Occurrence of acaricide resistance in *Rhipicephalus microplus* in brazilian municipalities: an integrative review

[Ocorrência de resistência a acaricidas do *Rhipicephalus microplus* em municípios brasileiros: uma revisão integrativa]

Tarcísio Miguel Teixeira[1] (iD) , Léo Mathias Miloca[1] (iD) , Kenny Tsuyoshi Sakane[1] (iD) , Selma Alves Rodrigues[1] (iD) , Pedro Henrique Lima Marchetti[1] (iD) , Ranulfo Piau Junior[1] (iD) , Carlos Eduardo Ribeiro[2] (iD) , Zilda Cristiani Gazim*[1] (iD)

1 Universidade Paranaense (Unipar), Umuarama, Paraná, Brazil ROR
2 Instituto Federal do Paraná (IFPR), Umuarama, Paraná, Brazil ROR
*corresponding author: cristianigazim@prof.unipar.br

Abstract: The objective of this study was to conduct an integrative review on the resistance of the tick *Rhipicephalus microplus* to synthetic acaricides, surveying the Municipalities where collections for resistance testing were carried out. The search was conducted in the Virtual Library of Veterinary Medicine and Animal Science (BVS-Vet), Google Scholar, CAPES Journal Portal, Web of Science, Scopus, and PubMed databases, considering publications between 2004 and 2025. Forty-six studies that met the inclusion criteria were selected. The analysis revealed that most of the research was conducted in the states of Rio Grande do Sul (69 Municipalities), Minas Gerais (66), and Mato Grosso do Sul (40). In the other states, few or no records were observed. The number of states, Municipalities, and publications found for pyrethroids were 11, 249, and 35; organophosphates 11, 145, and 28; carbamates 1, 37, 3; formamidine 12, 178, 27; phenylpyrazole 8, 65, 12; macrocyclic lactones 8, 27, 16; and benzylurea 6, 15, 10, respectively. Considering that livestock farming is present in 4,939 Brazilian Municipalities, available data on resistance are still limited. These results reinforce the need to implement public policies aimed at developing and implementing a national plan to combat cattle ticks.

Keywords: laboratory tests of acaricides; ectoparasites; geolocation; epidemiology.

Resumo: O objetivo deste trabalho foi realizar uma revisão integrativa sobre a resistência do carrapato *Rhipicephalus microplus* a acaricidas sintéticos, com levantamento dos Municípios brasileiros onde foram realizadas as coletas para os testes de resistência. A busca foi conduzida nas bases de dados Biblioteca Virtual em Medicina Veterinária e Zootecnia (BVS-Vet), Google Scholar, Portal de Periódicos da CAPES, Web of Science, Scopus e PubMed, considerando publicações entre 2004 e 2025. Foram selecionados 46 estudos que atenderam aos critérios de inclusão. A análise revelou que a maioria das pesquisas foi conduzida nos Estados do Rio Grande do Sul (69 Municípios), Minas Gerais (66) e Mato Grosso do Sul (40). Nos demais Estados, foram observados poucos ou nenhum registro. O número de Estados, Municípios e publicações encontradas para os piretróides foram 11, 249, 35; organofosforados 11, 145, 28; carbamatos 1, 37, 3; formamidina 12, 178, 27; fenilpirazol 8, 65, 12; lactonas macrocíclicas 8, 27, 16 e benzilureia 6, 15, 10, respectivamente. Considerando

que a pecuária está presente em 4.939 Municípios brasileiros, verifica-se que os dados disponíveis sobre resistência ainda são limitados. Esses resultados reforçam a necessidade de implantação de políticas públicas voltadas à elaboração e execução de um plano nacional de combate ao carrapato bovino.

Palavras-chave: biocarrapaticidograma; ectoparasitos; geolocalização; epidemiologia.

1. Introduction

The cattle tick, in addition to the suffering it inflicts on animals, is also responsible for significant economic losses. Miloca et al.[1], conducting regional research in the State of Paraná and extrapolating the data to the Brazilian livestock herd, predicted that the acquisition costs of the products alone could reach US$1.733 billion. In studies conducted by Grisi et al. [2] investigating national losses in milk and meat production, the value of US$ 3.24 billion annually was found in Brazil.

In turn, the study with econometric simulations carried out by Calvano et al. [3], with crossbred animals in three production systems, identified the following differences between infested herds and those treated with acaricides: the extensive system differed by 6.13 % in meat production per hectare; the semi-intensive system by 1.22 %; and the intensive system by 3.25 %. In a study carried out in India, Singh et al. [4] found that losses in crossbred animals can reach 65.63 % and in native animals 9.73 %. These data are justified by the natural resistance that zebu cattle have developed in a process of co-evolution with this ectoparasite [5].

Considering the aforementioned studies, the Brazilian herd was 238,626,442 head in 2023 [6], which means that most of the Brazilian beef cattle herd is raised in an extensive system, and the average price of a calf in 2024 was R$ 2,172.60 [7] (the price of the calf was chosen so as not to overestimate the values). It is possible to estimate a loss of 31.8 billion reais annually. However, it is noted that there is a need to improve studies on the damage caused by the cattle tick, since, according to Vanderstichel [8], Jonsson [9], and Jongejan and Uilenberg [10], the econometric equations used for these studies are not adequate, as well as the data are very broad generalizations that may result in unreliable data.

In addition to direct damage, ticks can also transmit parasites responsible for Bovine Parasitic Sadness [11], which can lead to the death of animals that have not developed an immune response to this disease. Given these losses and the obligation to raise animals in conditions that ensure their well-being, controlling cattle ticks is an ongoing activity on Brazilian farms [12]. Among the options presented for this treatment, synthetic and semi-synthetic chemical molecules are the most commonly used [13]. However, this method faces a major difficulty: selecting resistant populations after repeated use in the same location [14].

The genes responsible for providing resistance to the active ingredients may be uncommon in the population at the beginning of the process. However, as the use of the active ingredient increases, it promotes selection pressure, meaning that individuals with resistance will be selected and will gradually increase, resulting in the formation of a predominantly resistant population [15]. The rate at which a resistant population forms will depend on how the active ingredients are applied, the factors linked to the genes that provide resistance, and the characteristics of the environment. In the case of genes, the initial frequency of the resistance alleles and the inheritance pattern of the resistant allele (dominant, co-dominant, or recessive) are determining factors. Regarding the application methods, it will depend on whether they were carried out at

the appropriate concentrations, the quality of the chosen drugs, whether or not there was rational handling of the molecules, and the availability of sites that serve as refuge for future generations and that are not affected by acaricides [16]. Another important factor is the movement of animals, which can introduce these resistant individuals into new environments, expanding the problem and reducing control options [17].

Therefore, it is necessary to have a detailed understanding of the resistance profile of populations to acaricides and to promote their rational use to delay the emergence of resistance [18]. The use of acaricides, even when following the technical recommendations of the companies that produce them, has the potential to exert selection pressure and promote the formation of resistant populations. Therefore, the misuse of these products may accelerate and intensify this process, creating multi-resistant populations. The consequence of this intensive use increases the possibilities of meat and milk contamination, which, when consumed, can lead to human poisoning, causing neurotoxic and endocrine system disorders, allergies, coughs, and abnormalities in lung function. This situation reinforces the demand for research and technologies that promote the use of natural products with lower environmental and human health impacts [19].

