggest, certain haplotypic sequences within the β Casein gene such as GAGACCCC, GGAACCCC, GGAACCTC, GGAATCTC, GGGACCCC, GGGATCTC and GGGGCCCC, which have been reported to be linked to differential combinations of increased quantities of greater quality milk in terms of its composition, are also linked to increased breeding values for zoometric/linear appraisal traits. An insufficient representativity of the animals presenting the GGAATCCC and GGAATTTT haplotypes was found, hence the lack of possibilities to determine association between their presence and increased predicted breeding values for zoometric/linear appraisal traits. For those sequences for which no relevant associations with milk yield and component traits had been reported in literature such as GGAACCTT and GGGATCCC, maximum predicted values were small and even negative for important dairy type related traits. For certain haplotypic sequences such as GGGACCTC evaluation may be rather complex given they may participate of a rather conjoint than isolated effect together with the haplotypic sequences for other genes such as αS1 and αS2 casein gene haplotypes. Indeed, it is the differential combinations that can appear which determine the wide range of milk yield and composition levels from low to very high found by Pizarro Inostroza et al. (2020c).

As denoted by Figure 3 and 4, the results in the territorial map depicting the goats considered in the canonical discriminant analysis sorted across β Casein in Murciano-Granadina goats suggest the extreme possibilities may be marked by the haplotypic sequences GGAACCCC and GGGATCCC which was also revealed in Table S2, with GGAACCCC reporting the largest maximum values for predicted breeding values for zoometric/linear appraisal traits while the lowest maximum values were reported for GGGATCCC. GGAACCCC reported positive maximum predicted breeding values for all traits, while the opposite situation was described by GGGATCCC for which negative maximum predicted breeding values

For Peer Review

were reported for all zoometric/linear appraisal traits except for Rear Insertion Height, Bone Quality, Anterior Insertion, Udder Depth, Rear Legs Side View and Rear Legs Rear View.

CONCLUSIONS

The presence of β Casein haplotypic sequences GAGACCCC, GGAACCCC, GGAACCTC, GGAATCTC, GGGACCCC, GGGATCTC and GGGGCCCC, linked to differential combinations of increased quantities of greater quality milk in terms of its composition, may also be connected to increased zoometric/linear appraisal predicted breeding values. Considering the apparently desirable predicted breeding values for certain zoometric/linear appraisal traits such as rear insertion height, bone quality, anterior insertion, udder depth, rear legs side view and rear legs rear view in animals presenting the haplotypic sequence GGGATCCC in the β Casein may lead to potential confusion when aiming to implement selection for a dairy morphological type in Murciano-Granadina goats. This is drawn from the fact that the presence of such haplotypic sequence is parallel to a marked large negative value in the predicted breeding values of the rest of zoometric/linear appraisal traits, hence its consideration may not be recommendable until further studies involving more animals can shed some light on the genetic background of such association. Contrastingly, the consideration of animals presenting the GGAACCCC haplotypic sequence involves also considering animals which increase the genetic potential for all zoometric/linear appraisal traits, thus making them recommendable. This suggests the inclusion of the genotype or even the haplotype for β Casein in the stud catalogues of the Murciano-Granadina breed together with those of αS1 and κ Casein, which are routinely tested for in merit bucks, is highly encouraged. All in all, β Casein haplotypic sequences may help to routinely detect individuals which are able to genetically transmit a rather desirable dairy type to their descendants, as well as to discard those who do not.

ACKNOWLEDGEMENTS

This work would not have been possible if it had not been for the support and assistance of the National Association of Breeders of Murciano-Granadina Goat Breed and the PAIDI AGR 218 research group.

REFERENCES

Amills, M., J. Capote, and G. Tosser-Klopp. 2017. Goat domestication and breeding: a jigsaw of historical, biological and molecular data with missing pieces. Anim. Genet. 48:631-644.

For Peer Review

Anuthama, K., S. Shankar, V. Ilayaraja, G. S. Kumar, and M. Rajmohan. 2011. Determining dental sex dimorphism in South Indians using discriminant function analysis. Forensic Sci. Int. 212:86-89.

Baltrėnaitė, L., K. Liucvaikienė, N. Makštutienė, K. Morkūnienė, L. Šalomskienė, I. Miceikienė, R. Stankevičius, and S. Kerzienė. 2013. The influence of goat milk protein gene polymorphism to milk traits. Vet. Med. Zoot. 62(84):8-13.

Benyoub, K. Q., A. A. Ameur, and S. B. S. Gaouar. 2018. Phenotypic characterization of local goats populations in western Algerian: Morphometric measurements and milk quality. Genetics & Biodiversity Journal 2:69-76.

Boldman, K. G., L. A. Kriese, Vleck, Tassell, and S. D. Kachman. 1995. A Manual for Use of MTDFREML. A Set of Programs to Obtain Estimates of Variances and Covariances. 1st ed. US Department of Agriculture, Agricultural Research Service, Washington, DC.

Caravaca, F., J. L. Ares, J. Carrizosa, B. Urrutia, F. Baena, J. Jordana, B. Badaoui, A. Sànchez, A. Angiolillo, and M. Amills. 2011. Effects of αs1-casein (CSN1S1) and κ-casein (CSN3) genotypes on milk coagulation properties in Murciano-Granadina goats. J. Dairy Res. 78:32-37.

Caroli, A., F. Chiatti, S. Chessa, D. Rignanese, P. Bolla, and G. Pagnacco. 2006. Focusing on the goat casein complex. J. Dairy Sci. 89:3178-3187.

Chan, Y. 2005. Biostatistics 303. Discriminant analysis. Singapore Med. J. 46:54.

Chen, Z., Y. Yao, P. Ma, Q. Wang, and Y. Pan. 2018. Haplotype-based genome-wide association study identifies loci and candidate genes for milk yield in Holsteins. PloS one 13:e0192695.

Chessa, S., E. Budelli, F. Chiatti, A. Cito, P. Bolla, and A. Caroli. 2005. Predominance of β-casein (CSN2) C allele in goat breeds reared in Italy. J. Dairy Sci. 88:1878-1881.

Dagnachew, B. S., G. Thaller, S. Lien, and T. Ådnøy. 2011. Casein SNP in Norwegian goats: additive and dominance effects on milk composition and quality. Genet. Sel. Evol. 43:31.

Erduran, H. and B. Dag. 2021. Determination of factors affecting milk yield, composition and udder morphometry of Hair and cross-bred dairy goats in a semi-intensive system. J. Dairy Res. 88(3):265-269.

Fernández Álvarez, J., F. J. Navas González, J. M. León, C. Iglesias, and J. V. Delgado Bermejo. 2021a. A decade of progress of linear appraisal traits heritabilities in Murciano-Granadina goats. Arch. Zootec. 70:352-356.

Fernández Álvarez, J., J. M. León Jurado, F. J. Navas González, C. Iglesias Pastrana, and J. V. Delgado Bermejo. 2021b. CAPRIGRAN Linear Appraisal Evidences Dairy Selection Signs in Murciano-Granadina Goats and Bucks: Presentation of the New Linear Appraisal Scale. Arch. Zootec. 70:239-245.

Fernández Álvarez, J., J. M. León Jurado, F. J. Navas González, C. Iglesias Pastrana, and J. V. Delgado Bermejo. 2020. Optimization and Validation of a Linear Appraisal Scoring System for Milk Production-Linked Zoometric Traits in Murciano-Granadina Dairy Goats and Bucks. Appl. Sci. 10:5502.

Fernández Álvarez, J., J. M. León Jurado, F. J. Navas González, C. Iglesias Pastrana, and J. V. Delgado Bermejo. 2022. Applicability of an international linear appraisal system in Murciano-Granadina breed: fitting, zoometry correspondence inconsistencies, and improving strategies. Ital. J. Anim. Sci. 21:1232-1245.

Gama, L., and M. Bressan. 2011. Biotechnology applications for the sustainable management of goat genetic resources. Small Rumin. Res. 98:133-146.

For Peer Review

Gebreselassie, G., H. Berihulay, L. Jiang, and Y. Ma. 2019. Review on genomic regions and candidate genes associated with economically important production and reproduction traits in sheep (Ovies aries). Animals 10:33.

Gipson, T. A. 2019. Recent advances in breeding and genetics for dairy goats. Asian-Australas. J. Anim. Sci. 32:1275-1283.

Glusman, G., H. C. Cox, and J. C. Roach. 2014. Whole-genome haplotyping approaches and genomic medicine. Genome Med. 6:73.

