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DENTAL WEAR IN RUMINANTS: A SYSTEMATIC REVIEW

DESGASTE DENTÁRIO EM RUMINANTES: REVISÃO SISTEMÁTICA

DESGASTE DENTAL EN RUMIANTES: UNA REVISIÓN SISTEMÁTICA

https://doi.org/10.56238/sevened2025.036-078

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ABSTRACT
This article aims to discuss the main challenges and possibilities related to the continuing education of public school teachers, highlighting public policies, training practices and the importance of teacher engagement in this process. The methodology is a bibliographical research with a descriptive and exploratory approach. The results showed that the continuing education of public school teachers is a complex challenge, but essential for the construction of quality education. Ensuring adequate conditions so that teachers can participate in relevant training, connected to their reality, is a commitment that must be assumed by managers, public policies and society in general. In this sense, it was concluded that overcoming structural difficulties and valuing the professional development of teachers are necessary paths to transform public education into a more effective and humanizing learning space.

Keywords: Professional Development. Continuing Education. Public Policies.

RESUMO
O presente artigo tem por objetivo discutir os principais desafios e possibilidades relacionados à formação continuada de professores da rede pública, destacando políticas públicas, práticas formativas e a importância do engajamento docente nesse processo. A metodologia se trata de uma pesquisa bibliográfica de abordagem descritiva e exploratória. Os resultados mostraram que a formação continuada de professores da rede pública é um desafio complexo, mas fundamental para a construção de uma educação de qualidade. Garantir condições adequadas para que os professores possam participar de formações relevantes, conectadas à sua realidade, é um compromisso que deve ser assumido por gestores, políticas públicas e pela sociedade em geral. Nesse sentido, concluiu-se que superar as dificuldades estruturais e valorizar o desenvolvimento profissional dos professores são caminhos necessários para transformar a educação pública em um espaço de aprendizagem mais efetivo e humanizador.

Palavras-chave: Desenvolvimento Profissional. Formação Continuada. Políticas Públicas.

RESUMEN
El presente artículo tiene como objetivo discutir los principales desafíos y posibilidades relacionados con la formación continua de los docentes de la red pública, destacando las

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políticas públicas, las prácticas formativas y la importancia del compromiso docente en este proceso. La metodología consiste en una investigación bibliográfica con un enfoque descriptivo y exploratorio. Los resultados mostraron que la formación continua de los docentes de la red pública es un desafío complejo, pero fundamental para la construcción de una educación de calidad. Garantizar condiciones adecuadas para que los docentes puedan participar en formaciones relevantes y conectadas con su realidad es un compromiso que debe ser asumido por los gestores, las políticas públicas y la sociedad en general. En este sentido, se concluyó que superar las dificultades estructurales y valorar el desarrollo profesional de los docentes son caminos necesarios para transformar la educación pública en un espacio de aprendizaje más efectivo y humanizador.

Palabras clave: Desarrollo Profesional. Formación Continua. Políticas Públicas.

1 INTRODUCTION

Brazilian livestock plays a central role in the national economy and has a prominent position worldwide, especially in the breeding of ruminants for the production of food and raw materials such as meat, milk, wool and leather. In 2020, Brazil maintained the largest cattle herd in the world, with 217 million head, equivalent to 14.3% of the global total, followed by India with 190 million (EMBRAPA, 2021). In the same year, the country recorded a record production of 35.4 billion liters of bovine milk, while sheep and goat herds reached 20.6 million and 12.1 million head, respectively (IBGE, 2021).

The development of ruminant livestock in several countries, such as Brazil, occurs in a heterogeneous way in relation to form, being mostly empirical and extensive, with low technological levels and zootechnical results. Livestock farming is found in contrasting situations, employing from technological solutions to less sustainable ones (CAMPELLO, 2017). Goat farming, for example, in most farms does not express a significant productivity potential due to management problems, low labor and technological levels, nutritional and sanitary disorders, and high mortality rates in young and adult animals (CAMPELLO, 2017; AGOSTINHO, 2017).