However, the selection of substrates and/or essential oils with acaricidal potential and the development, from these, of products authorized for commercialization involves complex and lengthy research, as well as their acquisition not being simple and lacking *in vivo* testing, which has hindered the emergence of commercial products of this nature [20, 21]. It is worth highlighting that, unlike purely synthetic products, those of plant origin present a much greater range of variability in their composition, and, for this reason, there is less possibility of the selection of resistant tick populations. However, this positive quality of plant-based compounds requires more time and investment for safety testing and standardization of their use [22].

Chemical control is the most widely used method in the fight against ticks [23]. Therefore, the need for synthetic chemical control should not be discarded; on the contrary, it is necessary to keep the active ingredients viable, avoiding their depletion. However, for this purpose, it is necessary to understand the resistance situation in the country, and this information should serve as a basis for the development of a public policy that can implement the rational use of commercial acaricides.

In this sense, this research proposed to conduct a survey of studies on the resistance of the tick *Rhipicephalus microplus* to synthetic acaricides, indicating the municipalities where ticks were collected for resistance testing, such as the acaricide susceptibility test, and their respective states.

2. Material and methods

The methodological approach was to conduct an integrative literature review, which consists of the following steps: defining the information to be extracted, conducting the literature search, compiling and evaluating the data, analyzing the data, interpreting and presenting the results [24]. The parameters for searching and selecting the information were: i. Only studies that performed resistance tests of *R. microplus* to acaricides were selected: adult immersion test, larval immersion test, and larval packet test; ii. The threshold for resistance adopted was that of the World Health Organization, that is, when the efficiency of the tests was less than 95 % [25]; and iii. Only studies that identified the municipalities where resistance phenomena were recorded were selected.

The databases used were the Virtual Health Library – Veterinary Medicine and Animal Science (BVS – VET), Google Scholar, the Capes Periodicals Portal, Web of Science, Scopus, and PubMed. The descriptors used and their combinations to select the target articles were: "evaluation" AND "resistance" AND "Pyrethroids" AND "*Rhipicephalus microplus*" AND "Brazil". The third descriptor is changed in each search according to the list: Cypermethrin, Deltametrin, Alphametrin, Organophosphorus, Dichlorvos, Vapona, Chlorfenvinphos, Supona, Carbamate, Carbaryl, Amitraz, Formamidine, Fipronil, Phenylpyrazoles, Macrocyclic Lactone, Ivermectin, Abamectin, Doramectin, Eprinomectin, Spinisyn, Fluralaner, Benzoylurea, and Isoxazoline and its versions in Portuguese.

Using the descriptors, they selected the articles which were then subjected to exclusion criteria. Next, data on the resistance phenomenon were extracted from the selected articles, and tables were constructed for each group of active ingredients, indicating the states, municipalities, and respective authors. Based on the data organized in the Tables, maps were generated in Google Earth and Inkscape environments, showing each State and Municipality and indicating resistance phenomena according to the active ingredients (Figures S1, S2, and S3). Finally, a quantitative and qualitative analysis of the information obtained was carried out to determine if there is a standardization of studies carried out in Brazil or by the state that would allow for the establishment of epidemiological information on the parasite and more efficient control methods.

3. Results

Using the descriptors, 146 articles were found, and after selection, 46 met the requirements established in the exclusion criteria. The results were consolidated and presented in the form of Tables 1 to 9. Tables 1 to 7 present the acaricide classes, the Brazilian municipalities where resistance was identified, their respective states, and references to the studies conducted.

Table 1. Brazilian municipalities and states with records of the presence of *Rhipicephalus microplus* resistant to pyrethroids (permethrin, deltamethrin, and cypermethrin).

States	Municipalities	References	Endurance test
BA	Campo Formoso.	Raynal et al. (2018) [26]	AIT
	Guanambi, Ibiassucê, Itapetinga, Eunápolis, Amargosa, Conceição do Jacuípe, Feira de Santana, Serrinha, Capim Grosso, Miguel Calmon, Várzea do Poço, Piritiba, Mundo Novo, Morro do Chapéu, Várzea Nova, Jacobina, Jeremoabo, Luiz Eduardo Magalhães, and Ribeira do Pombal.	Santana et al. (2015) [27]	AIT
	Miguel Calmon.	Raynal et al. (2020) [28]	AIT
CE	Pacajus.	Higa et al. (2016 [29]	AIT
DF	Brasília.	Higa et al. (2016 [29]	AIT
MG	Araxá, Barbacena, Belo Vale, Bom Jardim de Minas, Bonfim, **Cachoeira Paulista****, Campina Verde, Carmo do Cajuru, Congonhal, Cristina, Delfim Moreira, Desterro de Entre Rios, **Franca*****, Guaraciaba, Ituiutaba, Jequitinhonha, João Pinheiro, Lagoa Dourada, Lagoa Formosa, Lima Duarte, Materlândia, Nanuque, Peçanha, Pompeu, Prados, Rio Pomba, Santa Cruz do Escalvado, Santa Rita do Ibitipoca, Santo Antonio do Grama, São Domingos do Prata, São João Del Rei, São João Evangelista, São Sebastião do Oeste, and São Vicente de Minas.	Marchesini et al. (2020) [30]	AIT and LPT
	Bocaiúva.	Carneiro et al. (2015) [31]	AIT
	Funilândia, Moema, Bocaiuva, Prudente de Morais, Brumadinho, Igarapé, and Montes Claros.	Zaldívar et al. (2024) [32]	AIT and LPT
	Guapé, Carmo da Mata, Passa Tempo, Oliveira, Boa Esperança, Bom Sucesso, Nepomuceno, Perdões, Lavras, Ijaci, Itumirim, Ingaí, Itutinga, and Nazareno.	Machado et al. (2014) [33]	AIT
	Uberlândia	Domingues (2012) [34]	LPT
	Vazante.	Mastrantonio et al. (2022) [35]	AIT
	Monte Carmelo.	Higa et al. (2016) [29]	LPT
MT	Nova Mutum.	Higa et al. (2016) [29]	AIT
MS	Água Clara.	Junior et al. (2022) [36]	AIT and *In vivo*
	Bandeirantes, Camapuã, Rio Negro, Rio Verde de Mato Grosso, Rochedo e São Gabriel do Oeste, Anastácio, Aquidauana, Dois Irmãos do Buriti, Porto Murtinho, Bela Vista, Bonito, Caracol, Campo Grande, Jaraguari, Sidrolândia, Terenos, Chapadão do Sul, Costa Rica, Angélica, Dourados, Glória de Dourados, Maracaju, Nova Alvorada do Sul, Ponta Porã, Rio Brilhante, Vicentina, Amambai, Eldorado, Iguatemi, Naviraí, Paranhos, Bataguassu, Nova Andradina, Aparecida do Taboado, Paranaíba, Água Clara, Ribas do Rio Pardo, and Três Lagoas.	Gomes et al. (2011) [37]	AIT
	Campo Grande, Iguatemi, Jaraguari, Nioaque, Ponta Porã, Paranaíba, Anastácio, Dois Irmãos do Buriti, Nova Alvorada do Sul******, and Aparecida do Taboado.	Higa et al. 2016 [29]	AIT and LPT
	Campo Grande.	Valsoni et al. (2020) [38]	AIT and LIT
PA	Santarém and Mojuí dos Campos.	Sousa et al. (2022) [39]	AIT