González Ariza, A., A. Arando Arbulu, F. J. Navas González, J. V. Delgado Bermejo, and M. E. Camacho Vallejo. 2021. Discriminant Canonical Analysis as a Validation Tool for Multivariety Native Breed Egg Commercial Quality Classification. Foods 10:632.

Group, C. M. 2016. Linear Appraisal (Update we received an email from ADGA this morning. in The Goat Spot Forum. Vol. 2022. Carbon Media Group, Bingham Farms, MI.

Hair, J. F., W. C. Black, B. J. Babin, and R. E. Anderson. 2010. Canonical correlation: A supplement to multivariate data analysis. Multivariate data analysis: a global perspective. 7th edn. Pearson Prentice Hall Publishing, Upper Saddle River.

Handhal, A. M., S. M. Jawad, and A. M. Al-Abadi. 2019. GIS-based machine learning models for mapping tar mat zones in upper part (DJ unit) of Zubair Formation in North Rumaila supergiant oil field, southern Iraq. J. Pet. Sci. Eng. 178:559-574.

Hao, K., C. Li, C. Rosenow, and W. H. Wong. 2004. Detect and adjust for population stratification in population-based association study using genomic control markers: an application of Affymetrix Genechip® Human Mapping 10K array. Eur. J. Hum. Genet. 12:1001-1006.

Harrell Jr, F. E., and M. F. E. Harrell Jr. 2019. Package ‘hmisc’. The R Foundation; Vienna, Australia: 2019. pp. 235–236. CRAN2018.

Hoeffding, W. 1994. A non-parametric test of independence. Pages 214-226 in The Collected Works of Wassily Hoeffding. Springer.

Hollander, M., D. A. Wolfe, and E. Chicken. 2013. Nonparametric statistical methods. John Wiley & Sons.

Horse), K. R. D. S. 2016. Genetic Profile & Statistics 2016 - 2017, KWPN-Approved and KWPN-Recognized Stallions. Page 132. KWPN (Royal Dutch Sport Horse), The Netherlands.

Hubbard, T., D. Barker, E. Birney, G. Cameron, Y. Chen, L. Clark, T. Cox, J. Cuff, V. Curwen, and T. Down. 2002. The Ensembl genome database project. Nucleic Acids Res. 30:38-41.

Inc., T. M. 2015. MATLAB. release R2015a ed., Natick, MA.

James, G., D. Witten, T. Hastie, and R. Tibshirani. 2013. An introduction to statistical learning. Vol. 112. Springer.

Jena, S., D. Malik, S. Kaswan, A. Sharma, N. Kashyap, and U. Singh. 2019. Relationship of udder morphometry with milk yield and body condition traits in Beetal goats. Indian J. Anim. Sci 89:204-208.

Li, X., Z. L. Wu, Y. Gong, Y. Liu, Z. Liu, X. Wang, T. Xin, and Q. Ji. 2006. Single-nucleotide polymorphism identification in the caprine myostatin gene. J. Anim. Breed. Genet. 123:141-144.

Manfredi, E., A. Piacere, P. Lahaye, and V. Ducrocq. 2001. Genetic parameters of type appraisal in Saanen and Alpine goats. Livest. Prod. Sci. 70:183-189.

Manly, B. F. and J. A. N. Alberto. 2016. Multivariate statistical methods: a primer. Chapman and Hall/CRC.

For Peer Review

ScholarOne support: (434) 964 4100

Marín Navas, C., J. V. Delgado Bermejo, A. K. McLean, J. M. León Jurado, and F. J. Navas González. 2021. Discriminant Canonical Analysis of the Contribution of Spanish and Arabian Purebred Horses to the Genetic Diversity and Population Structure of Hispano-Arabian Horses. Animals 11:269.

Martin, C., D. P. Morgavi, and M. Doreau. 2010. Methane mitigation in ruminants: from microbe to the farm scale. Animal 4:351-365.

Martin, P., M. Szymanowska, L. Zwierzchowski, and C. Leroux. 2002. The impact of genetic polymorphisms on the protein composition of ruminant milks. Reprod. Nutr. Dev. 42:433-459.

Miller, B. A. and C. D. Lu. 2019. Current status of global dairy goat production: An overview. Asian-Australas J. Anim. Sci. 32:1219.

Miller, S., D. Dykes, and H. Polesky. 1988. A simple salting out procedure for extracting DNA from human nucleated cells. Nucleic Acids Res. 16:1215.

Nanda, M. A., K. B. Seminar, D. Nandika, and A. Maddu. 2018. Discriminant analysis as a tool for detecting the acoustic signals of termites Coptotermes curvignathus (Isoptera: Rhinotermitidae). Int. J. Technol. 9:840-851.

Navas González, F. J., J. Jordana Vidal, J. M. León Jurado, A. K. McLean, and J. V. Delgado Bermejo. 2019. Dumb or smart asses? Donkey's (Equus asinus) cognitive capabilities share the heritability and variation patterns of human's (Homo sapiens) cognitive capabilities. J. Vet. Behav. 33:63-74.

Pieruccini-Faria, F., S. E. Black, M. Masellis, E. E. Smith, Q. J. Almeida, K. Z. H. Li, L. Bherer, R. Camicioli, and M. Montero-Odasso. 2021. Gait variability across neurodegenerative and cognitive disorders: Results from the Canadian Consortium of Neurodegeneration in Aging (CCNA) and the Gait and Brain Study. Alzheimers Dement. 17:1317-1328.

Pizarro Inostroza, M., V. Landi, F. Navas González, J. León Jurado, A. Martínez Martínez, J. Fernández Álvarez, and J. Delgado Bermejo. 2019. Non-parametric association analysis of additive and dominance effects of casein complex SNPs on milk content and quality in Murciano-Granadina goats. J. Anim. Breed. Genet. 137:407-422

Pizarro Inostroza, M. G., V. Landi, F. J. Navas González, J. M. León Jurado, J. V. Delgado Bermejo, J. Fernández Álvarez, and M. d. A. Martínez Martínez. 2020a. Integrating casein complex SNPs additive, dominance and epistatic effects on genetic parameters and breeding values estimation for murciano-granadina goat milk yield and components. Genes 11:309.

Pizarro Inostroza, M. G., V. Landi, F. J. Navas González, J. M. León Jurado, M. d. A. Martínez Martínez, J. Fernández Álvarez, and J. V. Delgado Bermejo. 2020b. Non-parametric analysis of casein complex genes epistasis and their effect on phenotypic expression of milk yield and composition in Murciano-Granadina goats. J. Dairy Sci. 103:8274-8291.

Pizarro Inostroza, M. G., F. J. Navas González, V. Landi, J. M. León Jurado, J. V. Delgado Bermejo, J. Fernández Álvarez, and M. d. A. Martínez Martínez. 2020c. Bayesian Analysis of the Association between Casein Complex Haplotype Variants and Milk Yield, Composition, and Curve Shape Parameters in Murciano-Granadina Goats. Animals 10:1845.

Poole, J. H. 1987. Rutting Behavior in African Elephants: the Phenomenon of Musth. Behaviour 102:283-316.

Poulsen, J. and A. French. 2008. Discriminant function analysis. San Francisco State University: San Francisco, CA.

Purcell, S., B. Neale, K. Todd-Brown, L. Thomas, M. A. Ferreira, D. Bender, J. Maller, P. Sklar, P. I. De Bakker, and M. J. Daly. 2007. PLINK: a tool set for whole-genome association and population-based linkage analyses. Am. J. Hum. Genet. 81:559-575.

For Peer Review

Rogerson, P. A. 2001. Data reduction: factor analysis and cluster analysis. Pages 192-197. Sage: London.

RStudio Team, R. 2015. RStudio. Integrated development for R.

Rychtářová, J., Z. Sztankoova, J. Kyselova, V. Zink, M. Štípková, M. Vacek, and L. Štolc. 2014. Effect of DGAT1, BTN1A1, OLR1, and STAT1 genes on milk production and reproduction traits in the Czech Fleckvieh breed. Czech J. Anim. Sci 59:45-53.

Salgado Pardo, J. I., J. V. Delgado Bermejo, A. González Ariza, J. M. León Jurado, C. Marín Navas, C. Iglesias Pastrana, M. d. A. Martínez Martínez, and F. J. Navas González. 2022. Candidate Genes and Their Expressions Involved in the Regulation of Milk and Meat Production and Quality in Goats (Capra hircus). Animals 12:988.

Sánchez Rodríguez, M., J. M. Cárdenas Baena, and G. Blanco del Campo. 2012. Rasgos descriptivos lineales. in Valoración morfológica del ganado caprino lechero. F. Cabrandalucía, ed. Servet Diseño y Comunicación, Zaragoza.

