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Precision Canine Phenomics: Leveraging Statistical Rigor with Spearman's Rank rho Correlations and Procrustes Residuals for Breed Standard Elements Selection

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ADDITIONAL KEYWORDS

Precision.
Phenomic Landscape.
Phenotypic Traits.
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Advanced Analytical Methodologies.

SUMMARY

In this comprehensive exploration of precision in defining dog breed standards, the article employs advanced analytical tools—Spearman's correlations and Procrustes residuals—to assess relationships among zoometric, phaneroptic, and behavioral variables. Spearman's correlations quantify associations between traits, guiding the prioritization of elements for robust breed standards, while Procrustes residuals add a geometric dimension, unveiling subtle morphological deviations. The synergistic integration of statistical and geometric analyses marks a paradigm shift in breed standard selection, empowering stakeholders to navigate the complexity of variables. The systematic evaluation of various physical and temperamental traits in dogs ensures a holistic understanding, and the application of statistical measures in Balearic Island dog breeds identifies compulsory elements and reveals combinations indicating a lack of distinctive features. The findings offer valuable insights for breeders, enthusiasts, and judges, guiding them to adhere to recognized standards for preserving and promoting distinctive breed qualities.

Fenómica Canina de Precisión: Aprovechando el Rigor Estadístico con las Correlaciones de Spearman y los Residuos de Procrustes para la Selección de los Elementos de los Estándares de Razas

PALABRAS CLAVE ADICIONALES
Precisión.
Paisaje Fenómico.
Rasgos Fenotípicos.
Relaciones Multifacéticas.
Metodologías Analíticas Avanzadas.

RESUMEN

En esta exhaustiva exploración de la precisión en la definición de los estándares de raza canina, el artículo emplea herramientas analíticas avanzadas, como las correlaciones de Spearman y los residuos de Procrustes, para evaluar las relaciones entre variables zoométricas, fanerópticas y de comportamiento. Las correlaciones de Spearman cuantifican las asociaciones entre rasgos, guiando la priorización de elementos para estándares de raza sólidos, mientras que los residuos de Procrustes añaden una dimensión geométrica, revelando sutiles desviaciones morfológicas. La integración sinérgica de análisis estadísticos y geométricos marca un cambio de paradigma en la selección de estándares de raza, capacitando a los interesados para navegar la complejidad de las variables. La evaluación sistemática de diversos rasgos físicos y temperamentales en perros asegura una comprensión holística, y la aplicación de medidas estadísticas en razas de perros de las Islas Baleares identifica elementos obligatorios y revela combinaciones que indican la falta de rasgos distintivos. Los hallazgos ofrecen valiosas perspectivas para criadores, entusiastas y jueces, guiándolos para adherirse a estándares reconocidos y preservar las cualidades distintivas de la raza.

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INTRODUCTION

In the dynamic landscape of canine genomics and phenomics, the quest for precision in defining breed standards necessitates advanced analytical methodologies. This technical exploration focuses on the strategic application of Spearman's correlations and Procrustes residuals, delving into the intricate relationships spanning zoometric, phaneroptic, and behavioral variables. By unraveling these statistical and geometric intricacies, this article aims to provide breed enthusiasts, geneticists, and researchers with a comprehensive understanding of how these tools synergize to elevate the precision and sophistication of breed standard selection.

Spearman's correlations (Roy-García et al. 2019) offer a robust statistical framework for assessing the

strength and directionality of relationships among zoometric dimensions, phenotypic features, and behavioral traits within a breed (Simonetti et al.) . By subjecting data to rigorous correlation analyses, researchers can quantify the degree of association between variables. This quantitative approach not only identifies key relationships but also serves as a foundation for prioritizing traits in the construction of comprehensive breed standards.

Complementing Spearman's correlations, Procrustes analysis introduces a geometric dimension to the study of morphological traits (Dijksterhuis & Gower 1991). By superimposing morphological landmarks, Procrustes residuals unveil the subtle deviations between observed and predicted configurations. This geometric scrutiny, rooted in landmark-based morphometrics, provides a nuanced understanding of canine conformation and behavior. As a result, Procrustes residuals become instrumental in discerning intricate variations and guiding the selection of elements that contribute to the distinct identity of a breed.

