Bioactives from Cerrado plant species for the sustainable control of veterinary dipterans: A focused synthesis

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ABSTRACT. The widespread use of synthetic insecticides in livestock production has raised concerns about parasite resistance, environmental contamination, and risks to animal and human health. In this context, plant-derived bioactives represent promising alternatives and potential bioinputs for the sustainable control of veterinary dipterans. This study presents a focused synthesis of scientific literature addressing the potential of bioactive compounds from plant species native to the Brazilian Cerrado, with emphasis on both their insecticidal potential and the main limitations and research gaps reported in the literature. Selected studies reporting insecticidal or repellent effects against dipterans of veterinary importance were analyzed to identify major classes of compounds, potential mechanisms of action, and methodological limitations. Among the species identified in the reviewed studies, *Enterolobium contortisiliquum* emerged as a promising Cerrado species with relevant bioactive potential. The available evidence indicates that compounds such as saponins, tannins, phenolics, and terpenoids may contribute to repellency, larvicidal activity, and interference with insect physiological processes. However, methodological heterogeneity, limited toxicological evaluation, and scarce field validation remain important challenges.

Key words: bioactive compounds; bioinputs; Cerrado; veterinary dipterans; sustainable pest management.

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INTRODUCTION

Brazilian beef cattle production has become one of the main pillars of national agribusiness, ranking among the world's largest producers and the leading exporter of beef, accounting for 27.7% of the global market share (Pereira et al., 2024). Despite its economic relevance, the sector faces substantial sanitary and productive challenges associated with ectoparasite infestations, particularly those caused by dipterans of veterinary importance. These insects negatively affect animal welfare and productivity and may also act as vectors of pathogens in livestock systems (Alikhan et al., 2018).

Dipterans of veterinary importance include hematophagous and synanthropic species capable of causing stress, blood loss, irritation, and reductions in animal performance. Among these species, *Haematobia irritans* (horn fly) is recognized as one of the most important ectoparasites affecting cattle production systems worldwide, especially under tropical and subtropical conditions (Jorge, Rosa & Santos, 2016). Belonging to the order Diptera, this species is characterized by a single pair of functional wings and halteres responsible for flight balance (Alikhan et al., 2018). Originally described by Linnaeus in 1758, *H. irritans* expanded globally alongside livestock production systems. In Brazil, the species was first recorded in Roraima between 1976 and 1977, spreading rapidly due to favorable climatic conditions and extensive grazing systems (Brito et al., 2005).

Infestations caused by *H. irritans* and other hematophagous flies negatively affect livestock productivity beyond the direct effects of hematophagy. Repeated biting behavior promotes chronic irritation and stress, impairing weight gain, milk production, feed conversion efficiency, and animal welfare. Severe infestations may also compromise leather quality and overall productivity (Brito et al., 2005). In Brazil, annual economic losses associated with ectoparasites in livestock systems are estimated at approximately US$ 13.96 billion, of which nearly US$ 3.24 billion are attributed to horn fly infestations (Grisi et al., 2014).

The conventional management of veterinary dipterans relies mainly on synthetic insecticides, including pyrethroids, organophosphates, insect growth regulators, and diflubenzuron-based formulations (Ouedraogo et al., 2021; Junquera et al., 2019; Khan et al., 2013). Although these compounds may provide short-term effectiveness, their extensive use has intensified concerns regarding parasite resistance, occupational exposure, and environmental contamination (Brewer et al., 2021). In Brazil, the indiscriminate application of insecticides and acaricides has contributed to the selection of resistant parasite populations, increasing control costs and reducing long-term efficacy (Oyarzún et al., 2008). Moreover, the persistence of chemical residues in soil, water, and animal production systems reinforces the need for safer and more sustainable control strategies (Barroso et al., 2023).

In this context, growing attention has been directed toward bioinputs (bioinsumos) derived from biological resources (Madhav et al., 2020). Plant-based bioinputs include bioactive compounds obtained from native species with insecticidal, repellent, or growth-regulating properties that may contribute to integrated pest management in livestock systems (MAPA, 2025). Among Brazilian biomes, the Cerrado stands out due to its biodiversity and phytochemical richness, representing a promising source of compounds with potential applications in veterinary pest control (Cruzeiro et al., 2024).

