REVISTA DE CIENCIAS

ZUBÍA

42

IER
Instituto de Estudios Riojanos

ZUBÍA
REVISTA DE CIENCIAS.
Nº 42 (2024). Logroño (España).
P. 1-429, ISSN: 0213-4306

Zubía 42 209-214 Logroño 2024

APPLICATION OF MULTIVARIATE MORPHOMETRY TO ACCESS THE MORPHOLOGICAL VARIABILITY IN SAUROPOD TEETH

MÓNICA RIBEIRO[1,2*], SOFIA PEREIRA[1,2], PEDRO MOCHO[3,4,5]

ABSTRACT

This study aims to explore and characterize the morphological variability in sauropod teeth through multivariate statistics using Principal Component Analysis (PCA), Discriminant Function Analysis (DFA) and Cluster analysis, and access the potential of these methods to classify them. We analyzed a sample of spoon-shaped, spatula-shaped, and compressed cone-chisel-shaped teeth. The apicobasal apex length, the total length of the distal apex margin, and the total length of the mesial apex margin are identified by PCAs as the most important variables affecting morphological variability. The DFAs enabled to differentiate the morphospaces occupation of the main sauropod groups analyzed (e.g., Camarasauridae, Turiasauria). Cluster analysis allowed differentiate teeth with low from moderate to high SI. The morphospaces of spoon-shaped, spatula-shaped, and compressed cone-chisel-shaped teeth were differentiated, some showing a slight overlap. The tooth wear seems to influence the obtained results, and teeth with moderate or strong wear should be excluded in future analyses.

Keywords: Multivariate statistics, Morphometric variables, Systematics, Dinosaurs, Sauropods.

1. INTRODUCTION

The fossil record of dinosaurian teeth is particularly abundant, either by their more resistant mineralogical composition or the continuous replace-

1. Departamento de Ciências da Terra, Universidade de Coimbra, Rua Sílvio Lima, Coimbra, Portugal. *mrelvas95@gmail.com
2. Centro de Geociências, Universidade de Coimbra, Coimbra, Portugal.
3. Instituto Dom Luiz, Universidade de Lisboa, Lisboa, Portugal.
4. Departamento de Geologia, Faculdade de Ciências da Universidade de Lisboa. Lisboa, Portugal.
5. Grupo de Biología Evolutiva, Facultad de Ciencias, Universidad Nacional de Educación a Distancia, Las Rozas de Madrid, Spain.

ment of these elements during the life of an individual. These two factors contribute decisively to the existence of numerous occurrences, especially in isolated form. This, together with the absence of diagnostic characters and their conservative morphology, especially for sauropod teeth, difficult tooth classification at lower taxonomic level (e.g., genus) using classical methods, namely description and anatomical comparison (e.g. Smith *et al.* 2005, Mocho *et al.* 2016).

This study thus aims to explore and characterize the morphological variability in sauropod teeth. This research is one of the first attempts to apply multivariate statistics to sauropod dinosaurian teeth, testing the effectiveness of this tool for differentiating morphospaces and evaluating its potential for classifying isolated specimens, especially for teeth with spoon-, spatula-, and compressed cone-chisel-shaped morphologies.

2. METHODOLOGY

A morphometric database was created based on published and unpublished sauropod teeth to analyze the tooth morphological variability in sauropods and explore their morphospaces at different taxonomic levels through statistical analyses. The teeth were measured using existing bibliography, as well as photographic records of specimens deposited in museums. Only spoon-, spatula- and compressed cone-chisel-shaped teeth were considered in this study. The pencil-shaped teeth were not included due to the difficulty of measuring some morphometric variables, especially the ones related to the apex morphology. In total, our database contains 466 specimens. The taxa selected for this analysis cover a wide range of forms referred to non-diplodocoid and non-titanosaurian sauropods, including members of Camarasauridae, Turiasauria, Mamenchisauridae, Brachiosauridae and Somphospondyli (including Euhelopodidae).