The synergy between Spearman's correlations and Procrustes residuals marks a paradigm shift in breed standard selection. Through a harmonious integration of statistical and geometric analyses, breeders and researchers can navigate the complex web of variables that define a breed's identity. This holistic approach empowers stakeholders to make informed decisions, not only based on statistical significance but also on the geometric nuances that contribute to the overall phenotypic and behavioral landscape.

This article aims to serve as a comprehensive guide to the technical application of Spearman's correlations and Procrustes residuals in the pursuit of precision canine phenomics. By combining statistical rigor with geometric insights, breed standard selection evolves into a meticulous and sophisticated process, ensuring that each element contributes meaningfully to the tapestry of a breed's identity.

MATERIAL AND METHODS

Breed Standards Elements

In the comprehensive evaluation of Balearic dogs (**Figure 1**), a systematic and logical approach is undertaken to assess a diverse range of physical and temperamental characteristics. This structured method ensures a thorough understanding of the dog's conformation, covering various aspects in a methodical order.

The assessment begins with the Recognition/ Classification phase, considering factors such as breed official consideration, RSCE recognition, type officiality, and FCI breed type. This provides a foundation for understanding the dog's pedigree and classification within recognized standards.

Moving to the General Appearance, the evaluation encompasses sexual dimorphism, with a focus on whether it is present or not, and any specific dimorphism features that may be observed. This is followed by a detailed exploration of temperament and behavior traits. Traits such as tranquility, courage, bravery, sociability, and others contribute to a holistic understanding of the dog's personality and disposition.

The assessment then delves into the Size and Weight considerations, differentiating between females and males. Parameters include height at withers and weight, providing insights into the dog's

Figure 1. Endangered dog breeds in the Balearic Island; Officially Recognised: (A) Ca de Bestiar (CB), (B) Ca Mè (CM), (C) Ca de Rater (CR), (D) Ibicean Hound(PI), (E) Ca de Bou (CBOU) and Breed Agroupation: (F) Menorcan Ca de Conills (CC).

physical build and proportions.

The evaluation proceeds to the Head and related features, examining the structure, size, shape, length, proportions, muscle development, symmetry, and definition of muscle groups. This thorough examination extends to the Jaws and Lips, considering masseteric conformation, lip size, and color.

The Snout is then scrutinized for size, color, and width, offering insights into the dog's facial characteristics. The Eyes are evaluated for size, shape, color, sight/expression, separation, and position.

Moving on to the Ears, their shape, implantation, size, position, and the presence of folds are considered. The Neck is assessed for muscle development, thickness, insertion, profile, length, and the presence or absence of a dewlap. The Thorax and Croup are evaluated for shape, muscle development, and other relevant features, followed by an examination of the Shoulders, Dorsal Line, and Fore Extremities. Parameters such as arm length, elbow position, carpus, metacarpus, finger arrangement, and others contribute to a comprehensive understanding of the forelimbs.

The evaluation extends to the Rear Extremities, considering muscle development, thigh and leg length, hock width, toe arrangement, and angles at different joints. The Tail is then examined for implantation, length, trace, birth, and section. The assessment includes an evaluation of the Coat, encompassing hair texture, length, color, and various coat-related characteristics. Eliminatory Faults are meticulously considered, covering a range of faults in different body regions, ensuring a critical examination of potential deviations from the standard.

The Minor Faults category addresses behavioral issues, tail irregularities, and missing premolars. Conversely, the Major Faults category highlights more severe deviations, including height at withers exceeding the croup, various mouth-related faults, bulldog-like tail, and coat irregularities.

The Use or purpose of the dog is also taken into account, providing context for the evaluation. Further scrutiny includes the Palate, Teeth, Eye Lids, Movements, and Skin, exploring various characteristics related to these features. This structured and systematic approach ensures a comprehensive and nuanced assessment, covering every aspect of a dog's physical and temperamental traits while considering potential faults and deviations from the standard.

