

# Cerrado, sociobiodiversity and health: A bibliometric analysis

## *Cerrado, sociobiodiversidade e saúde: uma análise bibliométrica*

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**ABSTRACT** The Cerrado plays a crucial ecological and economic role: it is the most biodiverse savanna in the world, a regulator of water availability, and one of the largest exporters of agricultural commodities such as soy, corn, and cotton. It is home to traditional peoples and communities, such as Indigenous and quilombola communities, who possess ancestral knowledge about its biodiversity. But they are poorly studied and practically ignored by public policies. In the current context of environmental degradation, where the expansion of agriculture threatens the integrity of the Cerrado biome, compromising the health and social reproduction of these communities, it becomes essential to map the knowledge produced in order to support interventions. A bibliometric analysis was employed on a sample of 478 articles (2018-2024), mapping academic production on the socio-biodiversity of the Cerrado, its relationship with the environment and health, identifying trends and research gaps. The results indicate that most scientific production is centered on the themes of ecological dynamics (44%) and impacts of agribusiness (31%), with the health dimension being marginally addressed (6%), especially the health of traditional peoples. We conclude that there is a critical gap in the articulation between socio-biodiversity and health, demanding urgent formulation of public policies that promote cultural preservation and appreciation.

**KEYWORDS** Cerrado. Biodiversity. Health. Bibliometrics.

**RESUMO** O Cerrado desempenha um papel ecológico e econômico crucial: é a savana mais biodiversa do mundo, regulador da disponibilidade hídrica e um dos maiores exportadores de commodities agrícolas, como soja, milho e algodão. Nele, habitam povos e comunidades tradicionais, como indígenas e quilombolas, que detêm conhecimentos ancestrais sobre sua biodiversidade, mas são pouco estudados e praticamente ignorados pelas políticas públicas. No contexto atual de degradação ambiental, em que a expansão agropecuária ameaça a integridade do Cerrado, comprometendo a saúde e a reprodução social dessas comunidades, torna-se fundamental mapear o conhecimento produzido para subsidiar intervenções. Uma análise bibliométrica foi empregada em uma amostra de 478 artigos (2018-2024), mapeando a produção acadêmica sobre a sociobiodiversidade do Cerrado, sua relação com o meio ambiente e a saúde, identificando tendências e lacunas de pesquisa. Os resultados apontam que a maior parte da produção científica está centrada nas temáticas de dinâmicas ecológicas (44%) e impactos do agronegócio (31%), sendo que a dimensão da saúde é marginalmente abordada (6%), especialmente a saúde dos povos tradicionais. Conclui-se que há uma lacuna crítica na articulação entre sociobiodiversidade e saúde, demandando urgência na formulação de políticas públicas que promovam a preservação e a valorização cultural.

**PALAVRAS-CHAVE** Cerrado. Biodiversidade. Saúde. Bibliometria.

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## Introduction

The Cerrado, the second largest biome in South America, extends over 1,983,017 km<sup>2</sup> and occupies approximately 23.3% of Brazilian territory<sup>1</sup>, distributed among the states of Goiás, Tocantins, Mato Grosso do Sul, southern Mato Grosso, western Minas Gerais, the Federal District, western Bahia, southern Maranhão, western Piauí, and parts of São Paulo. Recognized as the most biodiverse savanna in the world, harboring 12,829 cataloged native plant species, the Cerrado also plays a role in water regulation, as it is the source of the three largest South American hydrographic basins: the Amazon/Tocantins, São Francisco, and Paraná rivers<sup>2</sup>.

Currently, 49.9% of the Cerrado area remains covered by natural vegetation. The biome also plays an important social role: this territory is home to diverse peoples and traditional communities – including indigenous ethnic groups, geraizeiros, riverside dwellers, babaçu gatherers, vazanteiros, and quilombola communities – who together form part of Brazil's historical and cultural heritage. These populations possess vast ancestral and traditional knowledge about biodiversity. The interaction between biological diversity and local cultural practices defines sociobiodiversity, a central concept for the sustainable management of resources, despite being little studied and practically ignored by public policies. Consequently, the rights of these communities over their resources are not yet fully guaranteed<sup>2,3</sup>.

This wealth, however, is under intense threat. The Cerrado is the main frontier for the expansion of agricultural commodities, resulting in high and increasing rates of deforestation. The expansion of agriculture and environmental degradation, which includes the intensive use of pesticides, directly compromises the ecological integrity of the biome and, consequently, affects food security, traditional medicine, and the social reproduction of these communities,

transforming areas into 'sacrifice zones' for national development<sup>4</sup>.

The academic production on the interrelationship between sociobiodiversity, the environment, and, especially, human health in the Cerrado is fragmented and little explored. Therefore, it is essential to map the state of the art to understand how science has addressed the vulnerabilities and contributions of sociobiodiversity and its peoples, particularly the impacts on health. This bibliometric study aimed to map recent scientific production (2018-2024) on the sociobiodiversity of the Cerrado, seeking to identify trends and, crucially, research gaps focused on the health of traditional peoples.