Scheme, I. B. R. 2015. A basic guide to BREEDPLAN EBVs. Page 28. University of New England, Maine, USA.

Sugimoto, N., A. Takahashi, R. Ihara, Y. Itoh, A. Jouraku, T. Van Leeuwen, and M. Osakabe. 2020. QTL mapping using microsatellite linkage reveals target-site mutations associated with high levels of resistance against three mitochondrial complex II inhibitors in Tetranychus urticae. Insect Biochem. Mol. Biol. 123:103410.

Toalombo Vargas, P. A., F. J. Navas González, V. Landi, J. M. León Jurado, and J. V. Delgado Bermejo. 2020. Sexual dimorphism and breed characterization of Creole hens through biometric canonical discriminant analysis across Ecuadorian agroecological areas. Animals 10:32.

Vallas, M., T. Kaart, S. Värv, K. Pärna, I. Jõudu, H. Viinalass, and E. Pärna. 2012. Composite β-κ-casein genotypes and their effect on composition and coagulation of milk from Estonian Holstein cows. J. Dairy Sci. 95:6760-6769.

Van Vleck, L. D. 1993. Selection Index and Introduction to Mixed Model Methods. 1st ed. CRC Press.

Van Vleck, L. D. 2016. EPDs and Risk. Page 9 in Proc. Beef Improvement Federation Annual Meeting & Symposium. Hilton Garden Inn., Manhattan.

Visscher, P. M., W. G. Hill, and N. R. Wray. 2008. Heritability in the genomics era — concepts and misconceptions. Nat. Rev. Genet. 9:255-266.

Wiggans, G., F. Dickinson, G. King, and J. Weller. 1984. Genetic evaluation of dairy goat bucks for daughter milk and fat. Journal of Dairy Science 67(1):201-207.

Wiggans, G., J. Van Dijk, and I. Misztal. 1988. Genetic evaluation of dairy goats for milk and fat yield with an animal model. J. Dairy Sci. 71:1330-1337.

Wiggans, G. R., and S. M. Hubbard. 2001. Genetic Evaluation of Yield and Type Traits of Dairy Goats in the United States. J. Dairy Sci. 84:69-73.

Yahyaoui, M. H., A. Coll, A. Sánchez, and J. M. Folch. 2001. Genetic polymorphism of the caprine kappa casein gene. J. Dairy Res. 68(2):209-216.

Zhang, H., Z. Wang, S. Wang, and H. Li. 2012. Progress of genome wide association study in domestic animals. J. Anim. Sci. Biotechnol. 3:1-10.

Zhang, Q., J. Hu, and Z. Bai. 2020. Modified Pillai's trace statistics for two high-dimensional sample covariance matrices. J. Stat. Plan. Infer. 207:255-275.

For Peer Review

ScholarOne support: (434) 964 4100

Table 1. Minimum and Maximum predicted breeding values, standard error of prediction (SEP). accuracy (RTi) and reliability (R_{AP}) for zoometric and LAS traits obtained in bivariate analyses through REML methods sorted by sex and lactation stage.

Major area	Zoometric/LAS trait	Parameter	*Bucks* Minimum	*Bucks* Maximum	*Primipara* Minimum	*Primipara* Maximum	*Multipara* Minimum	*Multipara* Maximum
Structure and capacity	Stature (Height to withers)	PBV	-1.862	1.814	-1.850	2.513	-2.076	2.548
		SEP	0.110	0.790	0.400	0.720	0.350	0.750
		RAP	0.000	0.980	0.000	0.672	0.000	0.740
		Rti	0.000	0.990	0.000	0.820	0.000	0.860
	Chest Width	PBV	-1.158	1.589	-1.089	1.382	-1.370	1.373
		SEP	0.110	0.620	0.370	0.570	0.320	0.590
		RAP	0.000	0.960	0.000	0.593	0.000	0.672
		Rti	0.000	0.980	0.000	0.770	0.000	0.820
	Body Depth	PBV	-0.697	0.680	-0.486	0.506	-0.661	0.581
		SEP	0.080	0.290	0.210	0.270	0.190	0.270
		RAP	0.000	0.903	0.000	0.436	0.000	0.490
		Rti	0.000	0.950	0.000	0.660	0.000	0.700
	Rump Width	PBV	-0.838	0.911	-0.924	0.826	-1.024	0.911
		SEP	0.070	0.410	0.240	0.380	0.210	0.390
		RAP	0.000	0.960	0.000	0.608	0.000	0.689
		Rti	0.000	0.980	0.000	0.780	0.000	0.830
	Rump Angle	PBV	-0.693	0.886	-0.597	0.713	-0.862	0.775
		SEP	0.080	0.370	0.250	0.340	0.220	0.350
		RAP	0.000	0.941	0.000	0.504	0.000	0.578
		Rti	0.000	0.970	0.000	0.710	0.000	0.760
Dairy structure	Angulosity	PBV	-1.194	1.504	-1.351	1.184	-1.239	1.295
		SEP	0.110	0.580	0.360	0.530	0.310	0.550
		RAP	0.000	0.960	0.000	0.578	0.000	0.640
		Rti	0.000	0.980	0.000	0.760	0.000	0.800
	Bone Quality	PBV	-1.418	1.206	-1.131	1.060	-1.167	1.170
		SEP	0.070	0.430	0.250	0.390	0.220	0.410
		RAP	0.000	0.960	0.000	0.608	0.000	0.689
		Rti	0.000	0.980	0.000	0.780	0.000	0.830
Mammary system	Anterior Insertion	PBV	-1.937	2.690	-1.676	2.418	-2.083	2.763
		SEP	0.150	1.050	0.550	0.960	0.480	0.990
		RAP	0.000	0.980	0.000	0.656	0.000	0.740
		Rti	0.000	0.990	0.000	0.810	0.000	0.860
	Rear Insertion Height	PBV	-0.949	1.048	-0.958	0.798	-1.059	1.172
		SEP	0.080	0.460	0.290	0.420	0.250	0.440
		RAP	0.000	0.960	0.000	0.563	0.000	0.640
		Rti	0.000	0.980	0.000	0.750	0.000	0.800
	Median Suspensor Ligament	PBV	-1.201	1.688	-1.138	1.281	-1.390	1.556
		SEP	0.110	0.690	0.390	0.630	0.340	0.650
		RAP	0.000	0.960	0.000	0.608	0.000	0.689
		Rti	0.000	0.980	0.000	0.780	0.000	0.830
	Udder Width	PBV	-0.545	0.592	-0.429	0.487	-0.435	0.497
		SEP	0.070	0.260	0.180	0.240	0.170	0.240
		RAP	0.000	0.903	0.000	0.423	0.000	0.490
		Rti	0.000	0.950	0.000	0.650	0.000	0.700
	Udder Depth	PBV	-1.288	2.001	-1.165	1.441	-1.970	1.761
		SEP	0.000	0.710	0.000	0.650	0.000	0.670
		RAP	0.000	0.960	0.000	0.593	0.000	0.672

For Peer Review

		Rti	0.000	0.980	0.000	0.770	0.000	0.820
	Nipple Placement	PBV	-0.781	1.056	-0.939	0.685	-0.955	0.953
		SEP	0.080	0.440	0.270	0.400	0.230	0.420
		RAP	0.000	0.960	0.000	0.578	0.000	0.656
		Rti	0.000	0.980	0.000	0.760	0.000	0.810
	Nipple Diameter	PBV	-1.940	2.691	-1.668	2.405	-2.097	2.768
		SEP	0.150	1.050	0.550	0.960	0.480	0.990
		RAP	0.000	0.980	0.000	0.656	0.000	0.740
		Rti	0.000	0.990	0.000	0.810	0.000	0.860
Legs aplomb	Rear Legs Rear View	PBV	-0.735	0.643	-1.096	0.547	-0.981	0.589
		SEP	0.060	0.330	0.210	0.300	0.190	0.310
		RAP	0.000	0.960	0.000	0.548	0.000	0.608
		Rti	0.000	0.980	0.000	0.740	0.000	0.780
	Rear Legs Side View	PBV	-0.389	0.385	-0.366	0.248	-0.360	0.376
		SEP	0.060	0.220	0.160	0.210	0.150	0.210
		RAP	0.000	0.903	0.000	0.410	0.000	0.476
		Rti	0.000	0.950	0.000	0.640	0.000	0.690
	Mobility	PBV	-0.488	0.536	-0.357	0.375	-0.478	0.511
		SEP	0.060	0.220	0.160	0.210	0.140	0.210
		RAP	0.000	0.922	0.000	0.436	0.000	0.504
		Rti	0.000	0.960	0.000	0.660	0.000	0.710

Table 2. Multicollinearity analysis of predicted breeding values for zoometrics/linear appraisal traits in Murciano-Granadina goats. Interpretation thumb rule: VIF = 1 (not correlated); 1 < VIF < 5 (moderately correlated); VIF ≥ 5 (highly correlated).