Inherent to animal husbandry are its needs and difficulties, such as health problems that can compromise both production and animal welfare. It is possible to specifically observe animal oral health and relate it directly to these factors. Having their presence pre-dated, oral lesions are among the most common types of pathology reported in archaeological sets of animal bones (HOLMES *et al*., 2021).

Dental problems in goat farming are not part of the common concerns of rural producers and veterinarians. The reasons for this worrying lack are because these conditions are silent, chronic, not diagnosed by routine procedures and, apparently, in popular culture, have little impact on the profitability of the economy's activity, which is not real (CAMPELLO, 2019).

Abnormal chewing and rumination are sensitive indicators of many disorders, including infectious diseases. Although low productivity is the main reason for cattle slaughter, dental diseases are rarely considered as a possible explanation. Diseases such as periodontitis can be painful, leading to inefficient chewing with consequent loss of body condition and weight, increased susceptibility to diseases, animal suffering, and decreased productivity, with consequent economic impacts (BORSANELLI *et al.,* 2021).

As Campello (2017) puts it, periodontal diseases are among the most different forms of infection that affect both humans and animals. Excessive wear of the dental crown is a factor observed in both, being a lesion characterized by the irreversible loss of dental structure from the external surface, without bacterial involvement, which, by promoting dentin exposure, can develop tooth sensitivity. Associated with diseases such as periodontitis, they cause retraction and possible loss of teeth. Routine clinical examination of the oral cavity of cattle is essential for the disease to be diagnosed in a live animal (BORSANELLI *et al*., 2021). Since oral health is an initial factor in animal nutrition, its importance in growth, weight gain, productivity and quality of life is understood, identifying in this area a great potential for impact due to its relevance in economic and animal welfare issues. Thus, the central problem of this work is to understand what are the characteristics of tooth wear in ruminants and the main methods used in its analysis in the scientific literature. The objective of this work is to investigate the causes and patterns of this wear, as well as to review and discuss the methodologies used in its evaluation. To achieve the proposed objective, a Systematic Literature Review (RSL) was developed.

2 THEORETICAL FRAMEWORK

Between 2020 and 2021, Brazil approached the mark of 250 million head of cattle, sheep and goats, standing out worldwide as one of the major ruminant breeders. According to Borsanelli *et al*. (2021), diseases related to the dentition of these animals can be painful and generate inefficient chewing, with consequent losses of body condition and weight, and increased susceptibility to diseases. Even though the main reason for cattle slaughter is low productivity, dental disease is rarely considered a possible explanation.

In this way, the suffering caused by dental diseases affects the quality of life and animal welfare, contrary to what is inferred in the five animal freedoms, proposed by the Farm Animal Welfare Council of England in 1965, specifically in the third point, which guarantees freedom from pain, injury or disease.

From an economic point of view, in addition to the fundamental factor of decreased productivity, dental diseases are a population problem that even affect animals with higher added value and selected genetics, thus promoting significant economic impacts (CAMPELLO, 2017, BORSANELLI *et al*., 2021). Regarding the approach to quantifying tooth wear in ruminant animals, it is It is possible to find works in literature that they collaborate, directing steps of the proposed project, or even reiterating its relevance.

Wicpolt et al. (2022) point to reports of periodontitis cases around the world since the Neolithic period and, even so, when investigating cases of periodontitis in sheep in Pernambuco, they define the disease as little known by veterinarians and cattle breeders in the region, causing economic losses by interfering with the productive performance of the animals. As it is a disease diagnosed by visual inspection, the methodology used was the dental analysis of live animals and the capture of images for registration, in addition to microscopy of samples of slaughtered animals. The method of visual inspection by a professional in the area is satisfactory for purely qualitative analyses.