PB	Areia and Bananeiras.	Silva et al. (2020) [40]	AIT and LIT
	Gado Bravo, Queimadas, Barra de Santana, Campina Grande, Sousa, Vista Serrana, Pombal, Catingueira, Serra Branca, Marizópolis, S. J. de Piranhas, S. J. R. do Peixe, São Domingos Aparecida, S. J. L. Tapada, Paulista, S. S. Umbuzeiro, Sumé, Aroeiras, Cajazeiras, Patos, Monteiro, Prata, Boqueirão, Soledade, and Pocinhos.	Vilela et al. (2020) [41]	LPT and LIT
PE	Bom Conselho.	Silva et al. (2024) [42]	AIT
	Garanhuns, Brejão, Terezinha, Bom Conselho, São João, Recife, Camaragibe, Timbaúba, Vitória de Santo Antão, Bezerros, Limoeiro, Ribeirão, Gravatá, and Brejo da Madre de Deus.	Santana et al. (2019) [43]	AIT
PR	Medianeira and Santa Tereza D'Oeste.	Marchesini et al. (2020) [30]	AIT and LPT
	Santana do Itararé e Siqueira Campos.	Dolenga et al. (2022) [44]	AIT and LPT
RO	Jarú, Ouro Preto do Oeste, Ji-Paraná, Presidente Médici, and Rolim de Moura.	Brito et al. (2011) [45]	AIT
	Rolim de Moura.	Gomes et al. (2011) [37]	AIT
	Teixeirópolis.	Gasparotto et al. (2020) [46]	AIT
RS	Alegrete, Caçapava do Sul, Cacequi, Cachoeira do Sul, Dilermando de Aguiar, Encruzilhada do Sul, Faxinal do Soturno, Jari, Júlio de CasLIThos, Lavras do Sul, Nova Esperança do Sul, Nova Palma, Paraíso do Sul, Pinhal Grande, Restinga Sêca, Rosário do Sul, Santa Bárbara do Sul, Santa Maria, Santiago, São Francisco de Assis, São Gabriel, São Martinho da Serra, São Pedro do Sul, São Sepé, São Vicente do Sul, Silveira Martins, and Vila Nova do Sul.	Duarte (2021) [47]	AIT and LPT
	Barra do Quaraí, Uruguaiana, Quaraí, Sant'Ana do Livramento, Rosário do Sul, São Gabriel, Santa Margarida do Sul, Alegrete, Itaqui, Manoel Viana, São Francisco de Assis, Maçambará, São Borja, and Garruchos.	Pedrassani, Reisdorfer (2015) [48]	AIT
	Cacequi, Dilermando de Aguiar, Jari, Júlio de CasLIThos, Pinhal Grande, Restinga Seca, Santa Maria, Santiago, São Martinho da Serra, São Pedro do Sul, São Sepé, São Vicente do Sul, Tupanciretã, and Unistalda.	Carneiro et al. (2015) [31]	AIT
	Eldorado do Sul.	Reck et al. (2014) [49]	LPT and LIT
	São Jerônimo, São Francisco de Assis, São Borja, Santo Antônio das Missões, Santo Antônio da Patrulha, Santa Maria, Rosário do Sul, Quaraí, Minas do Leão, Lavras do Sul, Gravataí, General Câmara, Encruzilhada do Sul, Eldorado do Sul, Dom Pedrito, Capivari do Sul, Cacequi, Butiá, Arroio dos Ratos, São Leopoldo, Alegrete, Bagé, Barra do Ribeiro, Bossoroca, Cachoeira do Sul, Capão do Cipó, Garruchos, Glorinha, Itaqui, Montenegro, Pântano Grande, Rio Pardo, Salto do Jacuí, Santana do Livramento, Caçapava do Sul, Santana do Livramento, Santiago, São Gabriel, Santo Antônio da Patrulha, São Sepé, Uruguaiana, and Vacaria.	Klafke et al. (2017) [50]	AIT, LPT, and LIT
	Alegrete, Arroio Grande, Cacequi, Cachoeira do Sul, Dilermando de Aguiar, Erval Seco, Jóia, Lajeado, Nova Palma, Pântano Grande, Restinga Seca, Rio Pardo, Rosário do Sul,	Camillo (2009) [51]	AIT

	Santa Maria, Santa Rosa, Santiago, Santo Antônio das Missões, São Borja, São Gabriel, São Martinho da Serra, São Pedro do Sul, São Sepé, Toropi, and Tupaciretã.		
	Eldorado do Sul, Guaíba, and Butiá	Jongejan et al. (2024) [52]	LPT and RaTexT®*****
SC	Itaiópolis and Canoinhas.	Santana et al. (2015) [27]	AIT
	Bady Bassitt and Ipiguá.	Ueno et al. (2012) [53]	LPT
	Jaboticabal	Higa 2016 et al. [29]	AIT
SP	Durandé****, Ouroeste, and Potirendaba.	Marchesini et al. (2020) [30]	AIT and LPT
	Jacareí.	Torres-Santos et al. (2021) [54]	AIT
	São José do Rio Pardo and São Paulo.	Moraes et al. (2023) [55]	*In vivo*
	São Pedro.	Dolenga (2020) [56]	AIT

BA: Bahia; ES: Espírito Santo; MG: Minas Gerais; MS: Mato Grosso do Sul; PA: Pará; PB: Paraíba; PE: Pernambuco; PR: Paraná; RO: Rondônia; RS: Rio Grande do Sul; SC: Santa Catarina; SP: São Paulo. * Ritápolis was listed in Espírito Santo, but it belongs to Minas Gerais.** Cachoeira Paulista was listed as being in Minas Gerais, but it actually belongs to São Paulo. *** Franca was listed in Minas Gerais, but it belongs to São Paulo. **** Durandé was nominated in São Paulo, but he belongs to Minas Gerais. ***** The study used the LPT with adaptation, and RaTexT® (Rapid Tick Exposure Test) is a new methodology that is being tested. ****** Nova Alvorada do Sul was listed as belonging to Minas Gerais, but it actually belongs to Mato Grosso do Sul. AIT: Adult immersion test (acaricide biogram); LPT: Larval packet test; LIT: Larval immersion test.

Table 2. Brazilian municipalities and states with records of the presence of *Rhipicephalus microplus* resistant to organophosphates (diazinon, dioxathion, coumaphos, carbofenothion, ethion, phosmet, crotoxyphos, chlorfenvinphos, bromophos LIT, and chlorpyrifos).

