

The importance of keywords in Molecular Paleontology: exploring the Word Cloud resource for trends representation

A importância das palavras-chave em Paleontologia Molecular: explorando o recurso Nuvem de Palavras para representação de tendências

La importancia de las palabras clave en Paleontología Molecular: explorando el recurso Nube de Palabras para la representación de tendencias

Received: 11/12/2022 | Revised: 11/20/2022 | Accepted: 11/21/2022 | Published: 11/28/2022

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Abstract

A lot can be at stake, depending on the choice of words used to describe an emerging science, because terminology affects the way knowledge is developed. Molecular Paleontology is one such area where a wide variety of terms and expressions are being used to refer to their research approaches and objects of study. Thus, this study sought to investigate the frequency of use of recurrent keywords in Molecular Paleontology papers, in order to provide a collection of potential terms that may be useful to guide the choice of descriptors. This is a research carried out with a qualitative-quantitative approach to data. The sample consisted of secondary data, from 4 literature review works, which previously surveyed the papers that claimed findings of paleomolecular traces in different taxonomic groups of vertebrates. Data collection took place through the individual search for keywords and the simple count of their occurrence in each of the analyzed papers. For content analysis, the Word Cloud (WC) graphic method was used from the Infogram platform. In general, 263 keywords were obtained from a total of 45 reviewed papers. Of these, 148 terms were retrieved from 24 papers on non-avian dinosaurs, 79 terms from 14 papers on Cenozoic mammals, 26 terms from 5 papers on Mesozoic birds, and 10 terms from 2 papers on the Pterosauria clade and other Mesozoic marine reptiles. It was observed that the mapping carried out with the support of the WC resource is useful for suggesting terms that can be used as keywords. Thus, this research made it possible, in a preliminary way, to identify terminological and research trends in the field of Molecular Paleontology.

Keywords: Text mining; Information and communication technologies; Descriptors; Information retrieval; Research trends in geosciences.

Resumo

Muita coisa pode estar em jogo, a depender da escolha das palavras usadas para descrever uma ciência emergente, porque a terminologia afeta a forma como o conhecimento é desenvolvido. A Paleontologia Molecular é uma dessas áreas em que uma grande variedade de termos e expressões está sendo usada para referir-se às suas abordagens de pesquisa e objetos de estudo. Assim, buscou-se, neste estudo, investigar a frequência de uso de palavras-chave recorrentes em *papers* da área de Paleontologia Molecular, a fim de fornecer uma coleção de termos potenciais que possam ser úteis para orientar a escolha de descritores. Trata-se de uma pesquisa realizada com abordagem quali-quantitativa de dados. A amostra foi composta por dados secundários, provenientes de 4 trabalhos de revisão de literatura, que levantaram previamente os *papers* que reivindicaram achados de vestígios paleomoleculares em grupos taxonômicos distintos de vertebrados. A coleta de dados se deu por meio da busca individual de palavras-chave e da contagem simples de sua ocorrência em cada um dos *papers* analisados. Para análise do conteúdo, utilizou-se o

método gráfico Nuvem de Palavras (NP) a partir da plataforma Infogram. Foram obtidas, no geral, 263 palavras-chave presentes em um total de 45 *papers* revisados. Dessas, 148 termos foram recuperados de 24 *papers* sobre dinossauros não avianos, 79 termos de 14 *papers* sobre mamíferos cenozoicos, 26 termos de 5 *papers* sobre aves mesozoicas e 10 termos de 2 *papers* sobre o clado Pterosauria e outros répteis marinhos mesozoicos. Observou-se que o mapeamento realizado com o apoio do recurso NP é útil para sugestão de termos que podem vir a ser utilizados como palavras-chave. Assim, esta pesquisa possibilitou, de forma preliminar, a identificação de tendências terminológicas e de pesquisa no campo da Paleontologia Molecular.

Palavras-chave: Mineração de texto; Tecnologias de informação e comunicação; Descritores; Recuperação da informação; Tendências de pesquisa em geociências.