Comparing different diets in groups of goats, Hatt *et al*. (2019) concluded that tooth wear is more related to dietary characteristics — such as resources, content, and distribution of phytoliths — than to environmental factors, such as dust and sand, highlighting the need for more in-depth studies. The analysis of the abrasives present in the digestive tract was performed by computed tomography, a method considered reliable due to its technological precision, although it requires sedation and individual handling of the animals.

In a complementary way to Hatt et al. (2019), Ackermans et al. (2020) apply the same computed tomography methodology in sedated animals during 17 months of experiments, this time comparing the diet of each group to tooth wear factors such as tooth morphology and loss of volume of the dentition. Again, reliable quantitative results are generated by the method, but it is still possible to highlight its considerable cost of implementation, given the use of commercial computed tomography equipment.

Considering human tooth wear and the solutions employed, Machado *et al*. (2022) analyze the feasibility of using an intraoral scanner for monitoring erosive wear. Bovine teeth were used as specimens, submerged in acid and reevaluated every 24 hours. The results obtained are satisfactory with the perception of a loss of 0.5 mm per layer of analysis. The intraoral scanner is a portable tool, used in dental offices that has accuracy and reliability. However, its high cost is an unfavorable factor for its application.

From an interrelational perspective, the application of human technologies in animal contexts can offer effective and integrated solutions. The use of these technologies, combined with data analysis and artificial intelligence systems, enables the creation of informational bases that help in decision-making. Thus, the development of a tool capable of quantifying tooth wear in ruminants could favor research that relates this wear to diseases, variations in management, productivity (of meat and derivatives) and environmental factors, such as soil types and additives aimed at improving plant production.

At the same time that efficient production generates positive economic results, it contributes to the fulfillment of the UN Sustainable Development Goals for Brazil. Producing with smaller investments or in larger quantities at the same cost makes the product cheaper, attractive to the market and facilitates access to the final consumer. This perspective directly affects the 2030 Agenda on the topic of Zero Hunger and Sustainable Agriculture, reducing hunger and ensuring access to food (2.1), meeting nutritional needs (2.2) and increasing the productivity and income of small producers (2.3). Adequate consumption of inputs is related to Responsible Consumption and Production, efficiently using natural resources (12.2). Accessible technological development strengthens scientific capacities and generates tools to shift to more sustainable patterns of production and consumption (12.a).

The relevance of the theme presented and the lack of tools with the same objective present a substantial and innovative contribution of work to agribusiness, in addition to its concern with animal welfare, productivity and the possibility of technological development.

3 METHODOLOGY

3.1 THEME AND OBJECTIVE

The systematic literature review (RSL) described below follows the parameters proposed by Fabbri et al. (2016) and aims to investigate publications on tooth wear in ruminant animals, their contributions to the topic and to gather relevant information for the analysis and quantification of wear. Thus, the objective of the review is to define and rank the main causes of tooth wear in ruminants present in the literature, as a way to visualize the affected species, understand the generating factors and direct the collection of information and measurement of wear.

3.2 TOOL AND PROTOCOL CONSTRUCTION

For the management and elaboration of the review protocol, the systematic bibliography review management software *StArt (State of the Art through Systematic Review*), developed by the Software Engineering Research Laboratory of the Department of Computing of the Federal University of São Carlos (LaPES-UFSCar), was used. The steps proposed by the application itself were followed during the completion.

3.3 DATABASES, JOB PROFILES, PERIOD AND LANGUAGES.

The searches for papers were carried out in the *Scopus* and *Web of Science*

databases, due to their international coverage and academic reliability. The work profile was not limited to articles only, even though these were the only results obtained. Likewise, there was no restriction regarding the selection period, given the interest for the review in visualizing the emergence of the theme as outlined by the descriptors and its development over the years. As for the language, works were selected in English, due to its scope, and in Portuguese.