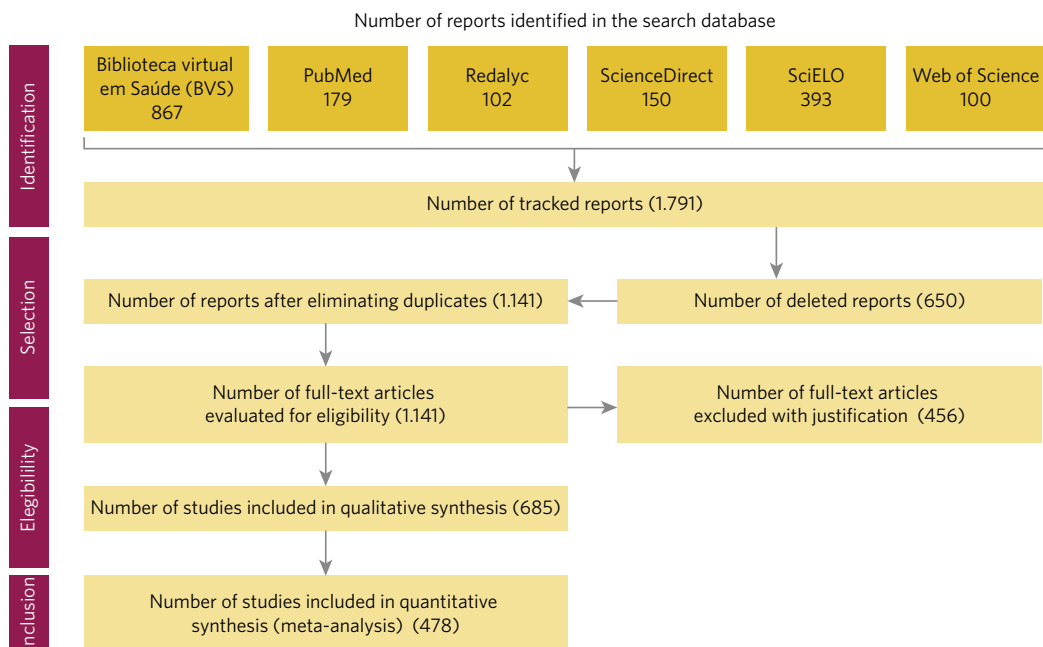
The bibliometric analysis consisted of consulting scientific articles published in databases specializing in the selected themes, namely: PubMed, ScienceDirect, Redalyc, Web of Science, Virtual Health Library (BVS), and Scientific Electronic Library Online (SciELO). The expectation is that the results will generate a solid basis for the formulation of public policies aimed at preserving biodiversity and valuing local cultures.

## Material and methods

### Data collection – PRISMA

In order to ensure rigor and transparency in the selection of scientific publications, this study used the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol as a methodological reference for data screening. Internationally recognized for its robustness in systematic reviews and meta-analyses<sup>5</sup>, PRISMA structures the selection of studies in four phases: identification, selection, eligibility, and inclusion, as illustrated in *figure 1*. This approach allows for the filtering of a large volume of records, ensuring the integrity and relevance of the analyzed data<sup>6</sup>.

Figure 1. Steps of the bibliometric review using the PRISMA protocol



Source: Own elaboration.

## Search strategy and databases

Bibliometric analysis was conducted using national and international databases of recognized reliability and scope: PubMed, ScienceDirect, Redalyc, Web of Science, BVS, and SciELO. These databases were selected due to their editorial characteristics and thematic coverage. *Table 1* presents the volume of documents identified between 2018 and 2024,

according to the keywords used, established based on the thematic focus.

To ensure greater precision in the search, the Boolean operator 'AND' was used, which restricts the results to articles that simultaneously contain all the selected terms, allowing for a more specific selection. The 'OR' operator, while broadening the scope, could compromise the relevance of the results by including articles on divergent topics.

Table 1. Search results (2018-2024) in the PubMed, ScienceDirect, Redalyc and Web of Science databases

Keywords	Number of articles per database			
	PubMed	Redalyc	ScienceDirect	Web of Science
A. Cerrado AND Sociobiodiversidade	-	-	-	-
B. Cerrado AND <i>Sociobiodiversity</i>	-	-	-	3
C. Cerrado AND Ambiente AND Saúde	22	-	-	47
D. Cerrado AND <i>Environment AND Health</i>	157	-	-	50
E. Cerrado AND <i>Social AND Biodiversity AND Health</i>	-	-	-	-
F. Cerrado AND <i>Traditional AND Nature AND Health</i>	-	-	100	-

Table 1. Search results (2018-2024) in the PubMed, ScienceDirect, Redalyc and Web of Science databases

Search results - Range (2018-2024)				
Keywords	Number of articles per database			
	PubMed	Redalyc	ScienceDirect	Web of Science
G. Cerrado AND Biodiversidade AND Tradicional* AND Saúde	-	102	50	-
<b>Number of articles per database</b>	<b>179</b>	<b>102</b>	<b>150</b>	<b>100</b>
<b>Total number of articles</b>				<b>531</b>

Source: Own elaboration.

Each database was selected according to its specialization: PubMed, focused on bio-medicine and public health; Redalyc, focused on social and environmental issues in Latin America; ScienceDirect, multidisciplinary with an emphasis on health and environmental sciences; Web of Science, recognized for its international scope and broad multidisciplinary coverage.

In order to encompass the socioeconomic, cultural, and political dimensions of socio-biodiversity in the Cerrado, the SciELO and

BVS databases, relevant in the dissemination of scientific information in public health and social sciences, were introduced, and new keywords were added, in addition to the term 'Brazil' in BVS to restrict the results to the national context (table 2). The search was limited to two keywords, as the addition of a third resulted in few or no articles. In the other databases, there was no need to add words, as the terms initially defined generated a satisfactory number of articles.