αS2 Casein	Tolerance	VIF	αS1 Casein	Tolerance	VIF	β Casein	Tolerance	VIF	κ Casein	Tolerance	VIF
PBV Nipple Diameter	0.85	1.18	PBV Nipple Diameter	0.78	1.28	PBV Rear Legs Side View	0.81	1.23	PBV Nipple Diameter	0.82	1.23
PBV Rear Legs Side View	0.81	1.23	PBV Rear Legs Side View	0.75	1.33	PBV Nipple Diameter	0.80	1.25	PBV Rear Legs Side View	0.79	1.26
PBV Median Suspensor Ligament	0.80	1.26	PBV Median Suspensor Ligament	0.72	1.38	PBV Median Suspensor Ligament	0.76	1.32	PBV Median Suspensor Ligament	0.78	1.29
PBV Udder Depth	0.71	1.41	PBV Udder Depth	0.66	1.52	PBV Udder Depth	0.65	1.53	PBV Udder Depth	0.61	1.63
PBV Mobility	0.60	1.68	PBV Nipple Placement	0.60	1.66	PBV Nipple Placement	0.60	1.67	PBV Mobility	0.61	1.64
PBV Nipple Placement	0.59	1.68	PBV Mobility	0.57	1.74	PBV Mobility	0.58	1.74	PBV Body Depth	0.55	1.83
PBV Body Depth	0.58	1.73	PBV Body Depth	0.54	1.84	PBV Body Depth	0.57	1.74	PBV Angulosity	0.54	1.85
PBV Angulosity	0.57	1.75	PBV Angulosity	0.54	1.85	PBV Angulosity	0.55	1.81	PBV Anterior Insertion	0.54	1.86
PBV Anterior Insertion	0.54	1.86	PBV Anterior Insertion	0.48	2.06	PBV Anterior Insertion	0.53	1.90	PBV Nipple Placement	0.53	1.90
PBV Bone Quality	0.48	2.07	PBV Bone Quality	0.48	2.07	PBV Bone Quality	0.49	2.05	PBV Bone Quality	0.50	2.00
PBV Udder Width	0.46	2.17	PBV Rear Legs Rear View	0.43	2.32	PBV Udder Width	0.44	2.25	PBV Rear Legs Rear View	0.48	2.08
PBV Rear Insertion Height	0.44	2.28	PBV Udder Width	0.43	2.33	PBV Rear Legs Rear View	0.43	2.31	PBV Rear Insertion Height	0.47	2.14
PBV Rear Legs Rear View	0.41	2.43	PBV Rear Insertion Height	0.38	2.67	PBV Rear Insertion Height	0.43	2.34	PBV Udder Width	0.46	2.17
PBV Rump Width	0.30	3.36	PBV Rump Width	0.29	3.47	PBV Rump Width	0.29	3.40	PBV Rump Width	0.30	3.28
PBV Chest Width	0.28	3.60	PBV Chest Width	0.25	3.98	PBV Chest Width	0.27	3.74	PBV Chest Width	0.27	3.77

PBV: Predicted Breeding Value; Tolerance: 1 – R^2.

Table 3. Pillai´s trace criterion for predicted breeding values for zoometrics/linear appraisal traits across Casein haplotypes in Murciano-Granadina goats.

Statistics/Haplotypes	αS2 Casein	αS1 Casein	β Casein	κ Casein
Pillai´s trace criterion	1.441	1.017	1.506	1.734
F (Observed value)	0.914	0.854	1.220	1.023
F (Critical value)	1.207	1.246	1.230	1.209
DF1	165.000	120.000	135.000	165.000

For Peer Review

DF2	1001.000	704.000	819.000	902.000
p-value	0.763	0.858	0.050	0.415

Table 4. Canonical discriminant analysis efficiency parameters to determine the significance of each canonical discriminant function.

Test of Function(s)	Wilks' Lambda	Chi-square	df	p-value
1 through 9	0.18	161.67	135	0.05
2 through 9	0.28	119.25	112	0.30
3 through 9	0.40	85.50	91	0.64
4 through 9	0.51	62.47	72	0.78
5 through 9	0.65	41.07	55	0.92
6 through 9	0.75	26.43	40	0.95
7 through 9	0.84	16.33	27	0.95
8 through 9	0.92	8.17	16	0.94
9 through 9	0.98	1.87	7	0.97

df: degrees of freedom.

Table 5. Results for the tests of equality of β Casein haplotype group means to test for difference in the means across Murciano-Granadina goats once redundant variables have been removed.

Predicted Breeding Value	Wilks' Lambda	F	df1	df2	p-value	Rank
Stature (Height to withers)	0.87	1.65	9	97	0.11	NS
Rump Width	*0.81*	*2.56*	*9*	*97*	*0.01*	*1*
Rear Insertion Height	0.87	1.58	9	97	0.13	NS
Rump Angle			9	97		NS
Angulosity	0.94	0.74	9	97	0.67	NS
Chest Width	*0.85*	*1.92*	*9*	*97*	*0.05*	*4*
Udder Width	0.87	1.57	9	97	0.13	NS
Nipple Placement	0.87	1.67	9	97	0.11	NS
Nipple Diameter	0.94	0.70	9	97	0.71	NS
Bone Quality	0.89	1.34	9	97	0.22	NS
Anterior Insertion	0.92	1.00	9	97	0.44	NS
Median Suspensor Ligament	*0.83*	*2.19*	*9*	*97*	*0.03*	*3*
Mobility	0.92	0.89	9	97	0.54	NS
Body Depth	*0.82*	*2.39*	*9*	*97*	*0.02*	*2*
Udder Depth	0.87	1.60	9	97	0.13	NS
Rear Legs Side View	0.88	1.41	9	97	0.19	NS
Rear Legs Rear View	0.88	1.47	9	97	0.17	NS

NS: Non-significant.