States	Municipalities	References	Endurance test
BA	Campo Formoso.	Torres-Santos et al. (2021) [54]	AIT
	Ipiaú.	Marchesini et al. (2020) [30]	AIT and LPT
	Miguel Calmon.	Raynal et al. (2020) [28]	AIT
ES	João Neiva and Ecoporanga.	Marchesini et al. (2020) [30]	AIT and LPT
	Montanha.	Higa et al. (2016) [29]	LPT
MG	Funilândia, Moema, Bocaiuva, Prudente de Morais, Brumadinho, Igarapé, and Montes Claros.	Zaldívar et al. (2024) [32]	AIT and LPT
	Guapé, Carmo da Mata, Passa Tempo, Oliveira, Boa Esperança, Bom Sucesso, Nepomuceno, Perdões, Lavras, Ijaci, Itumirim, Ingaí, Itutinga, and Nazareno.	Daher et al. (2012) [57]	AIT
	Santa Rita do Ibitipoca, Peçanha, Cristina, São João Evangelista, Peçanha, Bonfim, Prados, Barbacena, Carmo do Cajuru, Belo Vale, Jequitinhonha, São Domingos do Prata, São João Del Rei, **Cachoeira Paulista***, Congonhal, Lagoa Dourada, Delfim Moreira, Ituiutaba, Santa Rita do Ibitipoca, Rio Pomba, Guaraciaba, Pompeu, São Sebastião do Oeste, Lagoa Formosa, Nanuque, and Alpinópolis.	Marchesini et al. (2020) [30]	AIT and LPT
	Uberaba.	Santana et al. (2019) [43]	AIT
	Uberlândia	Domingues (2012) [34]	LPT
	Vazante.	Mastrantonio et al. (2022) [35]	AIT
MS	Água Clara.	Junior et al. (2022) [36]	AIT and *In vivo*
	Campo Grande, Nova Alvorada do Sul, Dois Irmãos do Buriti, and Aparecida do Taboado.	Higa et al. (2016) [29]	AIT and LPT.
	Campo Grande.	Valsoni et al. (2020) [38]	AIT and LIT

PB	Gado Bravo, Queimadas, Barra de Santana, Pombal, Serra Branca, Marizópolis, São José de Piranhas, São João do Rio do Peixe, São Domingos, Aparecida, São José de Lagoa Tapada, Paulista, São Sebastião do Umbuzeiro, Sumé, Patos, Monteiro, Boqueirão, Soledade, and Pocinhos.	Vilela et al. (2020) [41]	LPT and LIT
PE	Bom Conselho.	Silva et al. (2024) [42]	AIT
PR	Pinhais, and Siqueira Campos.	Dolenga et al. (2020) [46]	
	Santa Tereza D'Oeste.	Marchesini et al. (2020) [30]	AIT and LPT
	Santana do Itararé e Siqueira Campos.	Dolenga et al. (2022) [44]	AIT and LPT
RJ	Vassouras and Pinheiral.	Marchesini et al. (2020) [30]	AIT and LPT
RO	Jarú, Ouro Preto do Oeste, Ji-Paraná, Presidente Médici, and Rolim de Moura.	Brito et al. (2011) [45]	AIT
	Rolim de Moura.	Silva et al. (2020) [40]	AIT and LIT
	Teixeirópolis.	Gasparotto et al. (2020) [46]	AIT
RS	Alegrete, Arroio dos Ratos, Bagé, Barra do Ribeiro, Bossoroca, Caçapava do Sul, Cachoeira do Sul, Capão do Cipó, Dom Pedrito, Eldorado do Sul, Garruchos, Glorinha, Gravataí, Itaqui, Lavras do Sul, Montenegro, Pantano Grande, Quaraí, Rio Pardo, Rosário do Sul, Salto do Jacuí, Santa Maria, Santana do Livramento, Santiago, Santo Antônio da Patrulha, Santo Antônio das Missões, São Gabriel, São Jerônimo, São Leopoldo, São Sepé, Uruguaiana, and Vacaria.	Klafke et al. (2017) [50]	AIT, LPT and LIT
	Cacequi, Dilermando de Aguiar, Jari, Júlio de CasLIThos, Pinhal Grande, Restinga Seca, Santa Maria, Santiago, São Martinho da Serra, São Pedro do Sul, São Sepé, São Vicente do Sul, Tupanciretã, and Unistalda.	Machado et al. (2014) [33]	AIT
	Eldorado do Sul.	Reck et al. (2014) [49]	LPT and LIT
	Alegrete, Arroio Grande, Cacequi, Cachoeira do Sul, Dilermando de Aguiar, Erval Seco, Jóia, Lajeado, Nova Palma, Pântano Grande, Restinga Seca, Rio Pardo, Rosário do Sul, Santa Maria, Santa Rosa, Santiago, Santo Antônio das Missões, São Borja, São Gabriel, São Martinho da Serra, São Pedro do Sul, São Sepé, Toropi, and Tupanciretã.	Camillo (2009) [51]	AIT
SP	Bady Bassitt and Ipiguá.	Ueno et al. (2012) [53]	LPT
	Durandé and Potirendaba.	Marchesini et al. (2020) [30]	AIT and LPT
	São José do Rio Pardo.	Moraes et al. (2023) [55]	*In vivo*

BA: Bahia; ES: Espírito Santo; MG: Minas Gerais; MS: Mato Grosso do Sul; PB: Paraíba; PE: Pernambuco; PR: Paraná; RJ: Rio de Janeiro; RO: Rondônia; RS: Rio Grande do Sul; SP: São Paulo. * Cachoeira Paulista was listed as being in Minas Gerais, but it actually belongs to São Paulo. AIT: Adult immersion test (acaricide biogram); LPT: Larval packet test; LIT: Larval immersion test.

Table 3. Brazilian municipalities and states with records of the presence of *Rhipicephalus microplus* resistant to carbamates (carbaryl and promacil).

States	Municipalities	References	Endurance test
	Água Clara.	Junior et al. (2022) [36]	AIT and *In vivo*
MS	Bandeirantes, Camapuã, Rio Negro, Rio Verde de Mato Grosso, Rochedo e São Gabriel do Oeste, Anastácio, Aquidauana, Dois Irmãos do Buriti, Porto Murtinho, Bela Vista, Bonito, Caracol, Campo Grande, Jaraguari, Sidrolândia, Terenos, Chapadão do Sul, Costa Rica, Angélica, Dourados, Glória de Dourados, Maracaju, Nova Alvorada do Sul, Ponta Porã, Rio Brilhante, Vicentina, Amambai, Eldorado, Iguatemi, Naviraí, Paranhos, Bataguassu, Nova	Gomes et al. (2011) [37]	AIT

| | Andradina, Aparecida do Taboado, Paranaíba, Água Clara, Ribas do Rio Pardo, and Três Lagoas. | | |
| | Campo Grande. | Valsoni et al. (2020) [38] | AIT and LIT |

MS: Mato Grosso do Sul; PB: Paraíba. AIT: Adult immersion test (acaricide biogram); LPT: Larval packet test; LIT: Larval immersion test.

Table 4. Brazilian municipalities and states with records of the presence of *Rhipicephalus microplus* resistant to Formamidine (amitraz and cimiazole).