3.4 KEYWORDS AND BOOLEAN OPERATORS

For the initial survey of papers, keywords were defined that covered the widest possible range of results that did not distance themselves from the theme: *Ruminant; Dental Wear; Tooth Wear; Dental Volume; Tooth Volume; Dental Abrasion; Tooth Abrasion; Dental Attrition; Tooth Attritrion.*

At the same time, several combinations of Boolean operators were tested for each database and those that resulted in the largest number of articles presented were applied.

For the *Web of Science* database, the local filter *ALL FIELDS was applied,* using the expression: "*ruminant* AND (tooth wear OR tooth volume OR tooth abrasion OR tooth attrition OR dental wear OR dental volume OR dental abrasion OR dental attrition)"*

For the *Scopus* database, the local filter *ARTICLE TITLE, ABSTRACT, KEYWORDS was applied,* using the expression: "*ruminant* AND ("tooth wear" OR "tooth volume" OR "tooth abrasion" OR "tooth attrition" OR "dental wear" OR "dental volume" OR "dental abrasion" OR "dental attrition")"*

3.5 SELECTION STAGE AND CRITERIA

During the selection stage, criteria were defined for the use of the articles: 1 – Language: the work should be in English or Portuguese; 2 – Access: it was necessary to have access to the full text; 3 – The work should deal with ruminant animals; 4 – The work should address the issue of tooth wear in these animals;

In addition to the above criteria, duplicate jobs, those that appear in both databases, were removed. In this step, the titles, keywords and abstract of each article are read to make the selection.

3.6 EXTRACTION PHASE

For the data collection from the works selected for the extraction phase, questions

were elaborated about the approach to the theme in the work under analysis. Each following question could, depending on the application, accept one or several options as an answer. In question 1, we sought to list the motivation for the use of tooth wear at work. *Question 1 - Approach to the causes of wear (single option): A - Use wear to define other characteristics. (Age of fossil/animal and/or other) (wear and tear as a means); B - Analyzes/Explores causes for wear (wear as an end).*

In question 2, there was a survey of the possible causes or influences for the exhaustion, which were explored or only mentioned in the study. *Question 2 - Causes explored/cited (multiple options): A - Diet; B – Genetics; C – Occlusion; D – Others.*

The interest of question 3 is not only about which animals are treated, but mainly about meat animals and everyday human interaction, since most studies use tooth wear to classify fossils. The terms such as cattle, goats, sheep, and deer are not formal taxonomic categories, but rather common groups used to bring together animals with certain similar biological characteristics. All of the animals we are discussing belong to the Kingdom *Animalia*, Phylum *Chordata*, Class *Mammalia*, Order *Artiodactyla* (even-toed ungulate mammals such as oxen, deer, giraffes, etc.), and Suborder Ruminantia. *Question 3 - Taxonomy – Groups (Multiple Options): A – Cattle; B – Sheep; C – Goats; D – Cervids; E – Others.*

For question 4 we raised the methods of identification and classification of the wear that each work uses. What differentiates the "visual inspection" and "images" options is that in the former, the analyses are carried out directly on the copy, whether it is an original or a faithful replica. In the second, there is the need or choice of the author to capture and use the images for analysis. *Question 4 – Method of Identification (Multiple Options): A – Visual Inspection; B – Images; C – Others;*

Question 5 considers the relevance of the theme of tooth wear within the reviewed study and observes 2 situations: It only mentions wear, but does not quantify and/or qualify it methodologically; it applies some method of identification and/or quantification. *Question 5 – Methodological Approach (Single Option): – Only mentions wear and tear (does not quantify); B – Applies identification method.*

4 RESULTS AND DISCUSSIONS

Following the selection stages and criteria proposed in the methodology presented, with a survey carried out in October 2024, a total of 204 works were identified. 140 papers

were obtained for the *Web of Science database and* 64 papers for the *Scopus database.* With no restriction on the selection period, works were found between 1989 and 2024.