Table 2. Search results (2018 to 2024) using keywords appropriate to the SciELO and Virtual Health Library databases

Resultados das buscas - Intervalo (2018-2024)					Number of articles per database	
Keywords					Biblioteca Virtual em Saúde	SciELO
A.	Cerrado	AND	Health	Brazil	134	33
B.	Cerrado	AND	Agriculture	Brazil	110	53
C.	Cerrado	AND	Agribusiness	Brazil	3	8
D.	Cerrado	AND	Traditional communities	Brazil	12	8
E.	Cerrado	AND	Biodiversity	Brazil	212	91
F.	Cerrado	AND	Environment	Brazil	106	45
G.	Cerrado	AND	Impacts	Brazil	83	40
M.	Cerrado	AND	Fire	Brazil	83	33
O.	Cerrado	AND	Health policies	Brazil	11	1
Q.	Cerrado	AND	Vulnerability	Brazil	11	6
R.	Cerrado	AND	Glifosato	Brazil	10	13
S.	Cerrado	AND	Public policies	Brazil	19	15
U.	Cerrado	AND	Women	Brazil	7	4

Table 2. Search results (2018 to 2024) using keywords appropriate to the SciELO and Virtual Health Library databases

Resultados das buscas - Intervalo (2018-2024)					Number of articles per database	
Keywords					Biblioteca Virtual em Saúde	SciELO
W.	Cerrado	AND	Water resources	Brazil	18	9
Z.	Cerrado	AND	Water quality	Brazil	21	21
A.1	Cerrado	AND	Ecological restoration	Brazil	27	13
<b>Number of articles per database</b>					<b>867</b>	<b>393</b>
<b>Total number of articles</b>					<b>1,260</b>	

Source: Own elaboration.

## Screening and selection of studies

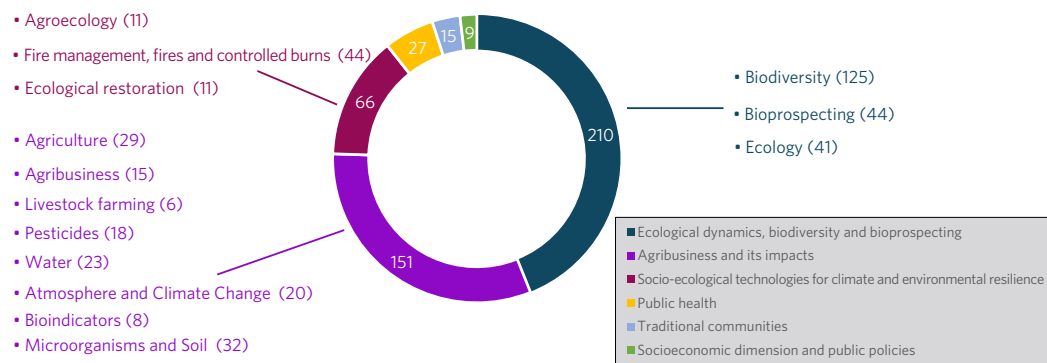
The initial search yielded 1,791 records, distributed among the databases BVS (867), PubMed (179), Redalyc (102), ScienceDirect (150), SciELO (393), and Web of Science (100). The entire screening process was carried out on the Rayyan platform, which assisted in identifying duplicates and applying inclusion and exclusion criteria. After excluding 650 duplicates and 456 articles unrelated to the themes, 685 remained. The articles selected for analysis were exported to a spreadsheet in CSV (Comma Separated Values) format, containing

abstracts, decisions, and observations made by the team, allowing for the identification of the main themes addressed and the construction of graphs that supported the analysis and discussion of the results.

## Results and discussion

Based on the analysis of the articles selected in the eligibility phase, 478 studies were included, dividing the themes based on a reading of the full texts (*graph 1*). In total, 6 main themes and 14 sub-themes were generated.

Graph 1. Number of articles published according to their themes (between 2018 and 2024) on the subject of sociobiodiversity in the Cerrado, environment and health in the databases BVS, PubMed, Redalyc, ScienceDirect, SciELO and Web of Science



Source: Own elaboration.

The theme of ecological dynamics, biodiversity, and bioprospecting stands out due to the large number of articles included, representing 44% of the total; followed by the themes of agribusiness and its impacts (31%) and socio-ecological technologies for climate and environmental resilience (14%). The other themes did not present significant numbers of articles: public health (6%), traditional communities (3%), and socioeconomic dimensions and public policies (2%). The themes will be presented below, with emphasis on the main aspects addressed in the articles.

### Ecological dynamics, biodiversity and bioprospecting

Recognized as one of the world's biodiversity hotspots and the second largest biome in the country, present in 23.3% of the territory, the Cerrado harbors a rich variety of endemic species<sup>2</sup> and provides several ecosystem services, such as climate regulation and the hydrological cycle, which depend directly on the conservation of its biodiversity<sup>7,8</sup>. The 125 articles on biodiversity, 41 on ecology and 44 on bioprospecting highlight both the ecological relevance of the biome and the impacts of anthropic actions and the undervaluation of traditional knowledge<sup>9-11</sup>.

Some studies indicate that environmental gradients and transition zones, such as ecotones and riparian forests, play a fundamental role in the composition and balance of biological communities, as they harbor highly specialized plant and animal species whose survival depends on factors such as seasonality, luminosity, and fire regimes<sup>12,13</sup>. However, intensive land use for agricultural production, the growth of urban areas, among other factors, severely impact biodiversity, resulting in habitat fragmentation, reducing the genetic connectivity of native species such as pequi (*Caryocar brasiliense*)<sup>11,14</sup>, compromising pollination services of mites, ants, and bees<sup>15,16</sup> and the diversity of mammals and fish, in addition to altering the ichthyofauna of streams, associated with

fragmentation and water quality, aggravated by agricultural practices in the surrounding area<sup>17</sup>. Even after the abandonment of pastures for more than a decade, the presence of exotic grasses and soil compaction hinder the restoration of native vegetation<sup>18</sup>.