For Peer Review

ScholarOne support: (434) 964 4100

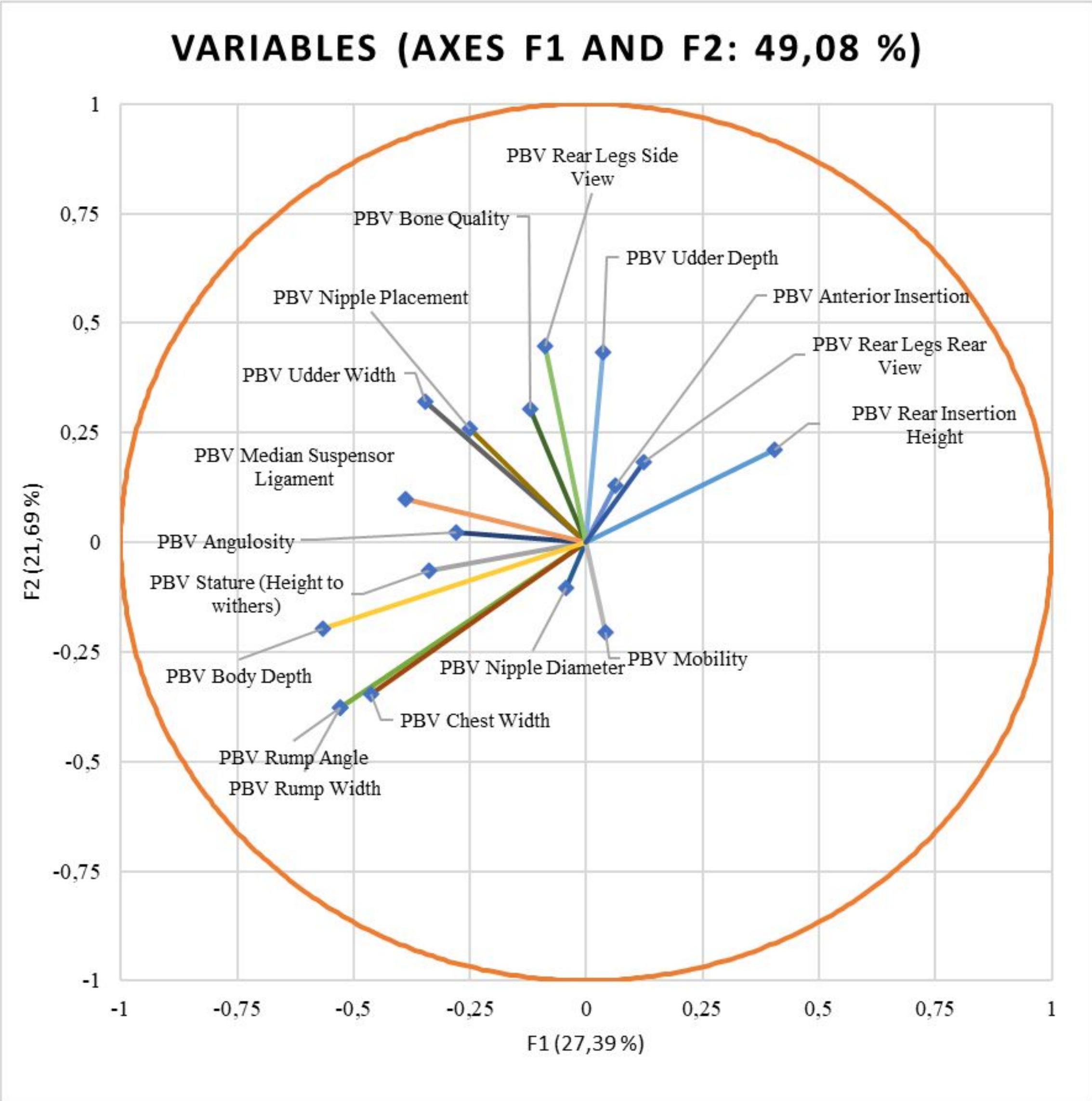

Figure 1. Discriminant loadings for predicted breeding values (PBVs) for zoometrics/linear appraisal traits determining the relative weight of each trait on each canonical discriminant function.

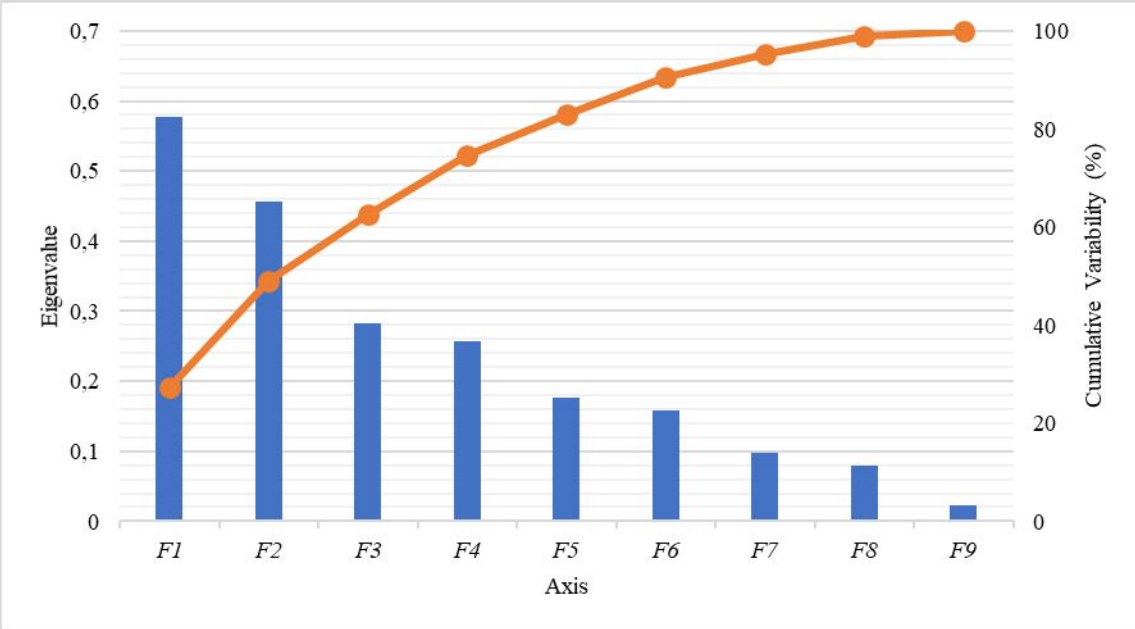

Figure 2. Canonical variable functions and percentages of self-explained and cumulative variance for β casein.

For Peer Review

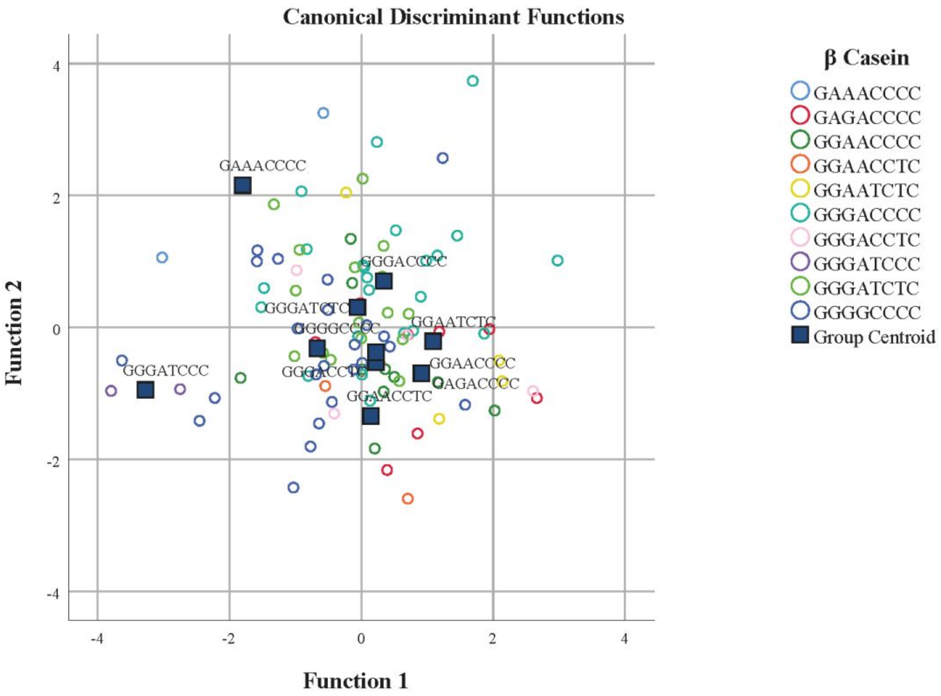

Figure 3. Territorial map depicting the goats considered in the canonical discriminant analysis sorted across β Casein in Murciano-Granadina goats.

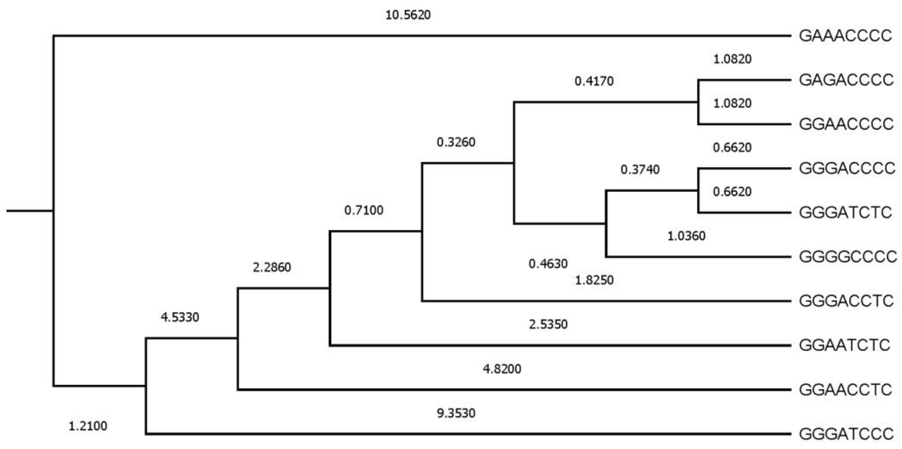

Figure 4. Dendogram constructed from Mahalanobis's distances across β Casein haplotypes.

Conclusions

Of the chapter 1:

1. 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. Indeed, 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.

2. Among the strategies proposed are the reduction/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.

3. The combination of PCA and categorical regression (CATREG) may be successful to optimize and validate the reduction of zoometric evaluation procedures and linear appraisal scoring systems in a way that they are not only able to describe what is happening in a certain population but also can be used to predict the future evolution of parameters basing on their linear correlations.

4. After the validation of CAPRIGAN LAS system was confirmed, the analysis of optimization suggests the removal of rump angle from the panel of zoometric traits implemented.

Of the chapter 2:

1. The progress reported for the heritabilities of the seventeen traits studied in this paper enable breeders to select animals that either improve or correct certain undesirable conditions or which ascribe to a desirable zoometric standard.

2. The progressive gain in heritability values for zoometric and LAS traits and reduction in their heritability standard errors through the years may derive from the technification and enhancement of the methods used to collect either phenotypic or genealogic data quantitively and qualitatively more efficiently.