Thirteen morphometric variables were defined (partially following the protocols defined by Smith *et al.* 2005 and Hendrickx *et al.* 2015). These were established based on the existing sample, as well as the morphometric variables historically considered as relevant in the description of sauropod dental morphology and with possible taxonomic value. The variables are: (1) crown apicobasal length; (2) maximum mesiodistal length of the crown; (3) mesiodistal length at the base of the crown; (4) mesiodistal length at the base of the apex; (5) apicobasal length at the base of the crown; (6) apicobasal length of the apex; (7) total length of the distal margin of the apex; (8) total length of the mesial margin of the apex; (9) labiolingual length at the base of the crown; (10) angle between the line joining the apex and the mesiobasal margin of the crown in relation to the horizontal; (11) number of denticles on the mesial carina; (12) number of denticles on the distal carina; and (13) Slenderness Index (ratio between the crown apicobasal length, and the maximum mesiodistal crown length defined, following Upchurch 1998). Most of the defined morphometric variables were measured in labial view, and the images were measured in *ImageJ* (Rasband (1997-2015)). Tooth

Zubía | *núm. 42 (2024), pp. 209-214*
ISSN 0213-4306

wear was classified as: absent or low, moderate, and high, following Mocho *et al.* (2016); and the teeth with moderate and high wear were removed after our first run of analyses.

To analyze the morphology of sauropod teeth, different multivariate morphometric analyses were used: PCA, DFA and Cluster analysis. These multivariate statistical analyses were carried out using the software Past 4.12b (Hammer *et al.* 2001).

3. RESULTS AND DISCUSSION

In the PCA, DFA and Cluster analysis, three scenarios were established, S1, S2 and S3. In S1 we used the complete dataset, in S2 and S3, we obtained a reduced dataset by removing specimens with six or more missing variables and specimens with moderate and high wear. For DFA, camarasaurid and turiasaurian teeth were grouped as Camarasauridae and Turiasauria; and in S3, they were grouped at species level.

3.1. Principal Component Analysis (PCA)

In S1, the sum of the variance of the PC1 and PC2 is 83,88% and the biplot shows that the variable with the highest positive contribution is the apicobasal length at the base of crown. In S2, the sum of the variance of the PC1 and PC2 is 85,9% and the biplot shows that variables with the highest positive contribution are the apicobasal length of the apex, the total length of the distal margin of the apex and the total length of the mesial margin of the apex. Between S1 and S2, the removal of worn teeth and teeth with more than six missing variables induces a slight increase in variance in the sum of the first two components. In S1, the variability is partially explained by the height of the tooth, while in S2 by the morphology of the apex.

3.2. Discriminant Function Analysis (DFA)

In S1, the DFA correctly classified 56,22%. Considering S2 (Figure 1), 67,92% of the specimens were correctly classified, with the main groups being correctly classified: Turiasauria 91,11%, Brachiosauridae 64,29%, Mamenchisauridae 54,05%, Somphospondyli 70,83% and Camarasauridae 68,87%.

In S3, the DFA correctly classified 57,34% of the samples. Some camarasaurid and turiasaurian species achieved high percentage of correct classification (e.g. *Losillasaurus giganteus* 83,33%, *Turiasaurus riodevensis* 60%, *Moabosaurus utahensis* 100%, *Camarasaurus* sp. (SMA 0002) 100%, *Camarasaurus supremus* 100%). Between S1 and S2 there was an increase of more than 10% in correctly classified teeth, which indicates that removing heavily worn teeth and teeth with more than six missing variables improves classification capacity. Incorrect classification for some of these may be associated with the presence of strong morphological variability throughout the row of teeth (e.g. *Camarasaurus* ssp.). The morphospace area occupied by

Camarasauridae and Turiasauria (low SI, spatulate- and spoon-shaped) differ from the area occupied by Brachiosauridae and Somphospondyli (high SI, compressed cone-chisel-shaped) and Mamenchisauridae (moderate SI, spatula-shaped). In S3, the area of the morphospace occupied by the different genera of Turiasauria overlap significantly, except for Early Cretaceous genera of North America. This might suggest that the tooth morphology of these two North American turiasaurs diverged from the Late Jurassic turiasaurs. The low number of specimens for some groups might affected the obtained results. The morphospaces of the different species of *Camarasaurus* overlap and it is not possible to observe relevant patterns.