On the other hand, several Cerrado species exhibit adaptive strategies, such as regrowth after fires or the accumulation of bioactive compounds in response to drought, characteristics that have aroused interest in the field of bioprospecting<sup>19</sup>. Several studies have investigated native Cerrado fruits, such as araticum (*Annona montana*), pequi (*Caryocar brasiliense*), cagaita (*Eugenia dysenterica*), baru (*Dipteryx alata*), mangaba (*Hancornia speciosa*) and buriti (*Mauritia flexuosa*), for their richness in phenolic bioactive compounds, flavonoids and other substances with anti-inflammatory, anticancer, prebiotic and antimicrobial properties, with the potential to prevent chronic diseases and develop high value-added foods, cosmetics and pharmaceuticals<sup>20,21</sup>.

Essential oils and plant extracts from the Cerrado have also proven effective as larvicides, repellents, and antifungals, constituting sustainable alternatives for the control of pests and vectors, such as *Aedes aegypti*, with benefits to public health and agricultural sustainability<sup>22,23</sup>. Phytoremediation is identified as a promising technique for the recovery of contaminated soils and waters, with species such as the lobeira (*Solanum lycocarpum*) demonstrating potential for the removal of heavy metals<sup>24,25</sup>. In parallel, the microbial biodiversity of the biome has been explored, mainly endophytic fungi, for their ability to produce secondary metabolites with applications in biocontrol, health, and bioenergy<sup>26-28</sup>.

Bioprospecting emerges as a link between traditional ecology and scientific knowledge, promoting innovations based on biological and cultural diversity. Species of the genus *Solanum* exhibit therapeutic properties, and unconventional vegetables grown by family farmers demonstrate the potential of the Cerrado for food security and sustainability<sup>29,30</sup>.

Rossi-Santos et al.<sup>31</sup> observed that communities in southeastern Cerrado structure their pharmacopoeia from native and exotic species, highlighting the dynamism and adaptability of traditional knowledge. Ribeiro Neto et al.<sup>32</sup> point out that there is a disconnect between popular uses and scientific experimentation with medicinal plants, revealing that research still neglects the preparation and application methods used by local communities. Barbosa et al.<sup>33</sup> identified 166 medicinal species in the quilombola community of Cedro/GO, traditionally used in the production of phytotherapeutic products, which represent the diversity of local knowledge, as well as their cultural, economic, and therapeutic relevance.

### Socio-ecological technologies for climate and environmental resilience

The so-called socio-ecological technologies have demonstrated the capacity to regenerate the environment, preserve socio-biodiversity and promote the health and autonomy of rural communities. The articles on agroecology (11), fire management, fires and controlled burns (44) and ecological restoration (11) reinforce the fundamental role of these technologies in mitigating climate change.

Agroecology has proven to be a deeply rooted alternative in the knowledge and practices of the peoples of the Cerrado. Among the studies included in this theme, several analyze the contribution of agro-extractive practices based on the sustainable use of native fruits, medicinal plants, and other resources of the territory, to food security, income generation, and the strengthening of the cultural identity of local communities<sup>34-37</sup>. Research indicates that these production systems, when well managed, are efficient allies in carbon sequestration<sup>38,39</sup>.

The experience described by Siqueira et al.<sup>40</sup> presents the production of agroecological seeds not only as a form of cultivation, but also as a political affirmation of autonomy, resistance, and belonging. The seed carries a symbolic value that transcends its agronomic

function, being the living memory of the territory. This profound meaning connects directly to ecological restoration practices that involve the collection and dissemination of native seeds by traditional communities. Technologies such as biodegradable capsules<sup>41</sup> and direct seeding<sup>42</sup> gain even more strength when combined with the protagonism of peoples who, historically, have been the guardians of biodiversity.

Ecological restoration, in turn, goes far beyond planting trees: it reactivates vital ecosystem cycles, such as nutrient cycling, water balance, and soil regeneration, contributing directly to human and environmental health. Although studies show that areas undergoing restoration exhibit significant improvements in soil quality<sup>43,44</sup>, the discrepancy between the native species available in nurseries and those that actually represent the diversity of the Cerrado compromises the ecological effectiveness of the restoration<sup>45</sup>.

Recent studies (33) show that fire is capable of fulfilling fundamental ecological functions, helping to maintain the diversity and balance of savanna environments<sup>46-48</sup>. Traditional burning practices, carried out in a controlled and seasonal manner, create mosaics in the landscape that reduce the intensity and extent of large-scale fires<sup>49,50</sup>. The criminalization of these practices has disrupted sustainable regimes and contributed to the increase in uncontrolled fires<sup>51,52</sup>. Initiatives such as Integrated Fire Management have been trying to reverse this scenario, betting on solutions built on science and local knowledge. Tools such as early warning systems<sup>53</sup> and strategic mapping<sup>54</sup> have been added to these practices with good results.

Studies on wildfires (11) show that their impact on human health continues to be a serious concern. In cities like Sinop/MT, the increased concentration of air pollutants resulting from fires is directly related to the aggravation of respiratory and cardiovascular diseases<sup>55</sup>. Studies estimate thousands of deaths associated with pollution generated

by wildfires<sup>56</sup>. In addition, fire affects the reproduction of various plant species<sup>57,58</sup>, modifies the fauna<sup>59</sup>, alters the soil microbiota<sup>60</sup>, causes water contamination<sup>61</sup> and favors erosive processes, especially in areas with less vegetation cover<sup>62</sup>.