Resumen

Es mucho lo que puede estar en juego, dependiendo de las palabras que se elijan para describir una ciencia emergente, porque la terminología afecta la forma en que se desarrolla el conocimiento. La Paleontología Molecular es una de esas áreas en las que se utiliza una amplia variedad de términos y expresiones para referirse a sus enfoques de investigación y objetos de estudio. Por lo tanto, este estudio buscó investigar la frecuencia de uso de palabras clave recurrentes en los artículos de Paleontología Molecular, con el fin de proporcionar una colección de términos potenciales que pueden ser útiles para orientar la elección de los descriptores. Se trata de una investigación realizada con un enfoque cualitativo-cuantitativo de datos. La muestra consistió en datos secundarios, de 4 trabajos de revisión de literatura, que previamente revisaron los artículos que afirmaban hallazgos de rastros paleomoleculares en diferentes grupos taxonómicos de vertebrados. La recolección de datos ocurrió a través de la búsqueda individual de palabras clave y el conteo simple de su ocurrencia en cada uno de los artículos analizados. Para el análisis de contenido se utilizó el método gráfico Nube de Palabras (NP) desde la plataforma Infogram. En general, se obtuvieron 263 palabras clave de un total de 45 artículos revisados. De estos, 148 términos se recuperaron de 24 artículos sobre dinosaurios no avianos, 79 términos de 14 artículos sobre mamíferos del Cenozoico, 26 términos de 5 artículos sobre aves del Mesozoico y 10 términos de 2 artículos sobre el clado Pterosauria y otros reptiles marinos del Mesozoico. Se observó que el mapeo realizado con el apoyo del recurso NP es útil para sugerir términos que pueden ser utilizados como palabras clave. Así, esta investigación permitió, de manera preliminar, identificar tendencias terminológicas y de investigación en el campo de la Paleontología Molecular.

Palabras clave: Minería de textos; Tecnologías de la información y la comunicación; Descriptores; Recuperación de información; Tendencias de investigación en geociencias.

1. Introduction

A lot can be at stake, depending on the choice of words used to describe an emerging science, because terminology affects the way knowledge is developed. (Eitzel et al., 2017). Currently, a wide variety of terms and expressions are being used to refer to Molecular Paleontology, its approaches, and objects of study.

Molecular Paleontology is an interdisciplinary field of study dedicated to the investigation of original complex organic molecules, associated with deep-time fossils, using innovative ultrastructural detection techniques in order to provide important information for the understanding of biology and evolution of organisms and the process of fossilization at the molecular level (Schweitzer, 2003, 2004; Bailleul, O'Connor & Schweitzer, 2019; Pan, 2020; Voegele et al., 2022).

The analysis of keywords used in paleomolecular investigations and published in high-impact journals is important. A keyword is a word or expression that summarizes the main themes of a text (Tripathi et al., 2018). In academia and in the scientific publication process, there are several reasons for the need to choose appropriate keywords, the main one being to describe and categorize a research, aiming at submitting manuscripts to a scientific journal. They also help as a tool for indexing and retrieving relevant articles in important academic databases, even influencing the reader's interest and the number of downloads and citations of articles (Uddin & Khan, 2016; Garcia, et al., 2019).

However, some researchers in geosciences have not paid much attention to the keywords they use to describe their research: the terms are often too broad or are purpose-limiting, or they lack specificity (Garcia, et al., 2019). When area-specific terminology is misused, its resulting interpretations can become inaccurate (Pourret, et al., 2020). However, if due rigor is applied to the selection of keywords, it becomes possible to identify trends in fields of interest that have not been previously considered (Tripathi et al., 2018).

Studies suggest that carrying out previous searches on other good works that address a similar topic is an effective strategy, which allows the author to observe which terms are considered most efficient to represent their work well (Garcia, et al., 2019). An optimization strategy, which has recently been applied to analyze previous and ongoing publications in geosciences, is *Word Cloud* (WC) (Hohemberger et al., 2021; Silva et al., 2021; Restrepo-Arango & Cárdenas-Rozo, 2022), a powerful technique that makes it possible to link and study a set of terms arranged visually, to explain and illustrate the content of a document or set of textual data (Santana & Salcedo, 2022).

