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No ecogeographical trends in body structure for Zebu (*Bos indicus)*

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ABSTRACT: Bergmann's rule is an empirical generalisation concerning body size in endothermic species. It states that within a species, body size varies such that individuals occupying colder environments tend to be larger than individuals who live in warmer environments. To test this law in domestic *Bos* species, we performed a systemic review of the literature on 60 Zebu (*Bos indicus*) and Zebu-derivative crossbreeds from Africa and Asia. The following data were obtained via a literature metareview for each breed: wither height, live weight, conformation of dewlap and hump, latitude, longitude, and Köppen-Geiger climatic data. The body mass index (BMI, body weight divided by the square of height) was obtained to assess body size. No trend in BMI was found along latitude or between BMI and Köppen-Geiger data. BMI was not clearly explained by the development of dewlap and hump, either, but it tended to increase with body mass. Although the validity of Bergmann's rule for Zebu breeds seems to be highly idiosyncratic and partially dependent on the study design, this study provides a new vision about the ecogeographical distribution of Zebu breeds.

Keywords**:** Bergmann's rule; body mass index; *Bos*; heat adaptation; Sanga; zeboide.

INTRODUCTION

Bergmann's rule claims that in homeotherms, body size increases inversely with temperature so that, intraspecifically, body size increases latitudinally. The rule is named after nineteenth-century biologist Carl Bergmann, who described the pattern in German in 1847, though he was not the first to notice it. That many scientists cannot refer to the original source of information because it has not been published in English has resulted in a reliance on others for interpretation and led to several problems, the largest of which is whether the definition of the rule should include the mechanism that had been proposed by Bergmann (Cortney, 2010). Bergmann's rule is most often applied to mammals and birds, which are endotherms, but some researchers have also found evidence for the rule in studies of ectothermic species (e.g., Chuan-kai, 2010 and Kamilar, 2012).

Cattle are one of the most economically important domestic animals in the world. Their origin, genetic diversity, conservation, and sustainable utilisation have received close attention for a long time. A total of 990 cattle breeds have been reported throughout the world; 897 are classified as local or indigenous breeds and 93 as transboundary breeds (Berthouly, 2010). Among these, 258 breeds have been reported in Asia, where cattle can be subdivided into humped and humpless (Berthouly, 2010). The humped cattle (Zebu) are more prevalent in southern regions of the continent, particularly in India and Pakistan (Berthouly, 2010). Zebu (*Bos indicus*) originated in India, and are thought to be the world's oldest domesticated cattle (genus *Bos*).

Here, we report a study in which we tested if modern Zebu conformed to Bergmann's rule. We carried out three analyses in the study. In the first, we replicated the approach employed in the main studies that found a correlation between body size and latitude. In the second, we examined the relationship between body size and climate data. In the third and final analysis, we investigated if the development of dewlap and hump could affect the rule.

MATERIALS AND METHODS

The sample comprised 60 Zebu and Zebu-derivative crossbreeds from Africa and Asia. Sanga cattle (cervicothoracic-humped cattle, *Bos taurus*), predominant in Southern Africa, were not considered for this research, as recent research suggests that they have part of their inheritance in common with European cattle, e.g., the Y chromosome is of the same shape as that in European breeds (Meyer, 1984). Zebu wither height (range 85–144 cm, Coefficient of Variation=10.0%) and body weight (range 120–480 kg, CV=25.5%) were registered for adults for all considered breeds. Data were obtained via a systemic literature review mainly from: http://dad.fao.org/, Porter (1991), and the basic Mason's dictionary. As 'height', we considered wither height, and as 'body weight', live weight. Data of dewlap (developed, medium, or fine) and hump (large-, medium-, or small-humped) were also obtained but due to a shortage of available information, this 'complete' description was available only for 30 breeds. To eliminate the effects of sexual dimorphism variation, breeds were studied only from female data. Widespread breeds were ascribed to their original area, so imported breeds were not considered out of the 'native cot'.

Bergmann's rule was initially formulated in relation to body weight (Bergmann, 1847) and this variable has been used by a number of researchers for human species (Roberts, 1953; Ruff, 1994; Katzmarzyk and Leonard, 1998). However, several other variables have also been used to assess the extent to which species conform to Bergmann's rule, including height, the body mass index (BMI; body weight [BW] divided by the square of height), the ratio of surface area to body weight (SA/BW), and the Ponderal Index (PI; body weight divided by the cube of height) (Schreider, 1950; Hiernaux and Froment, 1976; Walterm, 1976; Beall and Goldstein, 1992; Ruff, 1994). Given these uncertainties, we opted to use BMI but not PI (as they are h correlated, r_s=0.906). We did not consider body surface area because it is a value that is never described in domestic breeds.

There is also ambiguity regarding which variable should be used to represent temperature (Foster and Collard, 2013): latitude has been employed in some studies (Ruff, 1994; Fukase, 2012) whereas mean annual temperature in others (Roberts, 1953; Walter, 1976; Roberts, 1978; Katzmarzyk and Leonard, 1998; Wells, 2012; Gilligan and Bulbeck, 2007), and both latitude and mean annual temperature in still others (Stinson, 1990; Invahoe, 1998). The variables we utilised were latitude, longitude, and climate, which were obtained using online resources. Coordinate data were obtained from http://www.worldatlas.com/aatlas/latitude_and_longitude_finder.htm. When only a general geographic area was described, they were based on the breed's largest population centre or the approximate geographic centre of the breed's territory. Climate data for a given region were obtained from the source of the Köppen-Geiger digital map climate classification (http://koeppen-geiger.vu-wien.ac.at/present.htm) (Kottek, 2006), including 'main climate' (equatorial, arid, steppe, arid desert, warm, and snow) and 'precipitation' (fully humid, monsonal, summer dry, winter dry, hot arid, fully humid hot summer, winter dry hot summer, and fully humid warm summer) data.