Recent studies have demonstrated that extracts, essential oils, and secondary metabolites obtained from Cerrado plant species may exhibit insecticidal and repellent activity against dipterans of veterinary importance, including *H. irritans* (Showler, 2017; Castro et al., 2023). Among the species identified in the reviewed literature, *Enterolobium contortisiliquum* (tamboril) emerged as a representative Cerrado species due to its reported bioactive potential and possible applicability in sustainable livestock management strategies (Barros et al., 2023). In addition to reducing dependence on synthetic insecticides, plant-derived compounds may contribute to lowering environmental impacts and mitigating resistance development.

Despite the growing interest in plant-derived bioinputs, important scientific and technological challenges remain. Studies are still fragmented, methodologies are heterogeneous, and information regarding toxicological safety, formulation stability, and field-scale validation remains limited. Furthermore, integrative analyses involving the diversity of Cerrado bioactive compounds and their practical applications in veterinary dipteran control are still scarce.

Therefore, this study presents a focused synthesis of the scientific literature addressing bioactive compounds from Cerrado plant species with potential application in the sustainable control of dipterans of veterinary importance. The review aims to identify the main classes of bioactive compounds, their proposed mechanisms of action, representative plant species reported in the literature, and the principal scientific and technological limitations associated with their use as sustainable bioinputs in livestock systems.

MATERIALS AND METHODS

The literature survey was conducted using scientific databases including Scopus, Web of Science, Google Scholar, SciELO, and PubMed. The search strategy combined descriptors related to Cerrado plants, veterinary dipterans, bioactive compounds, phytotherapeutics, and sustainable pest management. The main databases and search descriptors used in the literature survey are summarized in Table 1.

Table 1. Databases and search descriptors used in the literature survey.

Database	Search descriptors/terms
Scopus	"Cerrado plants" AND "veterinary dipterans" AND "bioactive compounds"
Web of Science	"plant-derived bioactives" AND "livestock ectoparasites"
Google Scholar	"Cerrado bioinputs" AND "insecticidal activity"
SciELO	"phytotherapeutics" AND "dipterans" AND "livestock"
PubMed	"plant extracts" AND "Haematobia irritans"

Studies published in English and Portuguese investigating bioactive compounds derived from Cerrado plant species with potential insecticidal or repellent activity against dipterans of veterinary importance were prioritized. The selected literature was analyzed qualitatively, considering reported biological activities, chemical classes, proposed mechanisms of action, and identified research limitations.

RESULTS AND DISCUSSION

Overview of the Reviewed Literature

The reviewed literature comprised studies published in English and Portuguese that addressed bioactive compounds derived from Cerrado plant species with potential insecticidal or repellent activity against dipterans of veterinary importance. The analyzed studies included experimental investigations, literature reviews, and reports involving predominantly in vitro assays and, to a lesser extent, in vivo evaluations under livestock conditions. Most studies focused on the biological activities of plant extracts, essential oils, and secondary metabolites such as phenolics, terpenoids, alkaloids, tannins, and saponins. The reviewed publications were predominantly concentrated within the last decade, reflecting the growing scientific interest in sustainable bioinputs and plant-derived alternatives for veterinary pest management. The principal Cerrado species, bioactive compounds, and proposed mechanisms of action identified in the reviewed studies are summarized in Tables 2 and 3.

Table 2. Main chemical groups and proposed mechanisms of action of bioactive compounds from Cerrado plants with potential activity against dipterans of veterinary importance.

Compound Class	Representative Molecules	Mechanism of Action	Example Species	References
Terpenoids	Citronellal, Geraniol	Repellent and fumigant activity through volatile action; reduce insect landing and feeding behavior, contributing to decreased infestation levels	*Cymbopogon citratus, Cymbopogon nardus, Eucalyptus spp*	Silva et al. (2015); Baldacchino et al. (2013); Corrêa & Salgado (2011)
Phenolic Compounds	Flavonoids, tannins, lignin, coumarins	Antioxidant, antimicrobial, and allelopathic activities; involved in protection against oxidative stress and pathogens	*Cymbopogon citratus, Cymbopogon nardus, Enterolobium contortisiliquum, Dipteryx alata*	Silva et al. (2015); Borges & Amorim (2020); Lima et al. (2009); Barros et al. (2023)
Alkaloids	Amides and alkaloids (e.g., piperine, chavicine)	Insecticidal, repellent, and antifeedant activity; reduce feeding and survival rates in dipteran and coleopteran pests	*Piper tuberculatum, Piper nigrum*	Braga et al. (2017); Scopel et al. (2018)
Saponins	Diosgenin, Aescin, Soyasaponin	Amphiphilic glycosides that interact with membrane sterols, leading to increased permeability and cell lysis; contribute to plant defense through deterrent and antifungal effects	*Dioscorea spp., Glycine max, Aesculus hippocastanum.*	Hussain et al. (2019); Sharma et al. (2023)
Essential Oils (Complex Mixtures)	Citronellal, Geraniol, Linalool, Citronellol	Repellent and insecticidal activity associated with the volatility of monoterpenes; reduce insect landing, attraction, and larval viability through behavioral deterrence	*Cymbopogon citratus, Pelargonium graveolens, Lippia alba*	Baldacchino et al. (2013); Niculau et al. (2013)

Table 3. Main Cerrado plant species with reported insecticidal and repellent activity against dipterans of veterinary importance.