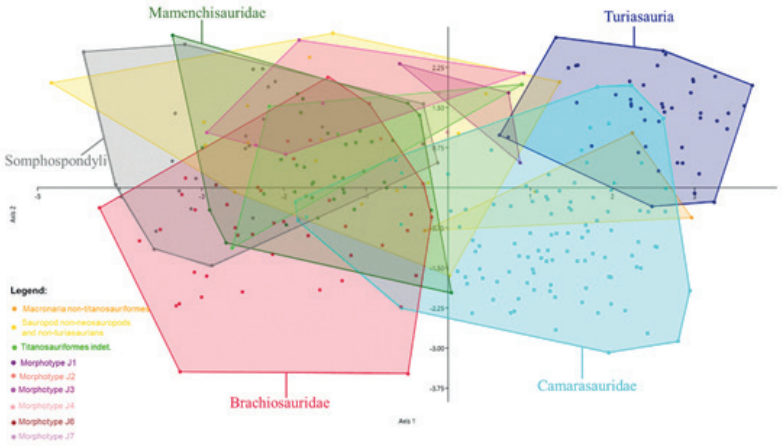

Figure 1 – DFA scenario 2.

3.3. Cluster analysis

Two main groups stand out in the Cluster analyses, a group represented by specimens of Somphospondyli, Brachiosauridae and Mamenchisauridae and the group represented by specimens of Turiasauria and Camarasauridae. The first is characterized by compressed cone-chisel-shaped teeth with high SI and spatula-shaped with moderate to high SI, the second one is characterized by spoon-shaped and spatula-shaped teeth with low SI values.

4. CONCLUSION

Morphological variability is significantly related to morphometric variables associated with the morphology of the apex. The analyses allow to differentiate the main types of morphologies considered in this study and to classify a significant number of teeth. The inclusion of moderately and highly worn teeth in the dataset seems to affect the obtained results. Multivariate analyses have some effectiveness and success in classifying sauropod teeth at supra-generic level, and should be considered as a useful tool in the classification of isolated specimens.

Zubía | *núm. 42 (2024), pp. 209-214*
ISSN 0213-4306

REFERENCES

Hammer, Ø., Harper, D. A. T., y Ryan, P. D. (2001). Past: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica* 4(1).

Hendrickx, C., Mateus, O., y Araújo, R. (2015). The dentition of megalosaurid theropods. *Acta Palaeontologica Polonica* 60(3), 627-642.

Mocho, P., Royo-Torres, R., Malafaia, E., Escaso, F., Silva, B., y Ortega, F. (2016). Turiasauria-like teeth from the Upper Jurassic of the Lusitanian Basin, Portugal. *Historical Biology* 28(7), 861–880.

Rasband, W.S. (1997-2015) ImageJ. National Institutes of Health, Bethesda, Maryland, USA. http://imagej.nih.gov/ij

Smith, J. B., Vann, D. R., y Dodson, P. (2005). Dental Morphology and Variation in Theropod Dinosaurs: Implications for Taxonomic Identification of Isolated Teeth. *The Anatomical Record - Part A Discoveries in Molecular, Cellular, and Evolutionary Biology* 285(2), 699-736.

Upchurch, P. (1998). The phylogenetic relationships of sauropod dinosaurs. *Zoological Journal of the Linnean Society* 124(1), 43–103.

ZUBÍA

42

9 770213 430000 00042

IER Instituto de Estudios Riojanos