Spearman's Rank Rho Correlations and Procrustes Residuals

XLSTAT Version 2014.5.03 was used to calculate Spearman's rank rho correlations and Procrustes residuals for studying canine traits comprising Balearic dog breeds stadards. For Spearman's correlations, we ranked variables to understand their relationships, and XLSTAT generated results with correlation coefficients and p-values. When analyzing shape differences using Procrustes analysis, XLSTAT compared two sets of landmark data, helping determine shape variations between datasets by computing Procrustes residuals. XLSTAT Version 2014.5.03 proves invaluable in simplifying and enhancing the exploration of canine morphological, phaneroptical and behavioral characteristics.

RESULTS

Procrustes Residuals

Table I reports average residuals derived from procrustes analysis per Breed standard Element and feature. Those elements for which a higher residual was reported are indicative of a lower consensius across breeds, hence could be appointed as distinctive elements whose consideration may be crucial for breed differentiation.The breed standard analysis delves into a detailed examination of various elements and features that collectively shape the unique characteristics of a specific dog breed. The average residuals per breed standard element, highlighted in bold, provide insights into the relative importance of individual traits within the breed standard.

Belly (Average Residual: 0.193)

Traits related to the belly, including trace and body proportionality, have a moderate impact on the breed standard.

Whithers Height/Croup Height (Average Residual: 0.231)

Achieving the right balance between whithers height and croup height is crucial, with a moderately influential impact on the breed standard.

Whithers Prominency (Average Residual: 1.197)

The prominence of the whithers stands out with a higher residual, indicating its significant role in defining the breed's appearance.

Chest (Average Residual: 3.383)

The chest, encompassing depth, length, and muscle development, holds substantial importance in the breed standard.

Coat (Average Residual: 1.756)

Various aspects of the coat, including color, length, and texture, contribute to the breed's standard with an average residual.

Craneal Region (Average Residual: 2.748)

Traits related to the cranial region, such as alignment of cranial and facial axes, approximate proportions, and forehead shape, collectively contribute moderately to the breed standard.

Ears (Average Residual: 3.323)

Ears, including fold presence, implantation, position, and shape, exhibit a higher residual, emphasizing their considerable influence.

Eliminatory Faults (Average Residual: 1.338)

Traits leading to eliminatory faults, encompassing various aspects from behavior to specific body parts, suggest a moderate impact on the breed standard.

Eyes (Average Residual: 2.820)

Eyes, with characteristics like color, position, separation, and shape, show a substantial residual, highlighting their considerable influence.

Fore Extremities (Average Residual: 1.074)

Traits related to fore extremities, including arm, carpus and metacarpus, elbow, fingers, and scapulohumeral angle, contribute to a moderately influential element.

General Appearance (Average Residual: 0.765)

The general appearance, covering sexual dimorphism, temperament/behavior, and overall head structure, has a moderate residual, suggesting its importance.

Jaws (Average Residual: 2.483)

Jaws, including masseteric conformation, lips color, and size, contribute significantly to the breed standard, with a higher average residual.

Loin (Average Residual: 3.500)

The loin, with traits related to width, exhibits a substantial residual, emphasizing its impact on the breed's overall body structure.

Major Faults (Average Residual: 1.303)

Traits leading to major faults, covering various aspects from behavior to specific body parts, suggest a moderate impact on the breed standard.

Movements (Average Residual: 2.491)

Traits related to movements, including type and overall movement characteristics, exhibit a considerable impact on the breed standard.

Neck (Average Residual: 2.583)

The neck, with traits like dewlap, insertion, length, muscle development, profile, and thickness, collectively contributes to a moderately influential element.

Recognition/Classification (Average Residual: 2.284)

Recognition and classification criteria, including breed official consideration and type officiality, exhibit a moderate residual, highlighting their significance.

Shoulders (Average Residual: 2.076)

Shoulders, with traits related to length and shape, contribute to a moderately influential element.