Plant Species (Scientific Name)	Common Name	Botanical Family	Plant Part Used	Predominant Bioactive Compounds	Type of Activity	Main Target Pest	Reference
Azadirachta indica	Neem	Meliaceae	Seeds / oil	Azadirachtin, Nimbin, Salannin	Insecticidal, repellent	*Haematobia irritans, Musca domestica*	Deleito & Borja (2008)
Allium sativum	Garlic	Amaryllidaceae	Bulb	Allicin, Disulfides	Insecticidal, repellent	Horn fly, ticks	Rohde et al. (2013)
Cymbopogon citratus	Lemongrass	Poaceae	Leaves / essential oil	Citral, Geraniol	Repellent	Hematophagous dipterans	Baldacchino et al. (2013)
Cymbopogon nardus	Citronella	Poaceae	Leaves / essential oil	Citronellal, Geraniol	Repellent	Horn fly	Silva et al. (2022)
Piper nigrum	Black pepper	Piperaceae	Seeds	Piperine	Insecticidal, repellent	Mites, dipterans	Scopel et al. (2018)
Piper tuberculatum	Long pepper	Piperaceae	Leaves and fruits	Piplartine, Piperine	Insecticidal, repellent	*Haematobia irritans*	Braga et al. (2017)
Ricinus communis	Castor bean	Euphorbiaceae	Seeds and leaves	Ricinine, Ricinolein	Insecticidal, repellent	Stable flies and larvae	Lopes et al. (2013)
Enterolobium contortisiliquum	Tamboril	Fabaceae	Seeds, bark, and fruits	Coumarins, Saponins, Tannins	Insecticidal, repellent, antibacterial	*Haematobia irritans*, ticks	Barros et al. (2023)
Pelargonium graveolens	Geranium	Geraniaceae	Leaves / essential oil	Geraniol, Citronellol	Repellent, insecticidal	Horn flies, mosquitoes	Niculau et al. (2013)
Vitex agnus-castus	Chaste tree	Lamiaceae	Leaves and flowers / essential oil	Vitexin, Casticin, Phenolic acids	Repellent, insecticidal	Flies and other dipterans	Ayres et al. (2021)

Cerrado Plants as Sources of Bioactive Compounds

The Cerrado biome, recognized as one of the world's biodiversity hotspots, represents an important source of plant species with potential applications in sustainable livestock systems (Cruzeiro et al., 2024). The environmental conditions characteristic of this biome, including acidic soils, seasonal droughts, and high solar radiation, contribute to the production of secondary metabolites involved in plant defense and ecological adaptation. This phytochemical diversity has stimulated increasing scientific interest in the investigation of Cerrado species as potential sources of plant-derived bioinputs for veterinary applications (Madhav et al., 2020; MAPA, 2025).

Bioinputs, also referred to as biological inputs, comprise a broad range of biotechnological products and processes derived from enzymes, microbial or plant extracts, secondary metabolites, and pheromones, mainly applied in integrated pest and disease management (Souza et al., 2022). Within this context, bioactive compounds constitute the functional basis of many bioinputs due to their ability to modulate physiological and ecological processes. These compounds exhibit antimicrobial, antifungal, insecticidal, growth-regulating, and resistance-inducing activities, contributing not only to phytosanitary protection but also to the resilience of agricultural ecosystems (Zaldivar et al., 2024; López-Cabeza et al., 2024).

Owing to its biodiversity and ecological complexity, the Cerrado has emerged as a promising source of bioactive molecules with potential applications in agriculture and livestock systems. The investigation of these natural resources may contribute to the development of environmentally compatible products capable of reducing dependence on synthetic chemical inputs while supporting sustainable agricultural practices (Ellwanger et al., 2023). Secondary metabolites synthesized by Cerrado plants play important roles in adaptation and defense against biotic stresses, such as herbivory and pathogen attack, as well as abiotic stresses including ultraviolet radiation, water scarcity, and temperature fluctuations. In addition to their ecological functions, these compounds also present pharmacological, nutritional, and industrial relevance, being explored in the formulation of medicines, cosmetics, aromatic additives, dyes, and biofertilizers (Borges & Amorim, 2020).