Through this technique, a cloud of *tags* is generated, in the form of a figure or image, which represents the degree of frequency in which words appear in a text, enabling the reader to become familiar with the thematic content and identify the most significant terms in a matter of seconds, without the need to read the entire document (Kalmukov, 2021).

Considering the growing relevance of the study of Molecular Paleontology, in the last two decades (Alves & Machado, 2020; Alves, et al., 2021), and the realization of the importance of the study of keywords in scientific publications, it was noticed that there are no studies carried out so far to verify the terminology used in the paleomolecular research area. Therefore, this study sought to investigate the frequency of use of recurring keywords in papers in the field of Molecular Paleontology, in order to provide a collection of potential terms that may be useful to guide the choice of descriptors.

2. Methodology

This is research carried out with a qualitative-quantitative approach to data. The use of a *mixed method* is characterized by allowing, in addition to quantitative data, from the use of descriptive statistics tools, the inclusion from the qualitative perspective of investigation to the analysis of data of the type *descriptors* (Ramírez-Montoya et al., 2021).

The sample consisted of secondary data from 4 literature review papers, which previously raised the papers that claimed findings of traces of paleo-molecules in distinct taxonomic groups of vertebrates.

The first study surveyed papers (n=52) for findings from the non-avian dinosaur group, published in the period 1966-2022 (Alves & Machado, 2020). The second study reviewed papers (n=35) related to Cenozoic mammals (Mammalia clade), published between 1962 and 2021 (Gomes, et al., 2022). The third study reviewed papers (n=12) on Mesozoic birds published in the period 2000-2020 (Alves & Machado, 2021a). The fourth study reviewed papers (n=11) on the Pterosauria clade and Mesozoic marine reptiles published between 2000 and 2020 (Alves & Machado, 2021b).

Data collection took place through the identification and extraction of keywords, when present, directly from the PDF file of each of the papers, which made up the 4 literature review papers mentioned above, and the simple count of its occurrence. In this study, *keywords*, *terms*, and *descriptors* are used interchangeably as synonyms. The collected data (research corpus) were transferred to a spreadsheet in the Microsoft Excel program, being organized in the form of a table (see Table 1), divided into four distinct sections by taxonomic groups: 1) non-avian dinosaurs, 2) Cenozoic mammals, 3) Mesozoic and 4) clade Pterosauria and Mesozoic marine reptiles. For content analysis, the *Word Cloud* graphic method was used from the Infogram® online platform (<https://infogram.com/>), which allows the visualization of the analyzed keywords in a size proportional to their frequency of occurrence in the research (Silva et al., 2021).

Table 1 - Research corpus consisting of articles selected from 4 literature review papers by taxonomic groups of vertebrates (n=45).