After the selection phase, we obtained 54 duplicate articles (26.47% of the total initial papers), 77 (37.74%) rejected articles and 73 (35.78%) accepted articles , moving forward to the data extraction phase.

The questions for the collection of data from the extraction phase would accept one or more answer options, to be defined by their application. Addressing the causes of wear in question 1, 60 studies used wear to define characteristics such as the age of the animal and the age of the fossil. The highest occurrences of the use of wear were to characterize diets of fossil species and in the validation of methods of identifying wear for species under study. On the other hand, in the second alternative of the first question, 13 studies specifically explored the causes of burnout. Thus, we see a distribution table of 82.2% of the articles using wear only as an instrument and the other 17.8% with a direct interest in investigating the causes of wear.

To survey the possible causes or factors that influence the exhaustion , question 2, of multiple options, considered from the interest of the work in the causes or only the allusion to these items. The diet of the animals appears in almost all of the 73 studies accepted for data collection, in 95.9% of them. Far from the references to diet, causes such as genetic factors (8.2%) and occlusion (6.8%) appear.

Among the other causes investigated for tooth wear, the geographic position of the herd and the season of the year of presence of the animals in the region of interest frequently appear, as many studies use the analysis of wear to reconstruct the customs of fossil species, or even the vegetation of the animals' time of life. In any case, geographical position and season of the year end up being indirectly related to diet, as they affect the supply of different food sources. In addition, rare studies were found that explored causes such as gender and oral infections.

Regarding the taxonomic groups present in the works, the use of wear analysis for the characterization of fossils and extinct species is reinforced, participating in the composition of the item *others* in a frequency of 34 works. The frequency of *deer*, appearing in 23 works out of the 73 under analysis. The search for beef animals and daily human interaction returned in ascending order: *sheep* with 10 results, *cattle* 14 and *goats* 16, referring to 13.7%, 19.2% and 21.9% respectively.

For the distribution of wear identification and classification methods, it is important to emphasize that one identification method does not necessarily cancel out another in the same work. The item *Visual Inspection* refers to analyses made directly on the copy or replica and has a frequency in 54.8% of the works. With a frequency close to the previous item of 58.9%, the *use of images* is the main characteristic among the methods for identifying and classifying wear. Regarding the *item others*, studies were found that used palpation, measurements with instruments such as calipers, or even chemically quantifying the loss of calcium ions in arches submerged in an acid medium. In all, the item others encompasses 27.4% of the works.

Finally, the number of studies that apply methods to identify/qualify/quantify wear. Of the 73 studies used for data collection, only 11 of them did not apply known methods. On the other hand, 62 used some method, whether this was the target of the research or not.

In summary, what the questions proposed by this systematic literature review were able to clarify is that most of the studies use the analysis of tooth wear as a tool, not being a direct concern and that its main use is in the characterization of extinct and fossil species, which indicates an opportunity for its use in beef animals, considering its economic and social relevance. Also, that diet is the fundamental factor for wear and tear and that the poignant results of wear and tear analyses are obtained through visual methods, with images or not.

Below, we will discuss the methods of identification and/or quantification of tooth wear in ruminants located during the performance of this RSL, in a historical and relevant organization.

4.1 METHODS OF WORKING WITH TOOTH WEAR

As a starting point identified by RSL, Walker and Teaford (1989) list studies on the use of electron microscopes in the analysis of mammalian tooth wear that emerged in the 1960s, and became common to surface analysis due to factors such as their resolution, non-destructive testing and ease of use. Still, the motivations for the development of wear studies present in the bibliography include the determination of the causes and rates of wear, jaw movement patterns, to find patterns of diet and animal behavior, and reconstruction of diets for paleontology.