In general, these metabolites are grouped into three major classes: terpenoids, phenolic compounds, and nitrogen-containing compounds such as alkaloids. These chemical groups have been associated with antimicrobial, antioxidant, repellent, and insecticidal activities relevant to sustainable pest management (Vizzotto et al., 2010). Despite scientific advances, important gaps remain regarding the ecological functions, biosynthetic pathways, and practical applications of many Cerrado-derived metabolites, reinforcing the need for integrative studies linking chemical ecology and sustainable agro-livestock management.

The biodiversity of the Cerrado has also demonstrated potential for the development of phytotherapeutics, bioinsecticides, and bioacaricides (Vizzotto et al., 2010). Studies included in this review highlighted species such as *Piper cubeba L., Coriandrum sativum L., Eichhornia crassipes Mart., Limonia acidissima L., Tamarindus indica L., Cocos nucifera L., Terminalia catappa L., and Syzygium cumini L.*, whose extracts and secondary metabolites have demonstrated insecticidal, repellent, and acaricidal activities. The reported biological effects include interference with insect neurotransmission, digestion, and reproductive processes, contributing to more selective and environmentally compatible pest control strategies (Corrêa & Salgado, 2011; Rani & Murthy, 2008).

Beyond pest management applications, secondary metabolites from Cerrado species also participate in ecological interactions involving pollinator attraction, protection against herbivory, and symbiosis with beneficial microorganisms. Recent studies additionally suggest antimicrobial and antifungal activities that may expand the applicability of these compounds in livestock management and post-harvest conservation (Almeida, 2024). Due to its ecological diversity and biological richness, Brazil occupies a strategic position for the development of sustainable bioproducts derived from Cerrado biodiversity. However, the consolidation of this potential depends on appropriate regulatory frameworks, investment in applied research, and public policies supporting green biotechnology and biodiversity conservation (Freitas et al., 2024). Initiatives such as the Brazilian Biodiversity Genomics Project reinforce national efforts to integrate conservation, technological innovation, and bioeconomic development (ICMBio, 2024). In this context, Cerrado biodiversity represents an important source of bioactive solutions with potential contributions to agro-livestock sustainability and environmentally responsible bioinput development.

Main Bioactive Compounds and Mechanisms of Action

Resistance to conventional insecticides represents a major challenge for the control of dipterans and other ectoparasites of veterinary importance, compromising the long-term effectiveness of livestock pest management and increasing production costs. The intensive use of synthetic insecticides contributes to the selection of resistant populations while intensifying concerns related to environmental contamination and risks to animal and human health (Barathi et al., 2024). In addition to metabolic resistance and target-site mutations, more complex mechanisms have been reported, including the sequestration of insecticidal molecules by olfactory proteins, which may reduce the efficacy of synthetic compounds and reinforce the need for alternative and environmentally compatible control strategies (Pu & Chung, 2024).

In Brazilian livestock systems, these challenges are particularly relevant due to the economic importance of cattle production and the impacts caused by ectoparasites such as *Haematobia irritans* (horn fly), which negatively affect weight gain, productivity, and animal welfare (Carvalho & Ze, 2017; Brito et al., 2005). Although synthetic insecticides may initially provide effective control, their continuous use has contributed to the emergence of resistant populations, compromising the efficiency of conventional management programs (Oyarzún et al., 2008).

In this context, plant-derived bioinsecticides have emerged as promising alternatives for integrated pest management. Obtained from plant species capable of naturally producing insecticidal, larvicidal, and repellent compounds, these products combine biological effectiveness with reduced environmental impact and biodegradability, contributing to decreased dependence on synthetic agrochemicals and more sustainable livestock production systems (Corrêa & Salgado, 2011).

Several studies included in the reviewed literature reported that Cerrado plant species produce bioactive secondary metabolites such as alkaloids, flavonoids, terpenoids, coumarins, and limonoids. These compounds are associated with insecticidal, repellent, and growth-regulating activities against dipterans of veterinary importance, highlighting their potential application in the development of sustainable bioinputs for livestock pest management (Showler, 2017; Castro et al., 2023; Barros et al., 2023; Cruzeiro et al., 2024).