With all data selected, we carried out three sets of analyses. In the first analysis, we began by regressing the latitude and longitude (W and S values expressed negatively). Spearman's (non-parametric) rank-order correlation coefficient (r_s) was the linear correlation coefficient (Pearson's *r*) of the ranks, with a Monte Carlo permutation test based on 9,999 random replicates. Spatial interpolation ('gridding') was used to interpolate spatially scattered two-dimensional (2D) data points (latitude and longitude) onto a regular grid. This gridding allowed the production of a map showing a continuous spatial estimate of scattered BMI. The interpolation algorithms were inverse distance weighted, in which the value at a grid node was the average of the *N* closest data points. The points were weighted in inverse proportion to distance.

Multivariate techniques minimise Type I error (increased risk of this error occurs when too many statistical tests are performed on the same variables in a data set, with each test having its own risk of Type I error) because they allow for simultaneous comparisons among the variables rather than requiring many statistical tests to be conducted. This is why in the second set of analysis, a canonical analysis was used for the latitude (absolute degrees), climatic data (Köppen-Geiger data, with 'main climate' and 'precipitation' values appearing separated), and traits related to hump (large-humped, medium-humped, small-humped or humpless) and dewlap (large, medium, fine). The goal of this analysis was to shed light on the impact of 'extra appendages' such dewlap and hump that could add to the size of the animal.

In the third analysis, we used linearly regressed BMI against body weight (log transformed), in order to establish if breed weight could affect BMI. Isometry and comparisons between slopes were tested with an analysis of covariance (ANCOVA) test. A polynomial of up to the fifth order was fitted to the data to study if a polynomial equation could improve the linear regression analysis. The algorithms for polynomials were based on a least-squares criterion and singular value decomposition (Press, 1992), with mean and variance standardisation for improved numerical stability. The Akaike Information Criterion (AIC) was the penalty for the number of terms, and it should be as low as possible to maximise fit. All the analyses were carried out in PAST version 2.17c (Hammer, 2001).

RESULTS AND DISCUSSION

Results

The ordinal correlation was not significant for latitude (r_s=-0.058, p=0.646) or for longitude (r_s=0.111, p=0.389). No trend of BMI was found along latitude (Figure 1), independently of the hemisphere. At the same time, BMI was not clearly explained by the development of dewlap and hump, latitude and Köppen-Geiger data (Figure 2).

BMI tended to increase with body weight (r_s=0.655, p<0.0001) (Figure 3). This regression was not isometrical (F=70.44, p<0.0001), with the slope being under 0 (a=0.808). The linear model seemed adequate, as testing of all polynomial modes (curves) up to the fifth order showed that the AIC for the first order fitted the data the best (AIC=10.739). The BMI vs body weight regressions were not different between large-humped and medium- or fine-humped breeds (F=1.138, p<0.05).

Heavier breeds were distributed identically to lighter breeds along latitude degrees (Figure 4). Therefore, the ability to support stressful environments seemed to be identical independently of the BMI**.**

Discussion

Bergmann's rule is an ecogeographical principle that states that within a broadly distributed taxonomic clade, populations and species of a larger size are found in colder environments, and those of a smaller size are found in warmer regions. Although originally formulated in terms of species within a genus, it has often been recast in terms of populations within a species. If reduction in relative surface area is indeed an adaptation to conserve heat, then a breed should increase in size from south to north. However, as Bergmann's rule has been demonstrated to have no basis in Zebu breeds (as no correlations were found between body size and latitude or environmental data), the 'thermal' interpretation of Bergmann's rule can be questioned. Moreover, larger breeds show a tendency towards a proportionately lower wither height. It must be recognised that an evident skewness when studying Zebus is that they include a disproportionately large number of extreme-climate populations, which could be a climate-biased artifact (demonstrated by a wide range of heights and weights). Dewlap and hump are either not enough to be mere adaptations to environment.

In conclusion, it could be suggested that the BMI of Zebus is correlated with other factors, such as altitude of the original area (Bergmann's rule was only published in German; therefore, the majority of researchers have relied on a single translation by Mayr. Bergmann's rule can be interpreted as that individuals of a species/clade at higher latitudes will be larger than those at lower ones, but also will be conditioned by altitudes, drought resistance, type, size and quality of food, and productive purposes (milk, draught…). In fact, considering the influence of biotic factors on body size in addition to abiotic factors such as temperature and precipitation has been done by some authors for different wild species, e.g., Chuan-kai, (2010) for temperature and precipitation and Kamilar, (2012) for thermoregulation, resource seasonality/scarcity, resource quality, and primary productivity, so ecological aspects must be considered when assessing Bergmann's rule. Artificial selection pressure also has to be considered, as we are dealing with domestic species, so the natural environment is not the only selective process.

The debate over which factor determines body size in Zebu cannot be settled with the variables considered in this research. One approach for future research would be to focus on local environmental factors, for instance, of particular importance is the fact that the distribution includes extreme dry areas, where every additional millimetre of rain makes a large difference, and to fix the relative effect of each factor could represent its effect on body size. An ultimate fact that must be taken into account is that some of the breeds may have been affected by selective 'modernisation', so some traits, body weight and wither height in particular, could have been strongly affected by the changes associated with selective improvement processes. In conclusion, the validity of Bergmann's rule for Zebu breeds seems to be highly idiosyncratic and partially dependent on each study design in question.

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