Most of the wear analysis cases identified by Solounias *et al*. (1994) until then, he used the mandibular first molar for wear analysis. For measurements performed with a microscope, the authors made molds of the maxillary second molars. The molar wear rates were investigated based on tooth height values and growth lines (cementum-enamel junction)

seeking a better understanding of the wear patterns in several species. The conclusions obtained by the work at the time were relevant to the development of the theme, such as the significant variation between different species of ruminants, reflecting their diets and environmental adaptations, crucial impact of diet and its abrasiveness on wear, implication on the evolution of species in relation to their feeding strategies and *habitat*, and also the modeling of wear patterns in paleontology.

The induction of tooth wear is proposed by Kaiser *et al.* (2009) as coming from 2 different situations: the contact of the tooth with food, classified as abrasion and the contact of the tooth with another tooth, treated by attrition. Each of them can be more or less present according to the type of diet, considering the animal's food source. Also, these animals can be divided into navigators, grazers and intermediaries. The authors' objective is to compare the wear and tear in 19 species of animals in captivity with data from free-living animals. Their conclusions reinforce the interference of the abrasive diet in the wear and consequently in the longevity of the animals, where captivity presents greater hygiene in the supply of food and generates lower rates of tooth wear.

4.1.1 Mesowear Method

Developed by Solounias and Fortelious (2000), the mesowear method has been widely used since its presentation because it is relatively fast and reliable in the characterization of wear. The method is based on the development of the veneers of the occlusal surfaces of the posterior teeth, created by the friction of feeding, taking into account two variables: The occlusal relief (*Occlusal Relief*), which is classified as high or low according to the depth of the valley formed by the cusps; The *cusp shape (Cuspid Shape*) which includes three attributes according to the degree of development of the facets: sharp, rounded and flattened, (KAISER *et al.,* 2009).

In the application of the Mesowear method in their first proposal, Kaiser et al. (2009) perform visual inspection of the teeth, using a magnifying glass when appropriate. The first samples were photographed and plotted on paper, but once the standards were set to the satisfaction of the authors, the rest of the material was recorded through direct scoring.

Kaiser *et al.* (2010) analyzed 37 species of ruminants of the *families Bovidae*, *Giraffidae* and *Cervidae*, using the *Mesowear* method in the second and third molars. Dental molds were made and the images were digitally processed to quantify the angle of alignment of the enamel ridges. The method proved to be effective, but dependent on manual steps.

Ozaki *et al*. (2010) investigate the relationship between feeding habits, molar wear and life expectancy in wild sika deer populations. They observed that the wear of the M1 and M3 molars increases with grass consumption and decreases with rainfall. M3 showed a stronger correlation with life expectancy, as it maintained masticatory function for longer than M1.

Other approaches to the *Mesowear* method are found during RSL. Fraser *et al.* (2014), with the aim of improving the usefulness of the method, propose a new scoring system with additional categories of wear, analyzing both maxillary and mandibular posterior teeth. The new mesowear system expanded the categories from four to five. Following the traditional method, the cusps were classified according to relief (high or low) and occlusal shape (sharp, rounded, very rounded, rounded-flattened, or flattened-flat). Each combination received a score from 1 to 5, representing increasing degrees of wear. The average score per species was used in the analyses.

For each scoring system, the extent to which the upper and lower teeth mesowear scores were able to differentiate species with different types of diet was evaluated. The analyses were performed using the R software, using single-factor analysis of variance and Tukey's test for comparisons between groups, or the *Kruskal-Wallis* test when the data did not meet the criteria of the analysis of variance. The authors found that the new expanded mesowear scoring system improves the correct classification rates of the diet and has high repeatability. Also, that the mesowear scores of the mandibular teeth are consistently lower than those of the maxillary teeth. Although the new scoring method reduces the difference in wear between the upper and lower arches, this variation may be associated with anodontics, i.e., the fact that the posterior teeth of the mandible are narrower than their maxillary counterparts.