Based on the analyzed literature, several plant-derived compounds have demonstrated insecticidal, repellent, or growth-regulating activity against dipterans of veterinary importance. Azadirachtin, found in neem (*Azadirachta indica*), acts as a growth inhibitor and endocrine regulator by interfering with molting and reproductive cycles, showing efficacy against hematophagous flies (Deleito & Borja, 2008). Sulfur compounds derived from garlic (*Allium sativum*) exhibit fumigant and repellent properties that affect insect feeding and olfactory behavior (Rohde et al., 2013). In addition, species of the genus *Piper*, widely distributed in the Cerrado biome, produce alkaloids and flavonoids with antifeedant, neurotoxic, and metabolic-regulating effects, including reported activity against *Haematobia irritans* (Braga et al., 2017; Scopel et al., 2018).

The reviewed studies also highlighted the relevance of volatile terpenoids from aromatic grasses such as *Cymbopogon citratus* and *Cymbopogon nardus*, whose compounds—including citronellal, geraniol, and limonene—function as natural repellents against hematophagous dipterans (Silva et al., 2015; Baldacchino et al., 2013). Similarly, ricinine from Ricinus communis has been associated with selective neurotoxic activity, while *Enterolobium contortisiliquum* contains coumarins such as scopoletin and umbelliferone, which exhibit larvicidal and hormonal effects (Lopes et al., 2013; Barros et al., 2023). Other species, including *Pelargonium graveolens* and *Vitex agnus-castus*, were also reported as sources of bioactive compounds capable of interfering with the feeding and reproductive behavior of flies and mosquitoes due to the presence of monoterpenes and flavonoids such as vitexin and orientin (Ayres et al., 2021).

The phytochemical diversity of Cerrado species contributes to a broad spectrum of biological activities against dipterans and other ectoparasites of veterinary importance. Compounds such as alkaloids, terpenoids, phenolics, saponins, and coumarins may interfere with insect nervous, digestive, and reproductive systems, producing toxic, repellent, or growth-inhibitory effects. Table 2 summarizes the principal chemical groups and proposed mechanisms of action identified in the reviewed studies, emphasizing their relevance for sustainable bioinsecticide development and veterinary pest management.

Beyond chemical characterization, understanding the botanical diversity associated with these compounds is equally important. Biological activity varies according to plant species, plant part, and extraction methodology, reflecting the complexity of Cerrado secondary metabolites and their ecological functions. Table 3 presents the main species reported in the literature, highlighting their predominant compounds, plant parts, and observed biological activities.

The evidence summarized in Tables 1 and 2 indicates that Cerrado species constitute a diverse source of bioactive compounds with potential activity against dipterans of veterinary importance. The reported insecticidal and repellent effects are associated with multiple chemical classes capable of interfering with insect behavior, development, and physiological regulation. In particular, species such as *Enterolobium contortisiliquum* illustrate how Cerrado phytochemical diversity may be linked to practical applications in sustainable parasite management and veterinary bioinput development.

From an analytical perspective, the evidence suggests that different classes of plant-derived compounds may contribute to the development of multifunctional bioinsecticides with complementary modes of action against veterinary dipterans. Such biochemical diversity may reduce the likelihood of resistance development while offering greater ecological compatibility compared with conventional synthetic insecticides.

Despite these promising findings, important gaps remain in the available literature. Although different extraction methods are expected according to plant species, plant parts, and target metabolites, the substantial heterogeneity in extraction procedures and bioassay conditions among studies limits reproducibility and complicates direct comparisons of biological activity. In addition, limited toxicological assessment and the scarcity of field-scale validation studies still hinder the practical application of Cerrado-derived bioinputs in livestock systems. These challenges reinforce the need for more integrative and reproducible approaches in future investigations involving Cerrado flora and veterinary dipteran control.

Enterolobium contortisiliquum as a Representative Cerrado Species with Potential for Veterinary Bioinputs

Among the species identified in the reviewed literature, *Enterolobium contortisiliquum* stands out as a representative Cerrado species due to its reported bioactive potential and ecological relevance. As a native species widely distributed in the biome, its use in the development of plant-derived bioinputs may contribute to reducing dependence on synthetic insecticides while promoting the sustainable use of Cerrado biodiversity. In addition, the occurrence of bioactive compounds such as coumarins highlights its potential applicability in environmentally responsible livestock pest management strategies (Barros et al., 2023).

Several plant species from the Cerrado have been investigated for their bioactive potential in ectoparasite management. Among these, *Enterolobium contortisiliquum* (tamboril) has received growing scientific attention due to its multifunctional biological properties and ecological importance. Although direct evidence against *Haematobia irritans* remains limited, the reported phytochemical profile and biological activities associated with this species support its consideration as a promising model for future studies involving veterinary bioinputs and sustainable parasite control strategies (Barros et al., 2023).