3. The physiological changes occurring along lactations (days in milk of a lactation), and if the goat is primiparous or multiparous need to be accounted for while measuring individuals due to the zoometric alterations that they promote. The lack of consideration of such changes involves the

fact that certain traits may not be able to cover for the variability described in international 9-point scoring scales, but a 5-point scale with the consequent reduction of heritability.

4. Discarding rump angle trait from the structure and capacity major area and including the angulosity trait ensures all traits in the same major area behave similarly which enhances the potential of selection strategies.

5. Highest estimates rather associate to the udder- and teat-related traits than those in the legs and feet major area. A priori on-farm selection criteria may have selected animals with better aplomb and mobility patterns which is the source for their relative fixation in the population, variability and heritability reduction.

6. The increase in the accuracy of estimations derives from the large number of individuals considered in the kinship matrix and to the routine application of DNA parentage testing.

7. Scale inversion on specific zoometric traits may help to address disagreement in the patterns of the rest of traits in the same major area without impairing the aim of selection for the trait whose scale has been modified itself.

8. Legs aplomb major area conforms a solid cluster in terms of the planification of selection strategies.

Of the chapter 3:

1. The inclusion of the genotype or even the haplotype for β Casein gene in the stud catalogues of the Murciano-Granadina breed together with those of αS1 and κ Casein, which are routinely tested for in merit bucks, is highly encouraged. All in all, β Casein haplotypic sequences may help to routinely detect individuals which are able to genetically transmit a rather desirable dairy type to their descendants, as well as to discard those who do not.

Cross-sectional conclusions:

1. Total variation across individuals in the multifactorial environmental context in which these are herded and thrive, is of extreme relevance in locally adapted breeds following a process of selection towards a particular productive outcome and is the source for the high estimates for heritabilities found.
2. The Murciano-Granadina breed has relatively stable additive genetic and phenotypic variances for zoometric/LAS traits derived from breed

standardization progress. Selection for zoometrics and LAS is equivalent as long as trained operators are able to distinguish and score for the variability present in the reality of the breed.

3. 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.

4. 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.

5. Even if linear appraisal derived morphofunctional traits are often not considered by breeders, our results suggest selection is feasible and may in turn make the animals more suitable for the productive demands, since selection for linear appraisal may indirectly improve the performance of the animals of the breed in question; for instance, aplomb, bone structure, muscle development or mammary conformation.

6. The selection for a better dairy type should follow a multidisciplinary approach comprising new perspectives on genomics, phenomics and biostatistics, which all together may help tailoring selection strategies fitting the context of the Murciano-Granadina breed.

General conclusion:

- Future breeding programs would benefit from modifying the collection system and the manner in which the zoometric traits are managed at a phenotypic and genetic level to ensure that selection for zoometrics/LAS does not translate into any unwanted change in functional fitness, maximizing the outcome of selection strategies to fit the particular reality of the goat species and the diverse range of breeds that it comprises. In these regards, tailoring specific linear appraisal systems and its consideration within the context of the genomic and statisitical tools available is of particular relevance in breeds immersed in a technification process towards an enhanced dairy type, thus seeking for maximized milk yields of a greater quality throughout the life of the animals (lifetime production) but without losing the bases of adaptability and rusticity are still valuable due to the context in which these local genetic resources are managed, preserved and bred.

Conclusiones

Del capítulo 1:

I. El análisis de la simetría en la curva de distribución de los rasgos lineales de valoración revela que las escalas internacionales que tradicionalmente se han utilizado no se ajustan a la distribución de los datos encontrados en la población murciano-granadina de cabras y machos. De hecho, son los primeros signos de selección de estos rasgos, en el contexto de una raza localmente adaptada a las duras condiciones y la orografía, lo que define el perfil zoométrico de una raza.

II. Entre las estrategias propuestas se encuentran la reducción/reajuste de los niveles en la escala como ocurre con los rasgos relacionados con las extremidades, la ampliación de la escala como ocurre en la estatura de los machos, o la subdivisión de la escala utilizada en los machos en dos categorías, sementales menores de dos años y sementales de dos años o más, respectivamente, pueden ayudar a comprender mejor el impulso de selección por caracteres zoométricos ligados al carácter lechero en la población murciano-granadina y su evolución futura para mejorar la rentabilidad y eficiencia de los Programas de Cría.

III. La combinación de PCA y regresión categórica (CATREG) puede tener éxito para optimizar y validar la reducción de los procedimientos de evaluación zoométrica y los sistemas de puntuación de evaluación lineal de manera que no solo puedan describir lo que está sucediendo en una determinada población sino también se puede utilizar para predecir la evolución futura de los parámetros basándose en sus correlaciones lineales.

IV. Después de que se confirmó la validación del sistema CAPRIGAN (LAS), el análisis de optimización sugiere la eliminación del ángulo de la grupa del panel de rasgos zoométricos implementado.

Del capítulo 2:

V. El progreso informado para las heredabilidades de los diecisiete rasgos estudiados en este trabajo permite a los criadores seleccionar animales que mejoren o corrijan ciertas condiciones indeseables o que se adhieran a un estándar zoométrico deseable.

VI. La ganancia progresiva en los valores de heredabilidad de los caracteres zoométricos y LAS, y la reducción de sus errores estándar de heredabilidad a lo largo de los años puede derivar de la tecnificación y mejora de los métodos utilizados para recolectar datos tanto fenotípicos como genealógicos de manera más eficiente a nivel cuantitativo y cualitativo.

VII. Los cambios fisiológicos que ocurren a lo largo de las lactaciones (días en leche de una lactación), así como si una cabra es prmípara (1 parto) o multípara (2 partos o más) debe tenerse muy en cuenta en la medición de los individuos debido a las alteraciones zoométricas que conllevan. La falta de consideración de tales cambios implica que ciertos rasgos pueden no ser capaces de cubrir la variabilidad descrita en las escalas internacionales de puntuación de 9 puntos, sino una escala de 5 puntos con la consiguiente reducción de la heredabilidad.

VIII. Descartar el rasgo del ángulo de la grupa del área principal de estructura y capacidad e incluir el rasgo de angulosidad asegura que todos los rasgos en la misma área principal se comporten de manera similar, lo que mejora el potencial de las estrategias de selección.

IX. Las estimaciones más altas se asocian más a las características relacionadas con la ubre y los pezones que con las del área principal de las patas y los pies. Los criterios de selección a priori en la granja pueden haber seleccionado animales con mejor aplomo y patrones de movilidad, lo que es la fuente de su relativa fijación en la población, la variabilidad y la reducción de la heredabilidad.

X. El aumento en la precisión de las estimaciones se deriva del gran número de individuos considerados en la matriz de parentesco y de la aplicación rutinaria de pruebas de parentesco por ADN.

XI. La inversión de escala en rasgos zoométricos específicos puede ayudar a abordar el desacuerdo en los patrones del resto de rasgos en la misma área principal sin perjudicar el objetivo de selección del rasgo cuya escala ha sido modificada.

XII. La macroárea de aplomo de patas y pies conforma un grupo sólido en cuanto a la planificación de estrategias de selección, aunque la dirección de selección debe ser opuesta a la de las áreas mayores de estructura y capacidad y sistema mamario.

Del capítulo 3:

XIII. Se recomienda encarecidamente la inclusión del genotipo o incluso el haplotipo para el gen de la β Caseína en los catálogos de sementales de la raza Murciano-Granadina junto con los de αS1 y κ Caseína, que se analizan de forma rutinaria en los machos de mérito. En general, las secuencias haplotípicas de β caseína pueden ayudar a detectar de forma rutinaria individuos que son capaces de transmitir genéticamente un tipo de leche bastante deseable a sus descendientes, así como descartar a aquellos que no lo hacen.

Conclusiones transversales:

XIV. La variación total entre individuos en el contexto ambiental multifactorial en el que estos se crían y se desarrollan, es de extrema relevancia en las razas autóctonas adaptadas al medio después de un proceso de selección hacia un resultado productivo particular y es la fuente de los altos valores de estimación de la heredabilidad encontradas.

XV. La raza Murciano-Granadina tiene variaciones genéticas y fenotípicas aditivas relativamente estables para los rasgos zoométricos/LAS derivados del progreso de la estandarización de la raza. La selección por zoometría y LAS es equivalente siempre que los calificadores estén capacitados y puedan distinguir y puntuar la variabilidad presente en la realidad de la raza.

XVI. La raza Murciano-Granadina ha derivado hacia mejores rasgos morfológicos ligados al carácter lechero pero sin perder el fundamento de la base zoométrica que le confiere una mayor adaptación al medio.