### Traditional communities

In the context of traditional communities, the scarcity of articles recorded (15) is noteworthy, mainly concerning the environmental damage caused by the expansion of agribusiness in the region or the growing number of complaints from social movements and civil associations about violations of the rights of Cerrado communities. Only two studies address these consequences for the health of the communities. Egger et al.<sup>63</sup> characterize as ecocide the process of environmental destruction and dispossession of traditional communities that has been occurring in the Cerrado, given the occupation by agribusiness, which they call a modern-colonial model with state incentives. Among other impacts, the authors highlight those caused by the intensive use of pesticides, such as acute poisoning, congenital malformations, and childhood cancers. In 2018, the Cerrado concentrated 73.5% of the total pesticides consumed in the country and presented more cases of exogenous poisoning and childhood cancer compared to other biomes. Other health conditions are related to water insecurity and mental illness resulting from the vulnerability generated by land loss or restrictions on its use.

Rigotto et al.<sup>4</sup> follow the same critical direction regarding agribusiness. Based on research with women from communities in Serra do Centro (municipality of Campos Lindos/TO), they investigate the impacts of soy farming on the lives and health of these women, which generate a sense of 'unease' regarding a set of vulnerabilities and risks that did not previously exist. The authors warn of the need to broaden the dialogue between public health and agroecology as a strategy for the political

and epistemic confrontation of the harmful consequences of the extractive model for health and well-being.

Queiroz and Maia<sup>64</sup> report on the experience of the indigenous community Santuário Sagrado dos Pajés, in Brasília, during the COVID-19 pandemic, and the strategies they adopted to mitigate its negative effects, such as intensifying communication and adapting rituals. Reis et al.<sup>65</sup> conducted an ethnomycological study of the Karajá indigenous people of Bananal Island, Tocantins (Cerrado-Amazon transition), and highlighted the community's knowledge of fungi and their use in adornments and medicinal purposes, demonstrating the importance of the relationship between culture and the environment and its preservation. Paim et al.<sup>66</sup> conducted a study on popular ethnobotanical knowledge in the Kalunga community regarding plants toxic to livestock in the region.

### Socioeconomic dimension and public policies

The theme of socioeconomic dimension and public policies was selected given the tensions generated for sociobiodiversity as a result of the dominant economic model in the Cerrado, always mediated by politics. Nine articles were analyzed, three of which highlight the harmful consequences of the prevailing economic model. Santos<sup>67</sup> analyzes the relationship between soybean production in the region of the states of Maranhão, Tocantins, Piauí and Bahia (Matopiba) and land and income inequalities. By comparing soybean-producing and non-producing municipalities, he concluded that, in the former, there was continued economic growth, greater than in non-producing municipalities, but without significant changes in land and income concentration, maintaining inequality. In non-producing municipalities, even those with smaller incomes and areas, there was a decrease in land and income inequality. Oliveira<sup>68</sup> and Pires<sup>69</sup>

trace the historical trajectory of conservative development that encourages the economic exploitation of the biome to the detriment of its balance, with Pires analyzing the State's contribution to the expansion of soy in the Matopiba region, whose particularity is the appropriation of land by transnational companies and investment funds, aligned with the global phenomenon of the financialization of environmental assets. This form of expansion and occupation has built strong political interests that have restricted the State's own scope of action in environmental policies for the biome.

The article by Perosa et al.<sup>70</sup> analyzes the application of Voluntary Sustainability Standards (VSS) by companies in the Cerrado Mineiro coffee region to identify whether they were able to guarantee labor rights after the 2017 labor reform, which made several standards more flexible. The authors conclude that, despite the importance of VSS as a mechanism of private governance, and their widespread use in the region, they were not able to go beyond the rules already provided for by law, leaving workers exposed to the insecurities of flexibility.

The article by Bachi and Carvalho-Ribeiro defines sociobiodiversity as

the conjunction of sociocultural and biological diversity associated with the collection and pre-processing of native species, such as non-timber forest products (NTFPs)<sup>71(9)</sup>.

Based on spatially explicit modeling, the authors identified suitable areas for combining Community-Based Tourism (CBT) with the sale of products managed by local traditional communities, although they acknowledge that markets for socio-biodiversity products lack infrastructure and institutional support, noting that the only commercially significant NTFP in the Cerrado is the pequi fruit. This explains the lower percentage held by the biome in the 15 CBT initiatives analyzed (11%), with only 7% located in municipalities with a high

incidence of existing NTFPs in the Cerrado.

In the area of public policy, only two articles were identified. Colman et al.<sup>72</sup> estimated that losses of native vegetation in the Cerrado, mainly on large private properties in the Matopiba region, will reach 30.6 million hectares by 2070. To reduce these losses, they recommend that this segment be targeted by policies to protect native vegetation. Trigueiro et al.<sup>73</sup> analyze the spatial variability between Cerrado regions in relation to socioeconomic and environmental factors and deforestation, identifying different vectors for the increase or decrease in different regions, postulating that public policies aimed at preserving the Cerrado should focus on spatial and regional specificities. A similar contribution is presented by Sano et al.<sup>74</sup>, who carry out a review of the biome's ecoregions. Considering that conventional agribusiness is not environmentally sustainable, the authors propose defining specific conservation and restoration targets for each ecoregion based on indicative assessments of the least and most threatened regions, in order to achieve better results.