Native to the Fabaceae family, *E. contortisiliquum* is widely distributed throughout the Cerrado and neighboring biomes, occurring from Mato Grosso to Rio Grande do Sul and extending into Bolivia, Paraguay, Argentina, and Uruguay (Bezerra et al., 2021). This broad distribution reflects a high degree of ecological adaptability and reinforces its relevance within native ecosystems.

Ecologically and productively, *E. contortisiliquum* performs multiple functions. Its nitrogen-fixing capacity and nutrient cycling contribute to soil enrichment, benefiting neighboring species and supporting agroecosystem stability (Inge et al., 2001; Cardoso et al., 2021). The species also provides canopy cover and thermal comfort in pasture environments, making it an important component in crop–livestock–forest integration systems. In urban and rural landscapes, its broad canopy and rapid growth are valued for shade and environmental restoration purposes (Barretto & Ferreira, 2011).

Beyond its ecological importance, *E. contortisiliquum* possesses recognized socioeconomic value. Its wood is characterized by moderate density, moisture resistance, and favorable workability, supporting applications in furniture manufacturing, rural structures, and artisanal production (Araújo et al., 2011). These multiple uses reinforce the strategic importance of the species within sustainable land-use systems and biodiversity-based production models. Figure 1 illustrates the general morphology of *E. contortisiliquum*, including the tree, leaves and fruit, which are characteristic diagnostic features of the species.

From a phytochemical perspective, *E. contortisiliquum* is a valuable source of secondary metabolites such as saponins, tannins, flavonoids, and cytolytic proteins, which function in plant defense against pathogens and herbivores and show promising potential for veterinary and agro-industrial applications. Studies have demonstrated that its extracts exhibit insecticidal, repellent, and antibacterial activity, particularly against parasites and microorganisms of livestock importance (Velasques et al., 2017; Castro et al., 2010).

Among the most relevant bioactive compounds is enterolobin, a protein isolated from *E. contortisiliquum* seeds that displays cytolytic activity and proven toxicity against *Callosobruchus maculatus* larvae (Velasques et al., 2017). This compound acts by promoting cell lysis and inhibiting larval development, demonstrating the potential of *E. contortisiliquum* as a biological control agent for agricultural pests and disease vectors.

Triterpenic saponins, which are abundant in the fruits and bark, constitute another major group of compounds. These metabolites exhibit detergent and emulsifying properties and are used in the formulation of soaps, cosmetics, and natural bioinsecticides (Sant'Ana et al., 2013). From a biological standpoint, saponins act as surfactants on the cell membranes of insects and microorganisms, altering their permeability and promoting cell lysis (Sharma et al., 2023). However, this same property, though valuable for pest control, requires caution, as excessive consumption of the fruits by herbivorous animals may lead to food poisoning—particularly during dry seasons, when forage availability is reduced (Tokarnia et al., 2012; Gadelha et al., 2015).

Figure 1. Tree (a), leaves (b), and fruit (c) of *Enterolobium contortisiliquum*.

Source: Author's elaboration.

In addition to saponins, condensed tannins—flavonoid polymerization products—have been quantified in significant concentrations in the bark of *E. contortisiliquum*, reaching approximately 20.83 mg per 100 mg of extract (Tirelli et al., 2010). These compounds play essential defensive roles by reducing plant palatability and digestibility for insects and ruminants, through their ability to bind to proteins and hinder enzymatic degradation (McDougall et al., 2005; Schaller, 2008). Furthermore, tannins display antifungal and antibacterial activity, reinforcing the antimicrobial potential of *E. contortisiliquum* and broadening its applicability as a multifunctional bioinput.

The set of compounds found in *E. contortisiliquum* reveals a multifunctional biochemical profile, in which different classes act synergistically—for instance, saponins and tannins exhibit a combined effect on membranes and proteins, thereby expanding the insecticidal spectrum. This diversity of mechanisms enhances the potential of tamboril as a strategic source for the development of veterinary bioinputs, particularly aimed at the integrated control of ectoparasites in sustainable livestock systems. Moreover, the simultaneous presence of compounds with insecticidal, antioxidant, antimicrobial, and immunomodulatory properties suggests that this species can contribute to the formulation of complex and multifunctional products, capable of acting not only in the direct control of pests but also in promoting animal health and ecological balance.