4.1.2 Microwear Method

Microwear is the quantification of microscopic marks, pits and scratches on the teeth, resulting from chewing different types of food. Pits form as a result of enamel-to-enamel contact; while scratches are formed by abrasive items such as phytoliths or earth being rubbed across the enamel surface. The texture of tooth microwear is used as a dietary indicator in paleoecology and vertebrate ecology. Unlike *mesowear*, which has characteristics of greater proportions and describes wear and tear throughout life, *Microwear* is determined only by the last meals, given that small changes in diet are enough to generate

microscopic marks. (FRASER *et al.* (2011), KAISER and BRINKMANN (2006), FRANCISCO *et al.* (2018)).

The analysis of the texture of tooth microwear observes parameters related to surface complexity, such as anisotropy and heterogeneity of enamel veneers at the micrometric scale. Other microwear analysis approaches are based on *ISO standard* roughness and texture parameters.

Francisco *et al*. (2018), using part of the parameters above, propose a new approach where, instead of a single parameter characterizing the entire surface, they perform surface samples generating 9 derived parameters with the aim of expanding the set of parameters. Samples were shaped, scanned and the identification of the most discriminative parameters was conducted through an automated procedure. In its initial form, the method incorporates the usual statistical tools, correlation analyses, and the necessary mathematical tests. The results indicate that a simplified version of the procedure is more efficient in identifying the desired discriminative parameters. And that the new method significantly improves the discriminatory power of tooth wear compared to previous approaches.

Due to its microscopic profile, microwear presents greater difficulties in visualization and analysis than mesowear.

A variety of measurement methods are available to collect topographic data from surfaces on a microscopic scale. These methods can be broadly grouped into contact and non-contact methods. Contact surface sensors inspect surfaces with a needle sensor (diamond or ruby tip), which moves over the surface mechanically under constant pressure. It converts the vertical and horizontal movements of the needle into an electrical signal. Non-contact methods are, for example, the laser tip scanning method, light refraction and diffraction methods, interferometric coherence, acoustic emission, and confocal scanning microscopy (KAISER and BRINKMANN, 2006). Next, we will discuss methods of topographic data collection and analysis present in the RSL.

4.1.3 Roughness

Worn tooth enamel resembles industrial technical surfaces, and can be described by surface roughness parameters defined by ISO standards, which statistically characterize the microtexture in different applications. (KAISER and BRINKMANN, 2006; SCHULZ *et al.*, 2010). The roughness parameters describe undulations and irregularities, characterizing vertical, horizontal and hybrid aspects of the topography. Together, they constitute an

effective statistical tool for analyzing the microtexture of surfaces. (KAISER and BRINKMANN, 2006).

Kaiser and Brinkmann (2006) investigated whether tooth microwear could be characterized by consolidated parameters of surface roughness, finding a strong similarity between industrial surfaces and microscars in molars of herbivores, based on molds of the arches of three bovine species. Using diamond-tipped profilometry on the maxillary second molar, 895 measurements confirmed that industrial roughness parameters describe the same scale as microwear, distinguish dietary groups, and quantify the balance between attrition and abrasion. These parameters reflect the influence of diet and establish a direct link between *the Microwear* and *Mesowear methods.*

Schulz *et al.* (2010), used texture parameters from ISO/DIS 25178-2 and Scale-Sensitive Fractal Analysis (SSFA) in 3D models by microscopy to quantify tooth microwear in herbivores. The authors evaluated the potential of these parameters as standardized tools and suggested that they reflect the relationship between abrasion and attrition, indicating lower bolus abrasiveness compared to ingested foods. Similarly, both Winkler *et al.* (2013) and Kubo and Fujita (2021), applied surface roughness parameter systems to describe microwear and perform paleontological analyses. The results demonstrated high efficacy and complementarity between the parameters, allowing quantitative and comparable analyses, reinforcing the potential of ISO standards as a standardized methodological basis for studies of tooth microwear.