Skin (Average Residual: 2.433)

Skin traits, including folds present and overall thickness, collectively exhibit a moderate impact on

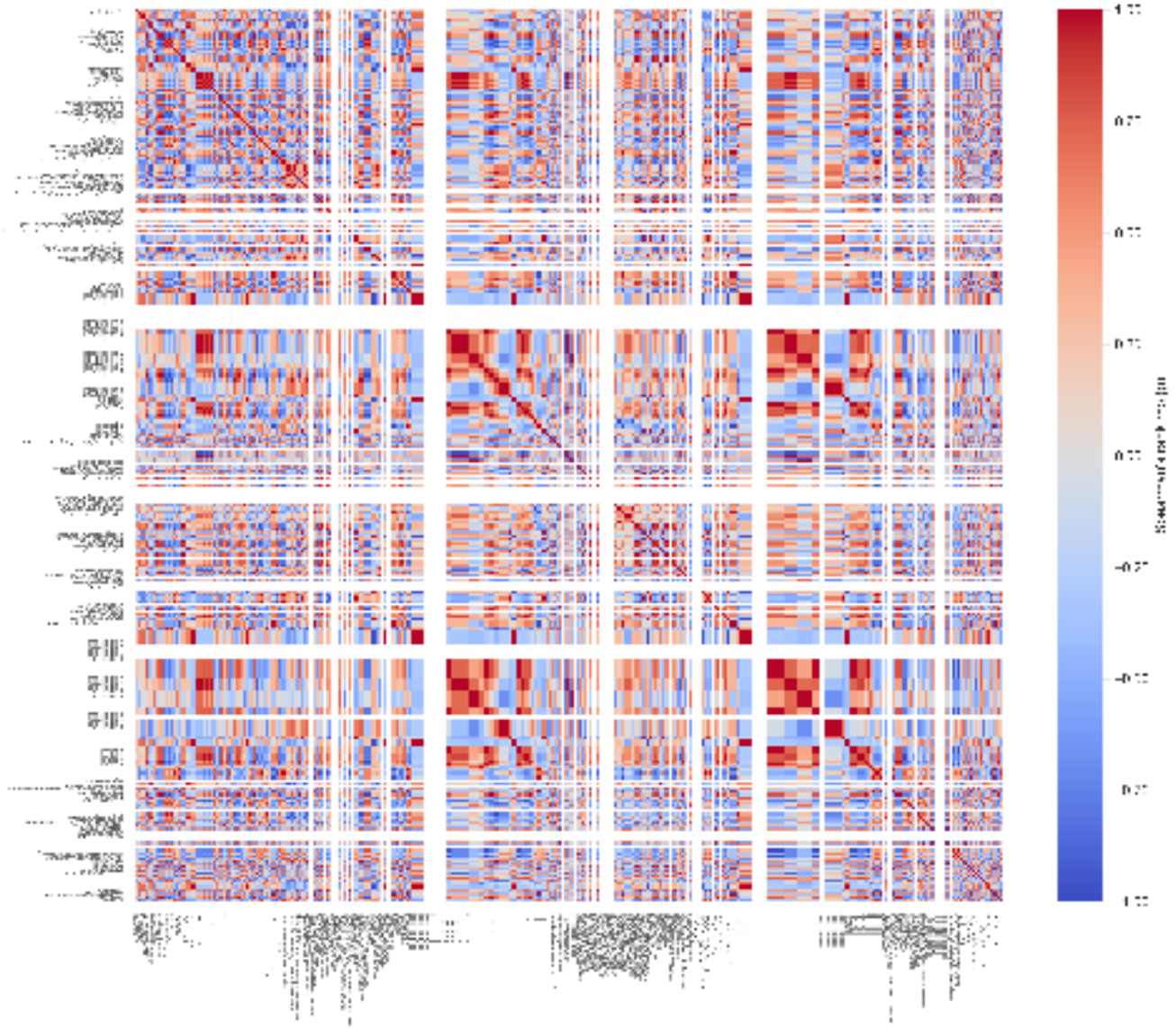

Figure 1. Spearman's Rank rho correlations across Breed Standard Elements and Features.

Table I. Average Residuals for Breed Standard Elements and Features.