With the exception of two articles that analyzed social inequalities and land conflicts caused by the expansion of the agricultural frontier in the Matopiba region, relevant structural issues, such as the demarcation of traditional territories and alternative means of production to monoculture, were mentioned superficially or not at all. The expansion of soybean monoculture in Matopiba is used to illustrate the change in the biome's landscape under the 'pretext of development', although the authors found, in field research conducted in 18 municipalities, changes in access to land and water, as well as environmental degradation, without the promised counterpart of inclusive development that would reduce social inequalities<sup>75,76</sup>.

## Public health

In the public health theme (27 articles), the works are mostly (14) about vectors

and causative agents of endemic or emerging diseases in areas or states that make up the Cerrado, marginally exploring the environmental dynamics of ecosystems and the theme of biodiversity. The articles address the presence or distribution of vectors of diseases such as spotted fever, leishmaniasis, glanders, malaria, Chagas disease, yellow fever, cryptosporidiosis and giardiasis.

In the case of dengue, two articles associate the disease with environmental dynamics. Fernandes et al.<sup>77</sup> analyze dengue in Mato Grosso and conclude that the increase in incidence was influenced by factors such as rainfall and deforestation, in addition to characteristics of municipal health policy, indicating areas where government action could further the reduction of the disease. Marinho et al.<sup>78</sup>, in turn, analyzing environmental changes in Tocantins, conclude that deforestation and climate change exerted a strong association with the increase in infections by dengue, chikungunya and zika.

The ecological study by Brito et al.<sup>79</sup> explores hospitalizations for neglected diseases in Piauí and points to a temporal decrease in hospitalization rates, but with clusters where rates remain high, with the greatest risks of hospitalization for elderly people, brown people and residents of municipalities with medium social vulnerability. Another ecological analysis associates socioeconomic conditions with the occurrence of snakebite in Tocantins and points to the regions with the highest risks<sup>80</sup>.

Silva et al.<sup>81</sup> conducted a broad study on the risk of infection by cryptosporidiosis and giardiasis and type of land use in Goiás. The conclusions highlight the relationship between the presence of parasites and watersheds in pasture areas or pastures with agriculture and absence of forest, indicating a higher risk of infection for the population residing in watersheds with a percentage of pastures above 50%, and that animal excrement can be a source of contamination in the Cerrado.

## Agribusiness and its impacts

The term agribusiness was coined in 1957 by American economists John Davis and Ray Goldberg of Harvard University to describe the integrated system of production, processing, and distribution of agricultural products. In Brazil, it gained strength in the 1990s with liberal policies and the so-called modernization of agriculture, which connected the agricultural sector to industrial production, forming global production chains dominated by large multinational corporations such as Monsanto, Syngenta, Bunge, and Cargill, which control everything from the supply of agricultural inputs (fertilizers, machinery, genetically modified seeds), through the industrial processing of raw materials, to the distribution of exports. From the 2000s onwards, agribusiness consolidated became with the expansion of agricultural commodities, which began to be seen as financial assets, with trading on stock exchanges and foreign investment. Since then, the Brazilian Cerrado has faced increasing threats caused by the accelerated replacement of native vegetation with monocultures such as soy, corn, and cotton, as well as pastures and eucalyptus, compromising biodiversity, human health, and the livelihoods of local communities.

The Cerrado is the leader in absolute deforestation, with 653,000 hectares deforested in 2024, of which almost two-thirds show signs of illegality. According to the 'National Inventory Report of Anthropogenic Emissions by Sources and Removals by Sinks of Greenhouse Gases in Brazil' from the Ministry of Science, Technology and Innovation<sup>82</sup>, in 2022, 70% of national emissions were generated by the change in land use and forestry sectors and by agriculture.

Since intensive agriculture is the main driver of ecological transformation in the biome, we have gathered in this section 18 articles on the topic of pesticides, 23 on water, 20 on atmosphere and climate change, 32 on soil and microorganisms, 8 on bioindicators,

6 on livestock farming, 15 on agribusiness, and 29 on agriculture, considering the interconnection between the impacts of the production model and the processes of environmental degradation, especially of the soil and water resources.

In the topic of pesticides, the adverse effects of the intensive application of herbicides and insecticides on the native biodiversity of the Cerrado are observed. Species such as baru (*Dipteryx alata*)<sup>83,84</sup>, cagaiteira (*Eugenia dysenterica*)<sup>85</sup> and sucupira (*Bowdichia virgilioides*)<sup>86</sup> showed high sensitivity to substances such as glyphosate, atrazine and nicosulfuron, even in reduced doses, compromising their survival and natural regeneration. In parallel, studies<sup>87,88</sup> show the use of herbicides to control resistant weeds, such as horseweed (*Conyza spp.*) and sourgrass (*Digitaria insularis*), which intensify the cycle of chemical dependence without solving the agronomic problem.

Another important warning concerns the toxicity of pesticides on non-target organisms. The insecticide imidacloprid has demonstrated lethal effects on earthworms and soil springtails<sup>89</sup>, pesticides have affected the visitation of pollinating bees<sup>90</sup> and genetic alterations in birds, tiziu (*Volatinia jacarina*), used as bioindicators of environmental contamination on coffee farms<sup>91</sup>. In addition,<sup>87</sup> the phenomenon of aerial spray drift increases environmental risks by reaching adjacent areas<sup>92</sup> and the inadequate management of pesticide packaging still represents a serious problem<sup>93</sup>.