XVII. El análisis particular de cada variable permite determinar estrategias específicas para cada rasgo y servir de modelo para otras razas, ya sean seleccionadas o en términos de selección.

XVIII. Incluso si los rasgos morfofuncionales derivados de la evaluación morflógica lineal a menudo no son considerados por los criadores, nuestros resultados sugieren que la selección es factible y, a su vez, puede hacer que los animales sean más adecuados para las demandas productivas, ya que la selección para la evaluación morfológica lineal puede mejorar indirectamente el rendimiento de los animales de la raza en cuestión; por ejemplo, aplomos, calidad de hueso, estrucutra y capacidad o sistema mamario

XIX. La selección de un mejor morfotipo lechero debe seguir un enfoque multidisciplinario que comprenda nuevas perspectivas sobre genómica, fenómica y bioestadística, que en conjunto pueden ayudar a adaptar las estrategias de selección al contexto de la raza Murciano-Granadina.

Conclusión general:

- Los futuros programas de mejoramiento se beneficiarían de modificar el sistema de recolección y la forma en que se manejan los rasgos zoométricos a nivel fenotípico y genético para garantizar que la selección para zoometría/LAS no se traduzca en ningún cambio no deseado en la aptitud funcional, maximizando el resultado de las estrategias de selección que se ajusten a la realidad particular de la especie caprina y la diversa gama de razas que la componen. En este sentido, la confección de sistemas de valoración morfológica lineal específicos y su consideración en el contexto de las herramientas genómicas y estadísticas disponibles cobra especial relevancia en razas inmersas en un proceso de tecnificación hacia un morfotipo lechero mejorado, buscando así maximizar la producción de leche de mayor calidad a lo largo de la vida de los animales (produccón vitalicia) pero sin perder las bases de adaptabilidad y rusticidad que siguen siendo muy valiosas debido al contexto ambiental en el que se manejan, conservan y crían estos recursos genéticos locales.

Bibliographic References

1. Miller, B.A.; Lu, C.D. Current status of global dairy goat production: An overview. *Asian-Australas J Anim Sci* **2019**, *32*, 1219.
2. Gama, L.; Bressan, M. Biotechnology applications for the sustainable management of goat genetic resources. *Small Ruminant Research* **2011**, *98*, 133-146.
3. Amills, M.; Capote, J.; Tosser-Klopp, G. Goat domestication and breeding: a jigsaw of historical, biological and molecular data with missing pieces. *Animal genetics* **2017**, *48*, 631-644.
4. Salgado Pardo, J.I.; Delgado Bermejo, J.V.; González Ariza, A.; León Jurado, J.M.; Marín Navas, C.; Iglesias Pastrana, C.; Martínez Martínez, M.d.A.; Navas González, F.J. Candidate Genes and Their Expressions Involved in the Regulation of Milk and Meat Production and Quality in Goats (Capra hircus). *Animals* **2022**, *12*, 988.
5. Guo, H.; Li, Z.; Ma, Q.; Zhu, D.; Su, W.; Wang, K.; Marinello, F. A bilateral symmetry based pose normalization framework applied to livestock body measurement in point clouds. *Computers and Electronics in Agriculture* **2019**, *160*, 59-70, doi:https://doi.org/10.1016/j.compag.2019.03.010.
6. Bukar-Kolo, Y.; Mustapha, M.; Zakariah, M.; Allo, A.; Adamu, L. Relationships between zoometric measurements, coat colors and body condition scores of the Nigerian indigenous dogs in Maiduguri, Northeastern Nigeria. *Res. J. Vet. Pract* **2016**, *4*, 51-59.
7. Olechnowicz, J.; Kneblewski, P.; Jaśkowski, J.; Włodarek, J. Effect of selected factors on longevity in cattle: A review. *J. Anim. Plant Sci* **2016**, *26*, 1533-1541.
8. González-Velasco, H.M.; García-Orellana, C.J.; Macías-Macías, M.; Gallardo-Caballero, R.; García-Manso, A. A morphological assessment system for 'show quality'bovine livestock based on image analysis. *Computers and electronics in agriculture* **2011**, *78*, 80-87.
9. Fernández Álvarez, J.; León Jurado, J.M.; Navas González, F.J.; Iglesias Pastrana, C.; Delgado Bermejo, J.V. Optimization and Validation of a Linear Appraisal Scoring System for Milk Production-Linked Zoometric Traits in Murciano-Granadina Dairy Goats and Bucks. *Applied Sciences* **2020**, *10*, 5502.
10. Martinez, B.; Vicente, C.; Picchioni, M.; Sanchez, M.; Gómez, E.; Peris, C. Integration of the linear morphological appraisal system in the dairy goat improvement genetic program of Murciano-Granadina breed. In Proceedings of XXXV Congreso de la Sociedad Española de Ovinotecnia y Caprinotecnia (SEOC), Valladolid, España, 22-24 de septiembre de 2010; pp. 470-474.
11. Association, A.D.G. Recent Goat Type Appraisal Data (Number of Appraisals by year). Availabe online: http://adga.org/36856-2/ (accessed on 26/01/2020).
12. Delgado, J.V.; Landi, V.; Barba, C.J.; Fernández, J.; Gómez, M.M.; Camacho, M.E.; Martínez, M.A.; Navas, F.J.; León, J.M. Murciano-Granadina goat: A Spanish local breed ready for the challenges of the twenty-first century. In *Sustainable goat production in adverse environments: Volume II*, Springer: 2017; pp. 205-219.
13. Sánchez Rodríguez, M.; Cárdenas Baena, J.M.; Blanco del Campo, G. Rasgos descriptivos lineales. In *Valoración morfológica del ganado caprino lechero*, Cabrandalucía, F., Ed. Servet Diseño y Comunicación: Zaragoza, 2012.
14. Murciano-Granadina, A.N.d.C.d.C.d.R. Calificación morfológica lineal. Availabe online: http://www.caprigran.com/ (accessed on 26/01/2020).
15. Pardo, G.; del Prado, A.; Fernández-Álvarez, J.; Yáñez-Ruiz, D.R.; Belanche, A. Influence of precision livestock farming on the environmental performance of intensive dairy goat farms. *Journal of Cleaner Production* **2022**, *351*, 131518, doi:https://doi.org/10.1016/j.jclepro.2022.131518.
16. Lynch, M.; Conery, J.; Burger, R. Mutation accumulation and the extinction of small populations. *The American Naturalist* **1995**, *146*, 489-518.

17. García-Ballesteros, S.; Gutiérrez, J.P.; Varona, L.; Fernández, J. The influence of natural selection in breeding programs: A simulation study. *Livestock Science* **2017**, *204*, 98-103, doi:https://doi.org/10.1016/j.livsci.2017.08.017.
18. García-Dorado, A.; Avila, V.; Sánchez-Molano, E.; Manrique, A.; López-Fanjul, C. The build up of mutation–selection–drift balance in laboratory Drosophila populations. *Evolution* **2007**, *61*, 653-665.
19. Kingsolver, J.G.; Hoekstra, H.E.; Hoekstra, J.M.; Berrigan, D.; Vignieri, S.N.; Hill, C.; Hoang, A.; Gibert, P.; Beerli, P. The strength of phenotypic selection in natural populations. *The American Naturalist* **2001**, *157*, 245-261.
20. Johnson, T.; Barton, N. Theoretical models of selection and mutation on quantitative traits. *Philosophical Transactions of the Royal Society B: Biological Sciences* **2005**, *360*, 1411-1425.
21. Xiao, P.T. Observations on the normal distribution of quantitative traits. *Medical Hypotheses* **1995**, *45*, 386-388.
22. Peng, B.; Yu, R.K.; DeHoff, K.L.; Amos, C.I. Normalizing a large number of quantitative traits using empirical normal quantile transformation. *BMC Proceedings* **2007**, *1*, S156, doi:10.1186/1753-6561-1-S1-S156.
23. Goh, L.; Yap, V.B. Effects of normalization on quantitative traits in association test. *BMC bioinformatics* **2009**, *10*, 1-8.
24. Li, Z.; Möttönen, J.; Sillanpää, M.J. A robust multiple-locus method for quantitative trait locus analysis of non-normally distributed multiple traits. *Heredity* **2015**, *115*, 556-564, doi:10.1038/hdy.2015.61.
25. Pizarro, M.; Landi, V.; Navas, F.; León, J.; Martínez, A.; Fernández, J.; Delgado, J. Non-parametric analysis of the effects of nongenetic factors on milk yield, fat, protein, lactose, dry matter content and somatic cell count in Murciano-Granadina goats. *Italian Journal of Animal Science* **2020**, *19*, 960-973.
26. Vieira, A.; Brandão, S.; Monteiro, A.; Ajuda, I.; Stilwell, G. Development and validation of a visual body condition scoring system for dairy goats with picture-based training. *Journal of dairy science* **2015**, *98*, 6597-6608.
27. Anzuino, K.; Bell, N.; Bazeley, K.; Nicol, C. Assessment of welfare on 24 commercial UK dairy goat farms based on direct observations. *Veterinary Record* **2010**, *167*, 774-780.
28. Pares-Casanova, P.M.; Sinfreu, I.; Villalba, D. Application of varimax rotated principal component analysis in quantifying some zoometrical traits of a relict cow. *Korean J Vet Res* **2013**, *53*, 7-10.
29. Vincent, S.; Araku, J.; Ayongu, F.; Chia, S.; Momoh, O.; Yakubu, A. Redundancy Elimination from Morpho-Stuctures of Nigerian Uda Rams Using Principal Component Analysis. *J Anim Pro Adv* **2014**, *14*, 520-526
30. Bulmer, M.G. The Effect of Selection on Genetic Variability. *The American Naturalist* **1971**, *105*, 201-211.
31. West-Eberhard, M.J. Phenotypic accommodation: adaptive innovation due to developmental plasticity. *Journal of Experimental Zoology Part B: Molecular and Developmental Evolution* **2005**, *304*, 610-618.
32. Assan, N. Morphology and its relationship with reproduction and milk production in goat and sheep. *Scientific Journal of Zoology* **2020**, *9*, 123-137.
33. Guan, D.; Martínez, A.; Luigi-Sierra, M.G.; Delgado, J.V.; Landi, V.; Castelló, A.; Fernández Álvarez, J.; Such, X.; Jordana, J.; Amills, M. Detecting the footprint of selection on the genomes of Murciano-Granadina goats. *Animal Genetics* **2021**, *52*, 683-693.
34. Gómez, M.; Miranda, J.; León, J.M.; Pleguezulos, J. FIRST RESULTS OF THE GENETIC EVALUATION OF LINEAR MORPHOLOGICAL TRAITS IN THE MURCIANO-GRANADINA BREED. *Actas Iberoamericanas de Conservación Animal-AICA* **2012**.