Breed Standard Element and Features	Average Residual per Breed Standard Element (in bold)/Partial Residuals per Feature
Belly	**0.193**
Trace	0.193
Body	**0.834**
Proporcionality	0.227
Whithers Height/Croup Height	0.231
Whithers Prominency	1.197
Whithers Skin	3.515
Whithers Width	0.215
Chest	**3.383**
Depth	2.362
Length	5.097
Muscle Development	3.515
Sternon	2.425
Width	3.515
Coat	**1.756**
Hair Colour	1.506
Hair Length	2.425
Hair Texture	5.096
Craneal Region	**2.748**
Alignment of Cranial and Facial Axes	1.715
Approximate Proportions	2.963
Forehead Shape and Width	2.215
Frontal Groove	0.968
Frontonasal Depression	3.405
Occipital Crest	4.482
Width and Length	3.279
Croup	**2.206**
Muscle Development	0.900
Shape	3.512
Dorsal Line	**1.316**
Length	2.426
Muscle Development	0.218
Profile	1.303
Ears	**3.323**
Fold Presence	3.451
Implantation	3.512
Position	3.341
Shape	4.524
Size	1.785
Eliminatory Faults	**1.338**
Back	0.968
Behaviour	1.481
Belly	1.862
Chest	2.169
Coat and Phaneroptics	2.201
Croup	3.511

Fore extremities	0.839
Head	1.318
Heigth at Whithers	0.054
Mouth	0.329
Neck	0.678
Proportions	1.266
Rear extremities	1.009
Reproductive Tract	0.054
Tail	1.516
Weight	0.054
Eye Lids	**1.863**
Conformation	1.863
Eyes	**2.820**
Colour	2.900
Position	5.747
Separation	2.482
Shape	1.604
Sight	2.149
Size	2.038
Female Size	**1.007**
Heigth at Whithers	0.785
Weight	1.640
Fore Extremities	**1.074**
Arm	0.139
Carpus and Metacarpus	1.779
Elbow	1.780
Fingers	1.892
Humeroradial Angle	0.063
Interdigital Membrane	1.775
Scapulohumeral Angle	1.146
General Appearance	**0.765**
Sexual Dimorphism	0.648
Temperament/Behaviour	0.774
Head	**1.981**
Definition of Muscle Groups	2.890
Length	0.213
Muscle Develpment	2.367
Proportions	0.659
Shape	3.009
Size	3.899
Structure	2.367
Symmetry	0.054
Jaws	**2.483**
Masseteric Conformation	2.483
Lips	**0.920**
Colour	1.781
Size	0.059
Loin	**3.500**

Width	3.500
Major Faults	**1.303**
Belly	0.155
Coat and Phaneroptics	2.494
Fore extremities	0.155
Head	1.924
Mouth	0.939
Rear extremities	1.866
Size/Proportions	0.059
Tail	0.054
Teeth	0.054
Thorax	2.917
Male Size	**1.151**
Heigth at Whithers	0.764
Weight	2.234
Minor Faults	**0.107**
Behaviour	0.054
Tail	0.212
Teeth	0.054
Mouth	**0.715**
Profile	0.715
Movements	**2.491**
Type	2.491
Neck	**2.583**
Dewlap	1.783
Insertion	0.260
Length	2.308
Muscle Development	3.492
Profile	4.163
Thickness	3.492
Palate	**0.184**
Colour	0.184
Rear Extremities	**1.144**
Coxofemoral Angle	1.427
Femorotibial Angle	0.054
Hock Width	2.450
Leg Length	0.212
Muscular Development	0.054
Thig Length	2.432
Tibiotarsianus Angle	1.427
Toes	1.643
Recognition/Classification	**2.284**
Recognition/Classification	2.284
Shoulders	**2.076**
Length	2.450
Shape	1.702
Skin	**2.433**
Folds Present	2.493

Thickness	2.373
Snout	**1.125**
Snout Colour	1.780
Snout Size	0.797
Snout Width	0.797
Tail	**1.145**
Birth	0.222
Implantation	1.736
Length	1.221
Section	2.492
Trace	0.056
Teeth	**2.182**
Bite Type	2.182
Thorax	**3.490**
Shape	3.490
Use	**1.957**
Function	1.957

the breed standard.

Snout (Average Residual: 1.125)

Traits related to the snout, including snout color, size, and width, contribute moderately to the breed's overall appearance.

Tail (Average Residual: 1.145)

The tail, with traits related to implantation, length, section, and trace, collectively exhibits a moderate impact on the breed standard.

Teeth (Average Residual: 2.182)

Traits related to teeth, including bite type, exhibit a moderate impact on the breed standard.

Thorax (Average Residual: 3.490)

Thorax traits, including overall shape and function, exhibit a substantial impact on the breed's body structure.