The theme of water reinforces the central role of agriculture in water degradation. Studies on intensive soybean irrigation point to the need to improve irrigation management through the use of technologies that consider the sensitivity of crops to water deficit<sup>94,95</sup>. Hydrological modeling has proven fundamental for forecasting flows, planning water rights and managing river basins; therefore, such modeling allows us to simulate hydrological behavior in the face of land use changes, data scarcity, and climate variability<sup>96,97</sup>. The

replacement of native vegetation with pastures and crops compacts the soil, reduces its porosity and water retention capacity, exacerbating erosion and surface runoff<sup>98,99</sup>.

Water quality monitoring reveals significant impacts of urban, industrial, and agricultural origin. Analyses have identified changes in quality parameters with the presence of heavy metals, excess nutrients, emerging compounds, and multi-resistant microorganisms that point to increasing risks to human health and water security<sup>100-102</sup>. The results of the studies reinforce the need for preventive actions and environmental control, especially in regions where there is effluent discharge<sup>103</sup> and/or intensive land use<sup>104</sup>.

In the area of atmosphere and climate change, the impacts of deforestation, wildfires, intensive use of fertilizers, and livestock farming are alarming. The increase in wildfires in the Cerrado has significantly increased the concentrations of tropospheric ozone (O<sub>3</sub>)<sup>105</sup>; soil preparation, nitrogen fertilization, and its agricultural use directly impact emissions of nitrous oxide (N<sub>2</sub>O) and carbon dioxide (CO<sub>2</sub>)<sup>106,107</sup>; and the impacts of livestock farming for beef production, show high levels of methane (CH<sub>4</sub>) emissions<sup>108</sup>.

Climate change also alters the distribution of native species, such as vernonia (*Lessingianthus*)<sup>109</sup>, jaborandi (*Pilocarpus microphyllus*)<sup>110</sup> and jatobá (*Hymenaea stigonocarpa*)<sup>111</sup>, which already show habitat loss under future scenarios. Studies highlight the relationship between deforestation combined with the conversion of natural areas into pastures and cropland with the reduction in precipitation, leading to the intensification of droughts<sup>112,113</sup>. Research on climate modeling and land use projections employs future scenarios to assess how rising temperatures and changes in precipitation will influence agricultural productivity, water availability and the spatial distribution of crops<sup>114,115</sup>.

In the area of soil and microorganisms, the cumulative effects of inadequate agricultural management appear clearly. The reduction of

organic matter, compaction, erosion and loss of microbial biodiversity are direct consequences of the conversion of the Cerrado into cultivated areas<sup>116,117</sup>. Conversely, the application of organic waste, such as composted sewage sludge<sup>118,119</sup>, and the use of beneficial microorganisms from *Trichoderma* strains<sup>120</sup> have proven to be viable alternatives for recovering fertility and restoring the biological balance of the soil.

The theme of bioindicators complements this overview by highlighting how organisms reflect levels of environmental degradation. The presence of aquatic insects and fish indicates the degree of integrity of streams in agricultural areas<sup>121,122</sup>. Bioaccumulative native fruits reveal contamination by heavy metals and the ecological response to land use<sup>123</sup>. On the other hand, studies affirm that, in agricultural and traditional areas, edaphic macrofauna is an important bioindicator of environmental quality, and the results show that conservation practices maintain or improve levels of soil stability and biodiversity<sup>124,125</sup>.

The research gathered under the themes of agribusiness, agriculture and livestock farming reveals that changes in land use and land cover affect freshwater ecosystems at different spatial scales. The metacommunity patterns found in 183 headwater stream sites located in the Cerrado, covering a total area of 46,394 km<sup>2</sup>, suggest that the most important mechanism for community assemblage at the local scale was environmental filtering and that land-use change can restrict dispersal at the regional scale<sup>126</sup>. Understanding these processes is crucial to achieving the conservation and restoration goals of biomes, with the protection of the entire watershed being the most efficient way to preserve the health of streams and aquatic biodiversity, associated with the promotion of integrative research between terrestrial and aquatic ecology.

When analyzing the replacement of pastures with agricultural areas, the conversion of native vegetation into industrial areas and rural constructions, in addition to the

reduction in water availability and the growth of areas with erosion, Alves et al.<sup>127</sup> estimated a vertiginous increase in exposed soil area on the order of 3,259.15% in the period from 1986 (7.81 ha) to 2016 (262.35 ha).

The conversion of native vegetation into monocultures and pastures directly impacts soil fertility, reducing nitrogen mineralization and inorganic nitrogen stocks<sup>128</sup>, in addition to causing compaction, hindering root development and nutrient absorption by plants<sup>129</sup>. In recent decades, there has been a significant increase in soil compaction in the Cerrado due to intensification practices in short-cycle crops and the growing use of machinery, even under the no-till system<sup>130</sup>.

Because it is an essential component for both soil health and addressing climate change, the loss of organic carbon in the soil is another critical problem. Although practices such as no-till farming and the use of integrated systems (crop-livestock-forestry) help to recover some of this carbon, this recovery depends on several factors, such as soil depth and the type of management adopted<sup>131</sup>.

With regard to water, it is well known that the Grey Water Footprint (GWF) has been increasing due to the intensive use of agrochemicals and agricultural expansion, bearing in mind that Brazil has led the global consumption of pesticides since 2008, according to Bombardi cited by Santos and Naval<sup>132</sup>. In the period covered by the research, we found only one article<sup>133</sup>, a pioneer in mapping the temporal and spatial dynamics of the water footprint of soybeans in the agricultural frontier of the Cerrado in the North and Northeast regions, from 1999 to 2018, which included the quantification of the GWF of the herbicide glyphosate according to the limit allowed by the European Union. The result confirmed that the expansion of high-tech soybean cultivation has increased the water footprint. However, since there is no continuous monitoring of this indicator, it will be difficult to plan the sustainable use of water. In addition, without a reduction in agrochemicals, the scarcity of

water to dilute toxic residues will threaten the viability of the crop.