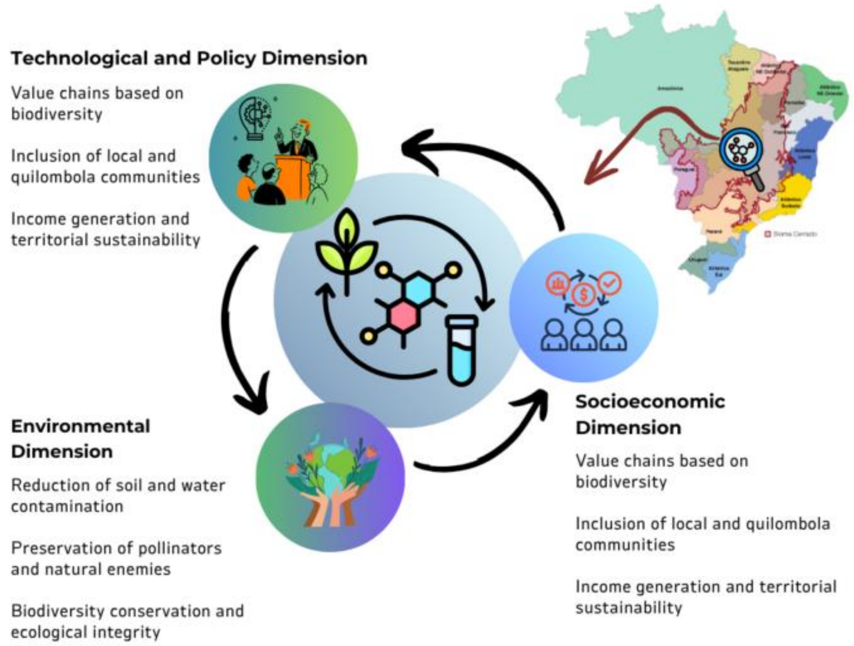
This integration of effects reinforces the view of tamboril as a bioeconomic model plant of the Cerrado, whose applications extend beyond the ecological domain, reaching productive and therapeutic dimensions. However, significant gaps still remain in the literature, particularly regarding methodological standardization and comparative toxicological assays, which are necessary to ensure the feasibility and safety of its large-scale application.

Environmental, Socioeconomic Implications, and Future Perspectives

The use of bioactive compounds derived from Cerrado plant species carries important implications for environmental sustainability and regional bioeconomy development. The partial replacement of synthetic pesticides with plant-derived bioinsecticides may reduce contamination of soil, water, and non-target organisms, thereby mitigating ecotoxicological risks and minimizing the accumulation of chemical residues in food chains (Barroso et al., 2023). This transition reinforces the growing interest in low-impact agricultural systems based on the sustainable use of natural resources and ecosystem conservation.

From an ecological perspective, bioinputs represent a pest management alternative compatible with ecosystem integrity. By favoring selective control and reducing dependence on broad-spectrum synthetic insecticides, these formulations may help preserve natural enemies, pollinators, and soil microorganisms, which are essential components of agroecosystem resilience and stability. In addition, the sustainable management and cultivation of native Cerrado species may support biodiversity conservation while reducing pressure associated with predatory extraction and habitat degradation. These multidimensional interactions are synthesized in Figure 2, which illustrates the environmental, socioeconomic, and technological dimensions associated with Cerrado-based bioinputs in livestock systems.

Figure 2. Systemic interactions of Cerrado-based bioinputs in sustainable livestock systems.



Source: Author's elaboration.

The diagram illustrates the interconnection among the environmental, socioeconomic, and technological–policy dimensions associated with the use of Cerrado-derived bioinputs. In this framework, Cerrado biodiversity represents a valuable source of bioactive compounds with potential applications in sustainable livestock pest management and bioinput development. The circular arrangement highlights feedback mechanisms among dimensions, in which environmental sustainability supports social inclusion, local participation fosters ethical technological development, and innovation contributes to ecosystem resilience, consolidating a regenerative bioeconomy model for livestock systems.

From a socioeconomic perspective, the development of bioinputs from native Cerrado species may stimulate sustainable value chains based on biodiversity valorization and regional development. Local communities, family farmers, and quilombola peoples—historically associated with ethnobotanical and insecticidal knowledge—may play an important role through localized production systems and solidarity-based bioeconomy initiatives (Lima, 2025; Benini et al., 2010). Such integration may promote income generation, strengthen social inclusion, and reduce dependence on imported agricultural inputs and environmentally harmful practices.