NON-AVIAN DINOSAURS											
Author	Journal	Keywords									
Ostrom et al (1990)	Organic Geochemistry	Indigeneity	Amino acids	Stable isotope abundance	Paleoecology	Food webs	Dinosaur	Judith River Formation			
Paylicki (1995)	Folia Histochemica et Cytobiologica	DNA	Bone	Osteocyte	Histochemistry	SEM	Dinosaur				
Gurley et al. (1991)	Journal of Protein Chemistry	Fossil proteins	Dinosaur proteins	Seismosaurus	Biomarkers	Fossil collagen	Fossil amino acids				
Pawlicki et al. (1998)	Annals of Anatomy	Fossil bone	Blood vessels	Red blood vessels	Scanning electron microscopy	X-ray microanalysis					
Schweitzer & Horner (1999)	Annales de Paléontologie	Dinosaur	Tyrannosaurus	Intravascular microstructures	Organic conservation						
Embery et al. (2000)	Connective Tissue Research	Dinosaurs bone	Non-collagenous protein	Proteoglycans	Phosphoproteins						
Schweitzer et al. (2005)	Proceedings of the Royal Society B: Biological Sciences	Palaeoimmunology	Dinosaur	Immunohistochemistry	Eggshell	Embryo	Histology				
Schweitzer et al. (2007)	Proceedings of the Royal Society B: Biological Sciences	Dinosaur	Soft tissues	Red blood cells	Osteocytes	Vessels	Preservation				
Manning et al. (2009)	Proceedings of the Royal Society B: Biological Sciences	Hadrosaur	Hell Creek	Soft tissue							
Lingham-Soliar & Plodowski (2010)	Naturwissenschaften	Psittacosaurus	Epidermal scales	Skin color	Skeletal pigmentation	Pigment diffusion	Crypsis				
Zylberberg & Laurin (2011)	Comptes Rendus Palevol	Collagen	Fossil bone	Vertebrates	TEM	Palaeohistology					
Schweitzer et al. (2013)	Bone	Osteocytes	Fossil	Dinosaur	T. rex	Ancient proteins	Ancient DNA				
Armitage & Anderson (2013)	Acta Histochemica	Osteocytes	Fossil	Dinosaur	Triceratops	Horn	Ancient soft tissue				
Cleland et al. (2015)	Journal of Proteome Research	Bachylophosaurus canadensis	Blood vessels	Dinosaur	Cytoskeleton	Actin	Tubulin	Myosin	Tropomyosin		
Vinther et al. (2016)	Current Biology	Defensive coloration	Countershading	Paleocolor	Jehol biota	Yixian Formation	Paleoenvironment	Behavioral ecology	Taphonomy	Preservation	
Moyer et al. (2016)	Proceedings of the Royal Society B: Biological Sciences	Beta-keratin	Scanning electron microscopy energy dispersive X-ray spectroscopy	Transmission electron microscopy	Immunofluorescence	Claw sheath	Soft-tissue preservation	Lagerstätte			

Wiemann et al. (2017)	PeerJ	Macroolithus yaotunensis	Dinosaur paternal care	Protoporphyrin	Biliverdin	Eggshell taphonomy	Reproduction	Egg color evolution			
Brown et al. (2017)	Current Biology	Dinosauria	Ankylosauria	Nodosauridae	Cretaceous	Alberta	Countershading	Coloration	Pigment	Pheomelanin	Predation
Arbour & Evans (2017)	Royal Society Open Science	Ornithischia	Thyreophora	Ankylosauria	Ankylosaurinae	Cretaceous	Campanian				
Schroeter et al. (2017)	Journal of Proteome Research	Paleoproteomics	Collagen I	Bone	Brachylophosaurus canadensis	Phylogenetics	Archosauria				
Ullman et al. (2019)	Cretaceous Research	Soft tissues	Molecular paleontology	Bone	Cretaceous	Osteocytes	Diagenesis				
Bailleul et al. (2020)	National Science Review	Cartilage	Dinosaur	Nuclei	Chromosomes	Collagen II	DNA markers				
Fabbri et al. (2020)	Palaeontology	Skin	Taphonomy	Hadrosaur	Melanin	Soft tissue					
van der Reest & Currie (2020)	Cretaceous Research	Dinosaur	Preservation	Fossilization	Dinosaur Park Formation	Vessels	Collagen	Osteocytes	Alberta		
PTEROSAURIA AND MESOZOIC MARINE REPTILES											
Author	Journal	Keywords									
Surmik et al. (2017)	Naturwissenschaften	Intraosseus	Physiology	Fossilized soft tissues	Nothosaurus	Middle Triassic					
Prado et al. (2019)		Melanin	Melanosomes	Pterosaurs	Palaeocolour	Crato Formation					
MESOZOIC BIRDS											
Author	Journal	Keywords									
Vinther et al. (2010)	Biology letters	Feather preservation	Melanosome	Feather colour	Bird						
Pan et al. (2016)	Proceedings of the National Academy of Sciences of the United States of America	Keratinous protein	Immunogold	ChemiSTEM	Melanosome	Early Cretaceous					
Peteya et al. (2016)	Palaeontology	Enantiornithes	Bird	Sexual selection	Melanosome	Feather colour	Bohaiornithidae				
O'Reilly et al. (2017)	Proceedings of the Royal Society B: Biological Sciences	Soft tissue preservation	Messel	Molecular fossils	Uropygial gland	Fossil bird	Eocene				