Alarming data also indicate that 29% of areas irrigated by center pivot systems suffer severe erosion, with the formation of gullies up to 1,200 meters deep, due to over-irrigation on sloping terrain<sup>134</sup>. On the other hand, the occurrence of dry spells and irregular rainfall harms non-irrigated production, requiring conservation management that favors the physical quality of the soil and more efficient water consumption, so as not to aggravate the water deficit<sup>135</sup>.

## Conclusions

The scarcity of publications in the period 2018-2024 on the socio-biodiversity of the Cerrado and its relationship with the environment and human health can be attributed to a combination of factors: academic bias that prioritizes other biomes (Amazon and Pantanal) and disciplinary fragmentation; lack of funding for biodiversity research, including inventories of species with the potential to leverage a socio-biodiversity economy; difficulty in considering other development trajectories given the dominant presence of agribusiness, encouraged by public policy stimuli; budget cuts that compromise environmental monitoring and enforcement; and a lack of public policies specifically aimed at the biome, aggravated by the fact that the period studied was particularly affected by the obscurantism sponsored by the governments of Michel Temer and Jair Bolsonaro, marked by negligence in the application of environmental legislation, and by the low production of studies by government agencies (Ministry of the Environment and Climate Change, Institute for Applied Economic Research and Brazilian Institute of Geography and Statistics). Not coincidentally, the highest rates of deforestation in the Cerrado were recorded during the terms of these presidents (2016-2022), given the

accelerated and largely illegal incorporation of new lands for agricultural commodities and cattle ranching.

In a biome destined to be a 'sacrifice zone', there is a visible disinterest, almost contempt, in utilizing the knowledge of traditional communities. Similarly, studies addressing land conflicts and the impacts of deforestation on the daily lives of these communities, such as limited access to water, education, and basic health services, are rare. Furthermore, without systematic research on the traditional knowledge of indigenous and quilombola communities, the understanding of management and conservation practices is partial, compromising the state's capacity to develop public policies aimed at the sustainable use of socio-biodiversity, including native fruits, oils, medicinal plants, and ethno/ecotourism.

Given this, the articulation between science, technology, public policies, and traditional knowledge is a necessary condition to address socio-environmental impacts and promote integrated strategies for the conservation and sustainable use of Cerrado resources. Some articles have documented the specific expressions of traditional communities and their role in preserving the biome, but have made little progress in developing biodiversity-based alternatives to address the impacts of the hegemonic model on the region. It is noteworthy, for example, that there is a lack of research that addresses health beyond diseases, but that treats healthcare as a beneficiary of socio-biodiversity. To this end, researchers must seek interdisciplinarity and intersectorality, although these practices are still rare in the Brazilian scientific community.

Despite the methodological and empirical advances observed in the studies analyzed, scientific production on agroecology in the Cerrado is still unequal in terms of geographic coverage, interdisciplinary dialogue, and articulation with local knowledge. In general, academic work follows a technocratic logic, without considering the sociocultural dimensions associated with agroecological practices

and structural issues such as land access, environmental justice, and gender inequality. This vast field of research has been covered by non-governmental organizations working in the Cerrado (the National Campaign in Defense of the Cerrado, which brings together 56 entities), and by some academic niches located at the Federal University of Goiás, the University of Brasília, the Oswaldo Cruz Foundation, among others. Therefore, the production of the scientific field *stricto sensu* lacks a position that values agroecology as a science and as a political banner.

Despite the thematic diversity of the research analyzed, approaches focused on defending the biodiversity of the Cerrado are scarce. Most articles avoid strong positions on hegemonic land use models, treating environmental impacts as ‘side effects’ of the production system, and not as reflections of political and economic choices that marginalize traditional knowledge and ways of life. When there are criticisms, they are directed at ‘excesses’ in the use of pesticides or the ‘inadequacy’ of a particular cultivation method, but not at the production model as a whole.

Meanwhile, the material basis for a socio-biodiversity economy remains precarious, as there is a lack of inventories of useful species, laboratory experiments, and funding for production chains. Even the potential economic agents are unknown, such as the quilombola communities that were included in the Census for the first time in 2022. Furthermore, although they are responsible for the interaction of biological diversity with the local cultural

practices that define socio-biodiversity, their rights over the territories they occupy are not fully guaranteed. Therefore, there is neither a legal basis nor sufficient data to guide effective public policies for this segment.

Without investment, products such as vegetable oils, native fruits, and herbal remedies cannot compete on an equal footing with agribusiness commodities. This asymmetry is exacerbated by the climate emergency, as it affects the very few areas that remain for traditional communities, bearing in mind that, for this segment, the territory is not only a productive space, but, above all, a central element of their identity. Furthermore, the lack of support for these value chains both perpetuates economic inequalities and jeopardizes ancestral knowledge and sustainable practices that could significantly contribute to the socio-environmental resilience of the Cerrado.

## Authorship contributions

Oliveira RLS (0000-0001-9920-3251)\*, Vinha VG (0000-0001-6217-2471)\* and Lobato LVC (0000-0002-2646-9523)\* contributed to the conception and design of the work, data collection, analysis and interpretation, writing, revision and critical analysis, and final approval of the manuscript. Lopes CEL (0009-0004-7788-7284)\* and Furtado MN (0000-0001-7661-0815)\* contributed to data interpretation, writing and critical revision of the manuscript. ■

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