States	Municipalities	References	Endurance test
BA	Campo Formoso.	Torres-Santos et al. (2021) [54]	AIT
	Guanambi, Ibiassucê, Itapetinga, Eunápolis, Amargosa, Conceição do Jacuípe, Feira de Santana, Serrinha, Capim Grosso, Miguel Calmon, Várzea do Poço, Piritiba, Mundo Novo, Morro do Chapéu, Várzea Nova, Jacobina, Jeremoabo, Luiz Eduardo Magalhães, and Ribeira do Pombal.	Raynal et al. (2018) [26]	AIT
	Ipiaú.	Marchesini et al. (2020) [30]	AIT and LPT
	Miguel Calmon.	Raynal et al. (2020) [28]	AIT
CE	Pacajus	Higa et al. (2016) [29]	AIT
ES	João Neiva, Ritápolis*, and Ecoporanga.	Marchesini et al. (2020) [30]	AIT and LPT
	Montanha.	Higa et al. (2016) [29]	LPT
MG	Alpinópolis, Araxá, Barbacena, Bom Jardim de Minas, Bonfim, Cachoeira Paulista*, Campina Verde, Candeias, Carmo do Cajuru, Congonhal, Cristina, Delfim Moreira, Desterro de Entre Rios, Franca**, Guaraciaba, Ituiutaba, Jequitinhonha, João Pinheiro, Lagoa Dourada, Lagoa Formosa, Lima Duarte, Materlândia, Nanuque, Peçanha, Pompeu, Prados, Rio Pomba, Santa Cruz do Escalvado, Santa Rita do Ibitipoca, São Domingos do Prata, São João Del Rei, São João Evangelista, São Sebastião do Oeste, and São Vicente de Minas.	Marchesini et al. (2020) [30]	AIT and LPT
	Bocaiúva.	Carneiro et al. (2015) [31]	AIT
	Guapé, Carmo da Mata, Passa Tempo, Oliveira, Boa Esperança, Bom Sucesso, Nepomuceno, Perdões, Lavras, Ijaci, Itumirim, Ingaí, Itutinga, and Nazareno.	Daher et al. (2012) [57]	AIT
	Vazante.	Mastrantonio et al. (2022) [35]	AIT
	Monte Carmelo	Higa et al. (2016) [29]	LPT
MS	Campo Grande.	Valsoni et al. (2020) [38]	AIT and LIT
	***Iguatemi, Campo Grande, Nioaque, Ponta Porã, Jaraguari, Nova Alvorada do Sul, Dois Irmãos do Buriti, Terenos, Vicentina, Bela Vista, Dourados, and Rochedo.	Higa et al. (2016) [29]	AIT and LPT
PB	Queimadas, Campina Grande, Sousa, Vista Serrana, Pombal, Catingueira, Serra Branca, Marizópolis, São João de Piranhas, São Domingos, Aparecida, São José de Lagoa Tapada, Paulista, São Sebastião do Umbuzeiro, Sumé, Aroeiras, Patos, Monteiro, Soledade, and Pocinhos.	Vilela et al. (2020) [41]	LPT and LIT
PE	Bom Conselho.	Silva et al. (2024) [42]	AIT
	Garanhuns, Brejão, Terezinha, Bom Conselho, São João, Recife, Camaragibe, Timbaúba, Vitória de Santo Antão, Bezerros, Limoeiro, Ribeirão, Gravatá, and Brejo da Madre de Deus.	Santana et al. (2015) [27]	AIT
PR	Santa Tereza D'Oeste and Medianeira.	Marchesini et al. (2020) [30]	AIT and LPT

States	Municipalities	References	Endurance test
	Santana do Itararé, Siqueira Campos.	Dolenga et al. (2022) [44]	AIT and LPT
RJ	Pinheiral and Vassouras.	Marchesini et al. (2020) [30]	AIT and LPT
RN	Mossoró.	Coelho et al. (2013) [58]	AIT
RO	Jarú, Ouro Preto do Oeste, Ji-Paraná, Presidente Médici, and Rolim de Moura.	Brito et al. (2011) [45]	AIT
	Rolim de Moura.	Silva et al. (2020) [40]	AIT and LIT
	Teixeirópolis.	Gasparotto et al. (2020) [46]	AIT
RS	Alegrete, Arroio dos Ratos, Bagé, Barra do Ribeiro, Bossoroca, Butiá, Caçapava do Sul, Cachoeira do Sul, Capão do Cipó, Capivari do Sul, Dom Pedrito, Encruzilhada do Sul, Garruchos, General Câmara, Glorinha, Gravataí, Itaqui, Lavras do Sul, Minas do Leão, Montenegro, Pântano Grande, Quaraí, Rio Pardo, Rosário do Sul, Salto do Jacuí, Santa Maria, Santana do Livramento, Santiago, Santo Antônio da Patrulha, Santo Antônio das Missões, São Gabriel, São Jerônimo, São Leopoldo, São Sepé, Uruguaiana, and Vacaria.	Klafke et al. (2017) [50]	AIT, LPT, and LIT
	Cacequi, Dilermando de Aguiar, Jari, Júlio de Castilhos, Pinhal Grande, Restinga Seca, Santa Maria, Santiago, São Martinho da Serra, São Pedro do Sul, São Sepé, São Vicente do Sul, Tupanciretã, and Unistalda.	Machado et al. (2014) [33]	AIT
	Eldorado do Sul	Reck et al. (2014) [49]	LPT and LIT
SP	Bady Bassitt and Ipiguá.	Ueno et al. (2012) [53]	LPT
	Durandé and Potirendaba.	Marchesini et al. (2020) [30]	AIT and LPT
	Jacareí, and Lorena.	Mendes et al. (2013) [59]	LIT
	São José do Rio Pardo.	Maciel et al. (2015) [60]	*In vivo* and AIT

BA: Bahia; ES: Espírito Santo; MG: Minas Gerais; MS: Mato Grosso do Sul; PB: Paraíba; PE: Pernambuco; PR: Paraná; RJ: Rio de Janeiro; RN: Rio Grande do Norte; RO: Rondônia; RS: Rio Grande do Sul; SP: São Paulo. * Ritápolis was listed in Espírito Santo, but it belongs to Minas Gerais. ** Franca was listed in Minas Gerais, but it belongs to São Paulo. *** Tests were conducted with different concentrations. AIT: Adult immersion test (acaricide biogram); LPT: Larval packet test; LIT: Larval immersion test.

Table 5. Brazilian municipalities and states with records of the presence of *Rhipicephalus microplus* resistant to phenylpyrazole (fipronil).