4.1.4 Other Methods

Several other methods of identification and analysis of tooth wear were identified in the systematic review, although with a low frequency of occurrence when compared to the previous ones. Veiberg *et al.* (2007) applied three-dimensional scanning to analyze the relationship between growth and tooth wear in Svalbard reindeer, obtaining accurate 3D models of the first molar (M1) and ensuring high consistency and quality in the measurements. Similarly, Gailer and Kaiser (2014) used 3D structured light scanning to evaluate the masticatory efficacy in cattle, relating the functional shape of the postcanine teeth to the biomechanical properties and abrasiveness of the diet, with complete virtual reconstructions of the dental arches. Gailer *et al.* (2016) used 3D scanning to analyze tooth shape and function, concluding that masticatory efficiency does not depend on an ideal

morphology and emphasizing the accuracy of the method as a reliable tool to integrate different analytical approaches.

Ackermans *et al.* (2018) applied computed tomography to evaluate tooth wear in goats under diets of different abrasiveness, confirming the reliability of the method, but highlighting its practical limitations due to the need for sedation of the animals. Similarly, Karme *et al.* Wang et al. (2016) utilized CT scans in a mechanical chewing experiment and observed that tooth tissue loss varies even in similar microwear patterns, warning against direct inferences about diet or wear rate.

4.2 FINAL CONSIDERATIONS - SYSTEMATIC LITERATURE REVIEW

The information obtained from the RSL contributes to elucidate previously raised issues and to outline the academic interest in the theme. Even without time constraint in the filters, the extensive Boolean expressions used in the searches resulted in a limited number of works. Even so, only 73 studies on tooth wear in ruminants were included (accepted) in the review, which highlights the specificity of the topic. Several methods of identifying tooth wear were found in about 85% of the studies, most of which were based on visual inspection and image analysis.

The greater recognition of wear and tear as a tool for inferring diet, and not as an indicator of oral problems, is a portrait of its wide application in paleontological studies. This finding arouses interest in the application of tooth wear in animal groups that provide immediate return and direct impact, whether in economic, ecological or animal welfare terms. In this context, a low representation of beef animals was observed among the studies reviewed, with only 16 studies involving goats, 14 with cattle and 10 with sheep, reinforcing the opportunities for expanding this approach.

The methods identified in the literature for the analysis of tooth wear have evolved from simple visual inspections to the use of electron microscopy, three-dimensional scanning and computed tomography. Molar teeth are the main targets of investigation due to their masticatory function, varying between the first, second and third molars.

The mesowear method has been of great relevance in the development of research since its proposal, being continuously adapted to the needs of the authors and to the advancement of data collection technologies. The search for greater repeatability and reliability has led the microwear approach (*Microwear*) to integrate technological tools, such as three-dimensional scanning and industrial surface roughness (ISO) parameters. The

choice of the method of analysis should be aligned with the specific objectives of each study. *Mesowear* reflects the wear accumulated over months or years, analyzing the occlusal relief and the shape of the cusps, while *Microwear* shows changes that occur at shorter intervals, from hours to days, and gains robustness with the use of standardized tools (FRASER and THEODOR, (2011); STRANI et al. (2018)).

5 CONCLUSION

The systematic review gathered and analyzed the main approaches to tooth wear in ruminants, highlighting their scientific and productive importance. The results showed the predominance of visual inspection and image analysis methods, as well as advances in electron microscopy, 3D scanning and computed tomography, reflecting technological advances and the search for greater precision in the analyses.

It was found that tooth wear has been widely explored as an indicator of diet, especially in paleontological studies, but it is still little applied in species of zootechnical interest, such as cattle, goats and sheep. This gap points to significant opportunities to expand this approach to productive contexts, with the potential to have a direct impact on the health, well-being and efficiency of herds.

Thus, the study contributes to consolidate existing knowledge, identify limitations and point out future directions for the development of tools that quantify tooth wear in ruminants. This practical application can support professionals and researchers in making decisions aimed at sustainable management, increased productivity, and promotion of animal welfare, strengthening the integration between science and agricultural production.

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