Use (Average Residual: 1.957)

Traits related to the dog's use or function exhibit a moderate impact on the breed standard.

In conclusion, this exhaustive analysis provides a holistic view of the specific dog breed, offering valuable insights into the breed's physical and behavioral characteristics. Breeders, enthusiasts, and judges can utilize this information to better understand and adhere to recognized standards, ultimately ensuring the preservation and promotion of the breed's distinctive qualities in line with established norms.

Spearman's Rank Rho Correlations

Figure 2 shows a heatmap reporting correlations across all elements in a breed standard and features. As suggested by the scale, the more intense the red colour is the larger positive correlations between element pairs is as well. On the contrary the more intense the blue colour is the larger the negative correlations across elements and features is as well.

DISCUSSION

In the context of Balearic Island dog breeds, the application of statistical measures like Spearman's correlations and Procrustes residuals becomes especially pertinent for the formulation and refinement of breed standards. The Balearic Islands, known for their rich cultural and historical diversity, host several indigenous dog breeds (Anguera Sansó 2003), each with unique characteristics that contribute to their distinct identity.

Spearman's Correlations

Identification of Compulsory Elements

For Balearic Island dog breeds, Spearman's correlations (Spearman 2010) can help identify elements that tend to co-occur and are crucial for defining breed characteristics. For instance, a positive correlation (Martínez Ortega et al. 2009) between "Coat Colour" (Alvarez et al. 2015) and "Tail Type" (Olivares 1995) might indicate that specific color patterns are associated with particular tail configurations in a breed, emphasizing the importance of considering these elements together in the breed standard.

Conversely, a negative correlation (Ortega et al. 2009) between certain traits could suggest that they are mutually exclusive or have an antagonistic relationship. Addressing such relationships is essential for crafting a breed standard that accurately reflects the unique features of Balearic Island dogs.

Procrustes Residuals

Identification of Compulsory Elements

Low Procrustes residuals between elements reveal a high degree of agreement in their configurations (Bermúdez 2009). In the context of Balearic Island breeds, this could mean that certain features, such as "Ear Shape" "(Silveira, Capote & Fernández 1998) and "Body Proportions," (Rudd Garcés) exhibit consistent relationships that contribute significantly to the overall breed standard. Deviations from these expected configurations might impact the distinctive appearance of the breed.

High Procrustes residuals (Rico Bermúdez 2009), however, highlight elements that do not conform well to the overall breed configuration. For example, if there are discrepancies between the observed and predicted shapes of "Tail Section" (G Costa 2007) and "Body Structure," (Castro et al. 2000), it becomes imperative to address these aspects to ensure a more accurate representation of the breed's distinctiveness.

Combinations Indicating Lack of Distinctive Features

Low Procrustes Residuals Across Breeds

If certain elements consistently exhibit low Procrustes residuals (Gower 1975) across various Balearic Island dog breeds, it may suggest that these features are not unique to a particular breed. For example, if "Coat Texture" (Pedreros Castellanos & Soler Morantes) shows low residuals across multiple breeds, it implies that this feature might be a common trait shared among them.

Low Spearman's Rank Rho Correlations

Low correlations (Schober, Boer & Schwarte 2018) among unique features across breeds could indicate that these elements are not crucial in distinguishing one Balearic Island breed from another. Breed standards should prioritize elements with strong correlations that contribute to the uniqueness of each breed within the Balearic Islands.

In summary, the application of statistical measures in the context of Balearic Island dog breeds offers a systematic approach to shaping and refining breed standards. By identifying interdependencies, evaluating configurations, and pinpointing distinctive features, these statistical tools enable breeders and standardization organizations to craft precise and culturally relevant standards that capture the essence of each unique Balearic Island dog breed. This ensures that breed standards not only reflect the historical and cultural context of the islands but also contribute to the preservation and recognition of these indigenous breeds.

CONCLUSIONS

In conclusion, this detailed analysis of breed standard elements and features, along with their respective residuals, provides valuable insights into the relative importance of various traits in defining the overall standard of the specific dog breed under consideration. Breeders, enthusiasts, and judges can use this information to prioritize key characteristics and ensure the preservation of the breed's unique qualities.

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