States	Municipalities	References	Endurance test
GO	Jataí	Salvador et al. (2025) [61]	*In vivo*
MG	Formiga	Salvador et al. (2025) [61]	*In vivo*
MS	Aquidauana.	Lopes et al. (2017) [62]	*In vivo*
PB	Gado Bravo, Queimadas, Barra de Santana, Campina Grande, Sousa, Vista Serrana, Pombal, Catingueira, Marizópolis, São João do Rio do Peixe, São Domingos, Aparecida, São José da Lagoa Tapada, São Sebastião do Umbuzeiro, Sumé, Aroeiras, Cajazeiras, Patos, Monteiro, Prata, Soledade, and Pocinhos.	Vilela et al. (2020) [41]	LPT and LIT
PR	Umuarama.	Gomes et al. (2015) [63]	*In vivo*
RO	Rolim de Moura.	Silva et al. (2020) [40]	AIT and LIT
RS	Alegrete, Bagé, Barra do Ribeiro, Bossoroca, Butiá, Caçapava do Sul, Cacequi, Cachoeira do Sul, Capão do Cipó, Capivari do Sul, Dom Pedrito, Encruzilhada do Sul, Garruchos, Glorinha, Itaqui, Montenegro, Pântano Grande, Rio Pardo, Rosário do Sul, Salto do Jacuí, Santa Maria, Santana do Livramento, Santiago, Santo Antônio da Patrulha, Santo Antônio das Missões, São Borja, São Gabriel, São Leopoldo, São Sepé, Uruguaiana, and Vacaria.	Klafke et al. (2017) [50]	AIT, LPT, and LIT

SP	Águas da Prata.	Gomes et al. (2015) [63]	*In vivo*
	Guaratinguetá, Atibaia, Castilho, Murutinga do Sul.	Torres-Santos et al. (2021) [54]	AIT
	São José do Rio Pardo.	Lopes et al. (2017) [62] Salvador et al. (2025) [61]	*In vivo*
	São Pedro.	Duarte et al. (2021) [35]	AIT and LPT

MS: Mato Grosso do Sul; PB: Paraíba; PR: Paraná; RO: Rondônia; RS: Rio Grande do Sul; SP: São Paulo.* The results presented are from field tests, but the study also conducted AIT, LIT, and LPT tests. AIT: Adult immersion test (acaricide biogram); LPT: Larval packet test; LIT: Larval immersion test.

Table 6. Brazilian municipalities and states with records of the presence of *Rhipicephalus microplus* resistant to macrocyclic lactones (abamectin, doramectin, eprinomectin, ivermectin, milbemectin, and moxidectin).

States	Municipalities	References	Endurance test
CE	Barro and Várzea Alegre.	Ferreira et al. (2023) [64]	LIT
	Barro and Várzea Alegre	Ferreira et al. (2022) [65]	LIT
GO	Jataí and Acreúna.	Maciel et al. (2016) [66]	*In vivo*
	Jataí	Salvador et al. (2025) [61]	*In vivo*
MG	Bocaiúva.	Carneiro et al. (2015) [31]	AIT
	Formiga, Candeias, Córrego Fundo, Pains, Arcos, Divinópolis, and Uberlândia.	Cruz et al. (2015) [67]	*In vivo*
	Formiga	Salvador et al. (2025) [61]	*In vivo*
MS	Campo Grande.	Valsoni et al. (2020) [38]	AIT and LIT
PB	São João do Rio do Peixe and Sousa.	Ferreira et al. (2023) [64]	LIT
	São João do Rio do Peixe and Sousa.	Ferreira et al. (2022) [65]	LIT
PR	Tapejara, Umuarama, and Icaraíma.	Cruz et al. (2015) [67]	*In vivo*
RS	Alegrete.	Vargas et al. (2003) [68]	AIT, LPT, and LIT
	Eldorado do Sul.	Reck et al. (2014) [49]	LPT and LIT
SP	Espírito Santo do Pinhal, São João da Boa Vista, and Tambaú.	Maciel et al. (2016) [66]	*In vivo*
	Vargem Grande do Sul, São João da Boa Vista, and Itirapuã.	Cruz et al. (2015) [67]	*In vivo*
	São João da Boa Vista and São José do Rio Pardo	Salvador et al. (2025) [61]	*In vivo*

CE: Ceará; GO: Goiás; MG: Minas Gerais; MS: Mato Grosso do Sul; PB: Paraíba; RS: Rio Grande do Sul; SP: São Paulo. * The results presented are from field tests, but the study also included AIT, LIT, and LPT tests. AIT: Adult immersion test (acaricide biogram); LPT: Larval packet test; LIT: Larval immersion test.

Table 7. Brazilian municipalities and states with records of the presence of *Rhipicephalus microplus* resistant to Benzylurea (fluazuron).

States	Municipalities	References	Endurance test
GO	Caçu.	Cruz et al. (2018) [69]	*In vivo*
	Jataí and Acreúna.	Maciel et al. (2016) [66]	*In vivo*
MG	Arcos.	Maciel et al. (2016) [66]	*In vivo*
	Formiga.	Cruz et al. (2018) [69]	*In vivo*
MS	Campo Grande.	Valsoni et al. (2020) [38]	AIT and LIT
	Terenos and Jaraguari.	Maciel et al. (2016) [66]	*In vivo*
PR	Umuarama.	Gomes et al. (2015) [63]	*In vivo*
RS	Eldorado do Sul.	Reck (2014) [37]	AIT, LPT, and LIT
SP	Águas da Prata.	Gomes et al. (2015) [63]	*In vivo*
	Espírito Santo do Pinhal, São João da Boa Vista e Tambaú, and Gastão Vidgal.	Maciel et al. (2016) [66]	*In vivo*

GO: Goiás; MG: Minas Gerais; MS: Mato Grosso do Sul; PR: Paraná; RS: Rio Grande do Sul; SP: São Paulo. AIT: Adult immersion test (acaricide biogram); LPT: Larval packet test; LIT: Larval immersion test.

Table 8 shows the number of Brazilian municipalities, as well as the number of studies carried out for each class of acaricides in which resistance was detected.

Table 8. States, number of municipalities, and number of studies on *Rhipicephalus microplus* resistance conducted with each acaricide.

Estados	P M	P R	O M	O R	C M	C R	Fo M	Fo R	Fe M	Fe R	L M	L R	B M	B R
BA	20	3	3	3			21	4						
CE	1	1					1	1			2	2		
DF	1	1												
ES			3	2			4	2						
GO									1	1	2	1	3	2
MG	56	7	46	6			49	5	1	1	8	3	2	2
MS	40	4	5	3	39	3	12	2	1	1	1	1	3	2
PA	2	1												
PB	27	2	19	1			20	1	23	1	2	2		
PE	14	2	1	1			14	2						
PR	4	2	5	3			4	2	1	1	3	1	1	1
RJ			2	1			2	1						
RN							1	1						
RO	6	3	6	3			6	3	1	1				
RS	68	7	51	4			48	3	31	1	2	2	1	1
SC	2	1												
SP	10	6	5	3			7	4	7	4	6	3	5	2

P: Pyrethroids; O: Organophosphates; C: Carbamates; Fo: Formamidine; Fe: Phenylpyrazole; L: Lactones; B: Benzylurea; M: Municipality; R: Reference; BA: Bahia; CE: Ceará; ES: Espírito Santo; GO: Goiás; MG: Minas Gerais; MS: Mato Grosso do Sul; PA: Pará; PB: Paraíba; PE: Pernambuco; PR: Paraná; RJ: Rio de Janeiro; RN: Rio Grande do Norte; RO: Rondônia; RS: Rio Grande do Sul; SC: Santa Catarina; and SP: São Paulo.

Table 9 summarizes the total number of studies (46) in which resistance was detected in 268 Brazilian municipalities.