The consolidation of this emerging sector also depends on institutional and policy support. Public policies aimed at research, certification, and commercialization of plant-derived bioinputs may strengthen innovation ecosystems and facilitate technology transfer. Investments in biotechnology and regional innovation hubs may support large-scale production while reinforcing the relationship between scientific development and community-based applications, promoting the sustainable and ethical use of Brazil's genetic resources.

Despite the growing body of evidence regarding the insecticidal and repellent potential of Cerrado plant species, current research remains largely exploratory. Most studies are limited to in vitro or semi-controlled assays involving model species such as *Haematobia irritans* and *Aedes aegypti* (Barros et al., 2023; Braga et al., 2017). Although different extraction methods are expected according to plant species, plant parts, and target metabolites, the substantial heterogeneity in extraction procedures and bioassay conditions among studies limits reproducibility and complicates direct comparisons of biological activity (Freitas et al., 2024). This heterogeneity also hampers dosage standardization and field validation of botanical insecticides.

From a technological perspective, scaling up plant-based formulations remains a major challenge. The chemical variability of secondary metabolites—affected by plant part, phenological stage, and environmental conditions—directly influences bioactivity and requires optimized production and quality-control strategies (Sharma et al., 2023). Technological advances such as microencapsulation and nanocarrier systems may improve formulation stability and prolong residual activity under field conditions, although these approaches remain scarcely explored for Cerrado-derived compounds.

Ecotoxicological and selectivity assessments also remain limited. Although species such as *Enterolobium contortisiliquum* and *Azadirachta indica* demonstrate promising activity against hematophagous dipterans, their effects on non-target organisms—including pollinators and beneficial arthropods—are still insufficiently understood (Barros et al., 2023; Deleito & Borja, 2008). Comprehensive risk assessment is therefore essential to ensure environmental compatibility and avoid undesirable ecological trade-offs within integrated pest management systems.

Another important challenge involves the socioeconomic and regulatory dimensions of innovation. The sustainable use of Cerrado species depends on mechanisms capable of reconciling biodiversity conservation with local socioeconomic development. Although community participation and traditional knowledge are increasingly recognized within the emerging bioeconomy (Lima, 2025; Benini et al., 2010), institutional barriers—including limited regulatory frameworks, insufficient protection of traditional knowledge, and restricted investment in biotechnology transfer—still constrain sectoral consolidation. Expanding support for applied research, certification systems, and regional innovation networks may help bridge the gap between laboratory-scale findings and practical application.

Although ethnobotanical knowledge was not specifically included as a selection criterion in this review, traditional uses associated with Cerrado plant species may contribute to future investigations involving biodiversity valorization and sustainable bioinput development. The integration of traditional knowledge with scientific research may favor the development of regionally adapted bioinputs while strengthening the responsible use of natural resources and the participation of local communities (Lima, 2025; Benini et al., 2010).

In the long term, the integration of phytochemical research, chemical ecology, and biotechnology will be decisive for transforming Cerrado biodiversity into tangible technological assets. Collaborative networks connecting universities, research institutions, and farming communities may accelerate the development of standardized bioformulations adapted to different ecological and production systems. In addition, omics-based tools and computational modeling may improve the identification of synergistic interactions among bioactive molecules and enhance the predictability and effectiveness of plant-derived insecticides.

Overall, translating experimental findings into scalable innovation depends on strengthening interdisciplinary research, ethical bioprospecting practices, and sustainable value chains. Advancing these dimensions may not only support the scientific validation of Cerrado-derived bioinputs but also reinforce their contribution to environmentally compatible livestock pest management and sustainable biotechnology development.

CONCLUSION

The reviewed literature indicates that Cerrado plant species constitute promising sources of bioactive compounds with potential applications in the sustainable management of dipterans of veterinary importance, including hematophagous species such as *Haematobia irritans*. The analyzed studies demonstrate that secondary metabolites, including terpenoids, phenolics, alkaloids, saponins, and coumarins, may contribute to insecticidal, repellent, and growth-regulating activities relevant to livestock pest management.

Among the species identified in the reviewed literature, *Enterolobium contortisiliquum* emerged as a representative Cerrado species due to its reported bioactive profile and potential applicability in plant-derived bioinputs. However, current evidence remains limited by methodological heterogeneity, insufficient toxicological assessment, and the scarcity of field-scale validation studies. Overall, the findings reinforce the importance of expanding integrative and experimentally validated investigations involving Cerrado biodiversity and plant-derived bioinputs for veterinary applications. Future research should prioritize reproducibility, safety assessment, and field validation in order to support the practical use of bioactive compounds in sustainable livestock systems.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest (personal, scientific, commercial, political, or financial) in the submitted manuscript.

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