Pan et al. (2019)	Proceedings of the National Academy of Sciences of the United States of America	Feather evolution	Keratin expression	Fossil-feather ultrastructure	Dinosaur-bird transition	Biomechanical properties					
CENOZOIC MAMMALS											
Author	Journal	Keywords									
Borja et al. (1997)	American Journal of Physical Anthropology	VM-0	Fossil proteins	ELISA	RIA	Monoclonal antibodies	Venta Micena				
Kuch et al. (2002)	Molecular Ecology	Ancient DNA	Atacama Desert	Climate change	Fossil middens	Phyllotis	Phylogeography				
Schweitzer et al. (2002)	Journal of Molecular Evolution	Fossil	Mammoth	Ancient proteins	Molecular preservation	Mass spectrometry					
Schweitzer, Wittmeyer & Horner (2007)	Proceedings of the Royal Society B: Biological Sciences	Dinosaur	Soft tissues	Red blood cells	Osteocytes	Vessels	Preservation				
Yuan et al. (2014)	Science China Earth Sciences	Coelodonta antiquitatis	Cytochrome b gene	Divergence time	Phylogeny						
Buckley (2015)	Proceedings of the Royal Society B: Biological Sciences	Ancient collagen	Macrauchenia	Toxodon	South American ungulates						
Colleary et al. (2015)	Proceedings of the National Academy of Sciences of the United States of America	Paleocolor	Melanosome	Mass spectrometry	Diagenesis	Pigmentation					
Cadena (2016)	PeerJ	Osteocytes	Blood vessels	Eocene	Germany	Messel Pit	Turtles	Crocodiles	Mammals	Molecular paleontology	
Cleland et al. (2016)	Proceedings of the Royal Society B: Biological Sciences	Collagen I	Palaeoproteomics	Museum specimens	Nasal turbinates						
Welker et al. (2017)	PeerJ	Palaeoproteomics	Phylogenetics	Rhinocerotidae	Ancient proteins	Stephanorhinus					
Buckley, Lawless & Rybczynski (2019)	Journal of Proteomics	Paleoproteomics	Giant camels	Ancient collagen	Arctic camel	Paracamelus	Camelops	Ancient albumin			
Buckley et al. (2019)	Quaternary Science Reviews	Gomphotheres	Notiomastodon	Ancient proteins	Collagen						
Zúniga et al. (2019)	Revista Ciencia y Tecnología	Mammals	Soft tissues	Blood vessels	Osteocytes	Red blood cells	Cancellous bone	Preservation			
Schmidt-Schultz, Reich e Schultz (2021)	PalZ	Proteomics	Extracellular bone matrix proteins	Proboscidea	Pliocene	Konservat Lagerstätte	Willershausen	Germany			

Source: Authors (2022).

4. Discussion

When we seek to present a certain consensus on the terminology of the area, we are faced with two main obstacles. The first concerns the absence of the practice of inserting keywords in scientific articles published in important international journals (Hartley & Kostoff, 2003), which contrasts with the reality of Brazilian scientific journals in which the presence of this resource is mandatory (SciELO Brazil, 2020).

We also observed that the historical period of the beginning of the use of keywords in scientific articles in the area of Molecular Paleontology dates back to the year 1978 (Pawlicki, 1978), although the study did not comprise the sample of this work. This data is corroborated by previous studies that surveyed the state-of-the-art regarding the general use of descriptors by high-impact journals indexed in important scientific databases and found the 70s-80s as the time point of origin, but with widespread use from the 1990s onwards (Hartley & Kostoff, 2003; González et al., 2018).