Table 9. Number of Brazilian municipalities and references by state where populations of *Rhipicephalus microplus* resistant to synthetic acaricides have been reported, number of heads per state, and percentage in relation to the national herd.

States	Municipalities	References	Herd numbers [70]	In relation to the national herd
RS	69	10	12,012,219,00	5.11%
MG	64	13	22,498,415,00	9.58%
MS	40	6	18,891,916,00	8.04%
PB	29	4	1,412,480,00	0.60%
SP	22	14	10,768,360,00	4.59%
BA	21	5	13,290,719,00	5.66%
PE	14	3	2,456,213,00	1.05%
PR	8	5	8,774,410,00	3.74%
RO	6	4	18,162,632,00	7.73%
ES	4	2	2,179,082,00	0.93%
CE	3	3	2,772,173,00	1.18%
GO	3	3	23,729,878,00	10.10%
PA	2	1	25,040,621,00	10.66%
RJ	2	1	2,765,715,00	1.18%
SC	2	1	4,540,794,00	1.93%
DF	1	1	85,544,00	0.04%
MT	1	1	34,246,313,00	14.58%
RN	1	1	1,173,351,00	0.50%
Total	268	47*	234,851,536,00	100%

BA: Bahia; CE: Ceará; ES: Espírito Santo; GO: Goiás; MG: Minas Gerais; MS: Mato Grosso do Sul; PA: Pará; PB: Paraíba; PE: Pernambuco; PR: Paraná; RJ: Rio de Janeiro; RN: Rio Grande do Norte; RO: Rondônia; RS: Rio Grande do Sul; SC: Santa Catarina; and SP: São Paulo. * This value does not match the sum of the values in the column, as some studies have covered more than one municipality.

4. Discussion

Upon consolidating the data (Tables 8 and 9), it was found that the resistance surveys were conducted with material from 18 Federative Units, out of a total of 27 Federative Units (Figs. S1, S2, and S3). Regarding municipalities, IBGE [70] indicated that 4939 carry out cattle farming, but the articles analyzed indicate 292 municipalities, that is, 5.92 % carried out some survey on the resistance status of the cattle tick. It is important to highlight that the data do not indicate a higher incidence of the parasite in the states, but rather that studies on resistance have been carried out in these states. Furthermore, the value of 292 does not include other resistance surveys that may have been conducted but were not published in articles.

In the state of Rio Grande do Sul (RS), 10 studies were found, and 69 municipalities with resistance were identified (Table 9 and Fig. S2). This result represents 13.88 % of the total of 497 municipalities that make up the State. The number of resistance studies detected in the State of Rio Grande do Sul is due to the implementation of Public Policies with the support of teaching and research institutions that develop work with resistance tests to acaricides [71]. Furthermore, Rio Grande do Sul offers postgraduate courses (master's and doctoral levels) at the Federal University of Santa Maria, with a focus on Pathology, Veterinary Clinical Pathology, and Animal Health and Reproduction [72]. As well as with the Desiderio Finamor Veterinary Research Institute, which has a master's program in animal health [73].

In Minas Gerais, 13 studies were conducted, and 64 municipalities with resistance were identified (Table 9 and Figure S.1). This number of municipalities represents 7.50 % of the municipalities that make up the state. These studies on cattle tick resistance in Minas Gerais are likely due to the presence of the Brazilian Agricultural Research Corporation (Embrapa Gado de Leite).

In the state of Mato Grosso do Sul (MS), 6 studies were carried out, which identified resistance in 40 municipalities, representing 49.37 % of the state's 79 municipalities (Table 9 and Figure S1). In the case of Mato Grosso do Sul, the number of studies is probably due to the presence of the Brazilian Agricultural Research Corporation (Embrapa Gado de Corte) and, as it is a state with a smaller number of municipalities, this results in a high percentage of the localities studied. It is noteworthy that in the case of Embrapa, there are resistance tests carried out in its units in Brazilian territory, such as Embrapa Pecuária Sul [74], Embrapa Rondônia [75] and others already mentioned in the work that could provide a lot of data for studies similar to this one. However, the data from these stress tests are not available.

In the state of Paraíba, 4 studies were found covering 29 municipalities, representing 13.00 % of the total. In the states of São Paulo and Bahia, the figures were 22 and 21, respectively (Table 9 and Figure S1). Regarding the other states, the number of municipalities was not representative in relation to the total (Table 9 and Figures S2 and S3). Demonstrating the need for national-level improvements in conducting and recording more studies on the phenomenon of cattle tick resistance.

It is noteworthy that 9 Federative Units did not present surveys of the resistance situation in their territories through scientific publications, a fact that reinforces the finding that the country lacks a systematic study of the ectoparasite and its resistance to the chemical molecules studied here.

The data collected indicate that the most extensive research was carried out by the Embrapa units: Beef Cattle (MS), Dairy Cattle (MG), and Embrapa Southeast Livestock (SP) (Fig. S1), as this institution has the structure and researchers for such studies and receives material from producers who wish to know the resistance profile of parasite populations in their herds. This information suggests that Embrapa could be the institution to establish a national project for the systematic study of resistance profiles to acaricide molecules and to develop rational management strategies to reduce the effects of the resistance phenomenon. Systemic studies could also be carried out by state institutions in partnership with universities that research this parasite.

The state of Rio Grande do Sul, which encompassed the largest number of municipalities studied, had its studies concentrated in the central and western regions of the state (Fig. S1). Probably due to research conducted by public state institutions. In the Central-West region, the state of Mato Grosso do Sul presented resistance studies in most municipalities and with a distribution throughout the state territory. The hypothesis for the greater scope of studies is the presence of Embrapa Gado de Corte.

Among the six states with the highest milk production values (MG, PR, RS, SC, GO, and SP) [76], only the state of Rio Grande do Sul, in the Central and Western regions, carried out a resistance survey in the number of municipalities (69 out of a total of 497) which represents almost all the municipalities in the central-western region. It is worth remembering that, in most cases, dairy cattle are of European origin (Holstein, Jersey, and Brown Swiss), and animals of this origin are the most susceptible to ectoparasites. Therefore, it is necessary that in these states the number of studies and their systematization be sufficient for an epidemiological understanding of the resistance phenomenon [77, 78].

The data presented in this study demonstrate that the state of Rio Grande do Sul is a region with a high incidence of resistance in cattle ticks to acaricides. However, it is important to note that the states in the Central-West, Southeast, and part of the South (SC and PR) regions have a climate that is more favorable to the development of the parasite [79]; however, no cases of resistance have been recorded, probably due to the lack of studies on the phenomenon of resistance.

The Northeast region, despite having temperatures favorable to ticks, has low humidity, which reduces their reproductive capacity in the free-living stage [80, 81]. In the North region, the climate is quite favorable to the development of the cattle tick [82]; however, it is possible that because these States are involved in raising zebu cattle (Nelore, Tabapuã, and Brahman), the parasite has not been such a big problem [83, 84].