35. Wiggans, G.; Van Dijk, J.; Misztal, I. Genetic evaluation of dairy goats for milk and fat yield with an animal model. *Journal of dairy science* **1988**, *71*, 1330-1337.
36. Wiggans, G.; Dickinson, F.; King, G.; Weller, J. Genetic evaluation of dairy goat bucks for daughter milk and fat. *Journal of Dairy Science* **1984**, *67*, 201-207.
37. Pizarro Inostroza, M.G.; Landi, V.; Navas González, F.J.; León Jurado, J.M.; Delgado Bermejo, J.V.; Fernández Álvarez, J.; Martínez Martínez, M.d.A. Integrating casein complex SNPs additive, dominance and epistatic effects on genetic parameters and breeding values estimation for murciano-granadina goat milk yield and components. *Genes* **2020**, *11*, 309.
38. Luigi-Sierra, M.G.; Landi, V.; Guan, D.; Delgado, J.V.; Castelló, A.; Cabrera, B.; Mármol-Sánchez, E.; Fernández-Álvarez, J.; Martínez, A.; Such, X. Identification of genomic regions associated with morphological traits in Murciano-Granadina goats. **2019**.
39. Gebreselassie, G.; Berihulay, H.; Jiang, L.; Ma, Y. Review on genomic regions and candidate genes associated with economically important production and reproduction traits in sheep (Ovies aries). *Animals* **2019**, *10*, 33.
40. Gipson, T.A. Recent advances in breeding and genetics for dairy goats. *Asian-Australas J Anim Sci* **2019**, *32*, 1275-1283.
41. Sugimoto, N.; Takahashi, A.; Ihara, R.; Itoh, Y.; Jouraku, A.; Van Leeuwen, T.; Osakabe, M. QTL mapping using microsatellite linkage reveals target-site mutations associated with high levels of resistance against three mitochondrial complex II inhibitors in Tetranychus urticae. *Insect Biochemistry and Molecular Biology* **2020**, *123*, 103410, doi:https://doi.org/10.1016/j.ibmb.2020.103410.
42. Zhang, H.; Wang, Z.; Wang, S.; Li, H. Progress of genome wide association study in domestic animals. *Journal of animal science and biotechnology* **2012**, *3*, 1-10.
43. Li, X.; Wu, Z.L.; Gong, Y.; Liu, Y.; Liu, Z.; Wang, X.; Xin, T.; Ji, Q. Single-nucleotide polymorphism identification in the caprine myostatin gene. *Journal of Animal Breeding and Genetics* **2006**, *123*, 141-144.
44. Caravaca, F.; Ares, J.L.; Carrizosa, J.; Urrutia, B.; Baena, F.; Jordana, J.; Badaoui, B.; Sànchez, A.; Angiolillo, A.; Amills, M. Effects of αs1-casein (CSN1S1) and κ-casein (CSN3) genotypes on milk coagulation properties in Murciano-Granadina goats. *Journal of Dairy Research* **2011**, *78*, 32-37.
45. Rychtářová, J.; Sztankoova, Z.; Kyselova, J.; Zink, V.; Štípková, M.; Vacek, M.; Štolc, L. Effect of DGAT1, BTN1A1, OLR1, and STAT1 genes on milk production and reproduction traits in the Czech Fleckvieh breed. *Czech J. Anim. Sci* **2014**, *59*, 45-53.
46. Martin, P.; Szymanowska, M.; Zwierzchowski, L.; Leroux, C. The impact of genetic polymorphisms on the protein composition of ruminant milks. *Reproduction nutrition development* **2002**, *42*, 433-459.
47. Pizarro, M.; Landi, V.; Navas, F.; León, J.; Martínez, A.; Fernández, J.; Delgado, J. Nonparametric analysis of casein complex genes' epistasis and their effects on phenotypic expression of milk yield and composition in Murciano-Granadina goats. *Journal of dairy science* **2020**, *103*, 8274-8291.
48. Yahyaoui, M.H.; COLL, A.; SANCHEZ, A.; FOLCH, J.M. Genetic polymorphism of the caprine kappa casein gene. *Journal of Dairy Research* **2001**, *68*, 209-216.
49. Pizarro Inostroza, M.G.; Navas González, F.J.; Landi, V.; León Jurado, J.M.; Delgado Bermejo, J.V.; Fernández Álvarez, J.; Martínez Martínez, M.d.A. Bayesian Analysis of the Association between Casein Complex Haplotype Variants and Milk Yield, Composition, and Curve Shape Parameters in Murciano-Granadina Goats. *Animals* **2020**, *10*, 1845.
50. Martin, C.; Morgavi, D.P.; Doreau, M. Methane mitigation in ruminants: from microbe to the farm scale. *Animal* **2010**, *4*, 351-365.
51. Caroli, A.; Chiatti, F.; Chessa, S.; Rignanese, D.; Bolla, P.; Pagnacco, G. Focusing on the goat casein complex. *Journal of Dairy Science* **2006**, *89*, 3178-3187.

52. Benyoub, K.Q.; Ameur, A.A.; Gaouar, S.B.S. Phenotypic characterization of local goats populations in western Algerian: Morphometric measurements and milk quality. *Genetics & Biodiversity Journal* **2018**, *2*, 69-76.
53. Erduran, H.; Dag, B. Determination of factors affecting milk yield, composition and udder morphometry of Hair and cross-bred dairy goats in a semi-intensive system. *Journal of Dairy Research* **2021**, *88*, 265-269.
54. Jena, S.; Malik, D.; Kaswan, S.; Sharma, A.; Kashyap, N.; Singh, U. Relationship of udder morphometry with milk yield and body condition traits in Beetal goats. *Indian J. Anim. Sci* **2019**, *89*, 204-208.
55. Fernández Álvarez, J.; León Jurado, J.M.; Navas González, F.; Iglesias PAstrana, C.; Delgado Bermejo, J.V. CAPRIGRAN Linear Appraisal Evidences Dairy Selection Signs in Murciano-Granadina Goats and Bucks: Presentation of the New Linear Appraisal Scale. *Archivos de zootecnia* **2021**, *70*, 239-245.
56. Fernández Álvarez, J.; León Jurado, J.M.; Navas González, F.J.; Iglesias Pastrana, C.; Delgado Bermejo, J.V. Applicability of an international linear appraisal system in Murciano-Granadina breed: fitting, zoometry correspondence inconsistencies, and improving strategies. *Italian Journal of Animal Science* **2022**, *21*, 1232-1245.