The second issue is the presence of various non-standard descriptors that, in our understanding, are not suitable for representing the field of Molecular Paleontology or its objects of study. This phenomenon can be explained due to the interdisciplinary nature of the area as a research topic. Therefore, these results were expected, since our experience with teaching Molecular Paleontology allows us to infer that no single term has yet been standardized for all contexts.

Another worrying point concerns the frequent scientific inaccuracies in geosciences that remain unverified, being repeatedly republished by the geoscientific community (Pourret, et al., 2020). In the specific field of Molecular Paleontology, it is no different. For example, there is the routine use of the term *soft tissues* (Figure 1), which our results identified as being the third most frequently used descriptor in scientific publications in the area.

It is common to see researchers associating traces of original organic biocomponents with the generic expression known as *soft tissues*, without, however, correctly defining it (Armitage & Solliday, 2020; Li et al., 2021; Sander & Müller, 2021; Senter, 2021; Voegele et al., 2022).

This term can mislead the lay population, through channels of popular dissemination in the national territory, which use anecdotal expressions such as “soft tissue” (Gazeta, 2005), “fossil meat” and/or “dinosaurian 'steak'” (Lopes, 2009), as well as Brazilian researchers in the humanities who associate such findings with organic tissues “so well preserved” (Vasconcellos Júnior, 2011, p. 21) or those who, perhaps, associate it with the idea of decaying animal carcasses (Parry et al., 2018).

This misunderstanding becomes explicit when we note that some research in the area uses the term “soft tissues” in a context in which these structures, which were once “soft”, are already completely replaced by minerals during the process of fossil diagenesis, retaining no or little original biochemistry (Alves & Machado, 2020).

A suggestion to avoid this semantic confusion associated with misinterpretation and misuse of the term in popular communications in our country would be to replace it, in scientific communications, with *mineralized*, *partially mineralized*, or *nonmineralized soft tissues*, or even *original soft tissues*, the depending on the context (Alves & Machado, 2020).

However, when what is in focus are the objects of study of Molecular Paleontology, that is, the traces of different original organic materials endogenously preserved in deep-time fossils, we strongly recommend the use and standardization of the expression *nonmineralized biomaterials* (Alves & Machado, 2021c), as it represents better qualitatively and quantitatively the different findings in question.

The term preservation, in turn, pointed out in this study as being the fourth most frequently used descriptor in papers (Figure. 1), is understood by us as being vague and generalist. An alternative to this problem is the use of the keyword *exceptional preservation*, which, in our opinion, better characterizes the high degree of preservation of details of histological, cellular, and molecular characteristics associated with endogenous and remaining original biomaterials that have been recovered from the fossil record (Alves & Machado, 2020).

Although it was not possible to identify it in our data, another important point of discussion is related to the fact that, in recent years, there has been a tendency to standardize the use of the term *Molecular Paleontology* as a keyword to be used in articles published by experts in the field (Cadena, 2016; Bailleul, et al., 2019; Ullmann, et al., 2019; Ullmann et al., 2021; Schroeter et al., 2022; Tahoun et al., 2022; Ullmann, et al., 2022). Therefore, we suggest that such a term, found in these more recent publications, be considered when choosing the keywords to be inserted in the manuscripts.

5. Conclusion

We observed that the mapping carried out with the support of the WC resource is useful for suggesting terms that may be used as keywords. Thus, this research made it possible, in a preliminary way, to identify terminological and research trends in the field of Molecular Paleontology.

The limitations of our study are concentrated in the set of data extracted from review articles that surveyed papers published in a given period of time and from pre-established databases for carrying out the search for articles. In view of this, we suggest that future studies develop new search strategies for keywords in papers, based on the use of systematized criteria for researching descriptors, in national and international indexing databases, of a specific or multidisciplinary area, thus increasing the chances of drawing a more comprehensive panel of the reality of the universe of common terms in the area.

For greater rigor in the selection of descriptors, we recommend that researchers who venture into basic research or teaching Molecular Paleontology carefully choose the keywords to be assigned to their manuscript, always based on terms present in publications by already established specialists in the field and properly justifying their use in the text.

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