Based on the studies systematized here, it can be concluded that the cattle tick is a complex parasite to be controlled. Its reproductive capacity and broad resistance to chemical control require rural producers and technical assistants to develop specific control strategies for

each herd or situation. However, developing these strategies requires a detailed understanding of the resistance status of the parasite population being targeted for control; in other words, effective control demands that resistance tests be carried out systematically in the herd. However, there is no state regulation in Brazil or any of the states that mandates the performance of these resistance tests, and this lack of studies weakens the decision-making capacity of producers and technicians, leading to more frequent applications of acaricides.

These applications, with intervals and concentrations not recommended, intensify the selection pressure on parasite populations, increasing the number of resistant individuals. When this malpractice is carried out with various products, the phenomenon of multiple resistance occurs [33, 36, 41, 44, 50]. Ultimately, the applications will multiply, and this practice will end up exposing workers, consumers, and the environment to greater possibilities of contamination. Therefore, it is important to schedule a systemic study in the country to rationalize the use of acaricides while methods are developed that avoid the use of chemical molecules.

According to Abbas et al. [4], Prolonged application of a single acaricide will result in allele fixation that confers resistance; however, rotation of active ingredients was able to prevent the emergence of resistance. However, this technique needs to be applied systematically throughout the country to prevent parasites with resistance alleles from spreading in large proportions through trade between properties or neighborhood contacts. This reinforces the importance of a systematic approach to geolocating resistance sources, which can also serve to guide the rotation of active ingredients across farms.

Systematized geolocation data on the occurrence of resistant strains can be used for preventive treatments by moving cattle to locations that do not have the resistance phenomenon. In Africa, observation of commercial farms that operated more strictly regarding the movement of infested animals revealed a decrease in the phenomenon of resistance [85].

Systematic, geolocated studies will provide a larger source of data for comparing field and *in vitro* results, which will serve to improve the algorithms that relate laboratory tests to field results and to define the best ways to apply the products [86, 61].

The studies lack a systematic approach to distributing the municipalities in a way that would allow for standardization of parasitism and the phenomenon of resistance. According to the Oxford Dictionary of Epidemiology [86], the study of disease control must elucidate its determinants and distribution. According to Sobral and Souza-Santos [79], the study of spatial distribution is an essential tool for devising strategies to combat diseases, and, certainly, this technique can be applied to cases in veterinary medicine. This problem is compounded by a lack of information among producers regarding the control of ixodid beetles and the absence of alternative control methods [80].

The work of systematizing studies on resistance must be constant, as the resistance profile can vary in space and time. Therefore, the genetic characteristics of the parasite, the cattle, the management system, the composition of the commercial product used, and the exchange of cattle between different regions will promote this dynamic in the characteristics of resistance. It is suggested that a network project be developed with an online platform where resistance survey data can be entered, along with data that

influence the behavior of parasite populations, such as rainfall patterns, temperatures, insolation, among others. This platform, where the data will be entered, must have the capacity to process geolocated data, presenting as a product maps of the parasitism profile by region and in the country as a whole.

According to the study by Higa et al. [29], in the State of Mato Grosso do Sul, Municipality of Campo Grande, samples were collected that showed resistance to organophosphates and others without resistance. This reinforces one of the proposals of this article, which is the need to geolocate the phenomenon of resistance found by property, including environmental and host data, to better understand the development of parasitism and how to combat it.

It is noteworthy that there are already software programs capable of performing this processing of geolocated information (SPRING-INPE [88] and GEODA [89]) and there is also the possibility of using artificial intelligence tools (Machine Learning [90]) to cross-reference information and establish patterns regarding the characteristics of the environment, the host, and the parasite. With this information, the possibility of developing new management plans with better administration of the use of chemical molecules is expanded.

Another aspect observed in this review was the lack of a standardized methodology for parasite collection and legal support for mandatory collections on properties. Therefore, researchers are restricted to the outputs of research units or producers who agree to participate voluntarily in the study. Salvador et al. [61], they found inconsistencies between laboratory tests and field tests, especially for products containing cypermethrin, chlorpyrifos, and macrocyclic lactones. Prior to this study, Santos et al. [87] found that the larval pack, larval immersion and syringe immersion tests for Amitraz did not yield results with sufficient similarity to affirm that they were statistically equivalent to the phenomenon in the field.

However, with systematic and geolocated studies of the resistance phenomenon, it is possible to establish a better predictive relationship between the control capacity of acaricides tested in the laboratory and what will actually be obtained in the field. Finally, Jongejan et al. [52] highlight that it is necessary to develop faster tests in order to carry out a broader study of infested herds; however, these new tests also need to be standardized through larger-scale comparative studies.

5. Conclusion

Given the current situation, four conclusions are possible based on the data found: i. Multiple resistance appears inevitable and will likely occur with new molecules; ii. Geolocation data is missing; iii. Further studies are needed to ensure that laboratory tests more accurately reflect the reality of resistance in the field; v. There is no presentation of a national plan for the control of *R. microplus*. These findings reinforce the need for a federal institution to assume coordination and, together with state entities, plan and implement a plan to confront the parasite and its consequences. Finally, it is concluded that the systematization and availability of information on the phenomenon of resistance, through standardized resistance tests compared to data from field experiments, can support veterinary medicine professionals when prescribing acaricides and manufacturing companies in their research on dosage and product combinations.

Supplementary material (Available only in the online version: https://revistas.ufg.br/vet/article/view/81941)

Graphic Abstract.
Figure S1. Map showing the occurrence of *Rhipicephalus microplus* resistance to synthetic acaricides in the states of Rio Grande do Sul (1A), Minas Gerais (1B), Mato Grosso do Sul (1C), Paraíba (1D), São Paulo (1E), Bahia (1F), Brazil.
Figure S2. Map showing the occurrence of *Rhipicephalus microplus* resistance to synthetic acaricides in the states of Pernambuco (2A), Paraná (2B), Rondônia (2C), Espírito Santo (2D), Ceará (2E), and Goiás (2F), Brazil.
Figure S3. Map showing the Ooccurrence of *Rhipicephalus microplus* resistance to synthetic acaricides in the states of Pará (3A), Rio de Janeiro (3B), Santa Catarina (3C), Federal District (3D), Mato Grosso (3E), Rio Grande do Norte (3F), Brazil.

Conflict of interest statement

The authors declare no conflict of interest.

Data availability statement

The data will be provided upon request to the corresponding author.

Author contribution

Conceptualization: Teixeira, T. M., Gazim, Z. C., Ribeiro, C. E.; Investigation: Teixeira, T. M., Gazim, Z. C., Miloca, L. M., Junior, R. P., Marchetti, P. H. L., Ribeiro, C. E.; Methodology: Gazim, Z. C., Teixeira, T. M., Miloca, L. M., Sakane, K. T., Rodrigues, S. A., Marchetti, P. H. L., Junior, R. P., Ribeiro, C. E.; Writing: Teixeira, T. M., Gazim, Z. C., Miloca, L. M., Junior, R. P., Ribeiro, C. E.; Validation: Rizzo, H., Melo, E. O. L.; Project administration: Teixeira, T. M., Gazim, Z. C.

Generative AI use statement

The authors did not use generative artificial intelligence tools or technologies in creating or editing any part of this manuscript.

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