


Review

Acaricidal and Repellent Effects of Essential Oils against Ticks: A Review

Sidi Mohammed Ammar Selles ^{1,2,*} , Mokhtaria Kouidri ^{1,3}, Marta G. González ⁴, Julia González ⁵, María Sánchez ^{4,6}, Azucena González-Coloma ⁷ , Jaime Sanchis ^{4,8}, Latifa Elhachimi ⁹, A. Sonia Olmeda ¹⁰ , José Maria Tercero ⁶ and Félix Valcárcel ⁴ 

- ¹ Institute of Veterinary Sciences, University of Tiaret, Tiaret 14000, Algeria; mokhtariakouidri@yahoo.fr
 - ² Laboratory of Research on Local Animal Products, University of Tiaret, Tiaret 14000, Algeria
 - ³ Laboratory of Farm Animal Products, University of Tiaret, Tiaret 14000, Algeria
 - ⁴ Grupo de Parasitología Animal, Departamento de Reproducción Animal (INIA-CSIC), 28040 Madrid, Spain; marta.glez.degano@gmail.com (M.G.G.); maria2985@hotmail.com (M.S.); sanchisjaime@gmail.com (J.S.); valcarcel.felix@inia.es (F.V.)
 - ⁵ Center for Vector Biology, Department of Entomology, Rutgers University, New Brunswick, NJ 08901, USA; julia.gonzalez@rutgers.edu
 - ⁶ Villamagna S.A., Finca “La Garganta”, 14440 Villanueva de Córdoba, Spain; jmtercero@fincalagarganta.com
 - ⁷ Instituto de Ciencias Agrarias (ICA), Consejo Superior de Investigaciones Científicas (CSIC), 28006 Madrid, Spain; azu@ica.csic.es
 - ⁸ Facultad de Veterinaria, CENUR Litoral Norte, Universidad de la República, Rivera, Salto 1350, Uruguay
 - ⁹ Département de parasitologie et de Santé Publique, Institut Agronomique et Vétérinaire Hassan II, Rabat B.P. 6202, Morocco; latifa.elhachimi@gmail.com
 - ¹⁰ Departamento de Sanidad Animal, Facultad de Veterinaria, Universidad Complutense de Madrid, 28040 Madrid, Spain; angeles@ucm.es
- * Correspondence: nuider10@yahoo.fr



Citation: Selles, S.M.A.; Kouidri, M.; González, M.G.; González, J.; Sánchez, M.; González-Coloma, A.; Sanchis, J.; Elhachimi, L.; Olmeda, A.S.; Tercero, J.M.; et al. Acaricidal and Repellent Effects of Essential Oils against Ticks: A Review. *Pathogens* **2021**, *10*, 1379. <https://doi.org/10.3390/pathogens10111379>

Academic Editor: Sara Moutailler

Received: 10 September 2021

Accepted: 15 October 2021

Published: 26 October 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Abstract: Tick control is a priority in order to prevent the transmission of vector-borne diseases. Industrial chemical acaricides and repellents have been the most efficient tools against hard ticks for a long time. However, the appearance of resistances has meant the declining effectiveness of the chemicals available on the market. The trend today is to develop alternative control methods using natural products to replace nonefficient pesticides and to preserve the efficient ones, hoping to delay resistance development. Traditional in vitro evaluation of acaricidal activity or resistance to synthetic pesticides have been reviewed and they mainly focus on just one species, the one host tick (*Rhipicephalus (Boophilus) microplus* (Acari: Ixodidae)). Recent reports have called for the standardization of natural product components, extraction techniques, and experimental design to fully discover their acaricidal potential. This study reviews the main variables used in the bibliography about the efficiency of natural products against ticks, and it proposes a unification of variables relating to ticks, practical development of bioassays, and estimation of ixodicidal activity.

Keywords: ticks; natural compounds; efficacy; standardization

1. Introduction

Ticks are forced bloodsucker ectoparasites belonging to the Order Ixodida, which comprises three families: Ixodidae (hard ticks, 720 species), Argasidae (soft ticks, 186 species), and Nuttalliellidae (1 species) [1,2]. They are also one of the main groups of disease vectors, and tick-borne diseases (TBDs) have long been recognized as one of the major constraints to livestock development in various countries [3], particularly in the cattle industry in tropical and subtropical regions [4]. Likewise, they are the most devastating as they cause huge economic losses [5]. These losses are estimated in the billions of US dollars [4], as a consequence of higher production costs due to constant antiparasitic treatments [6] and the effects generated by the infestation: blood loss, reduced weight gain and milk production, and skin damage at the site of attachment [7].

Many commercially available chemicals are used in current tick control strategies: arsenicals, chlorinated hydrocarbons, carbamates, macrocyclic lactones [8,9], organophosphates, formamidines, pyrethroids [8–11], fluzuron, and fipronil [10,11]. They have generally been sprinkled on, poured on, or injected into animals, with high costs for farmers [10,11].

Unfortunately, the misuse, overuse, and inappropriate application of chemical acaricides led to the development and selection of resistance in the tick population [4,7,12–15]. However, apart from their high costs, these acaricides could also be potentially hazardous through contamination of ruminant milk and meat [13,16,17] and thus, may have an effect on human health [18,19], as well as contamination of the environment with residues harmful to humans and animals [15,16,18,20,21]. Due to this and the growing interest in organic farming practices, several acaricides have undergone restriction of use in the global market, such as organochlorines, organophosphates, and pyrethroids [18]. Consequently, the development of new agents and/or effective alternative strategies for their control is necessary [6,22]. Therefore, many other current strategies used for control of resistant tick populations such as biological control using pathogens or predators, pheromone-assisted control, herbal pour-on or dip preparations including green manufactured nanoparticles, and vaccination, as well as design of acaricide resistance mitigation programs based on integrated pest management control [3,23,24].

Among these alternative strategies, plant-derived products can be promising acaricidal product sources, especially essential oils [6,7,15,23,24]. The essential oil's acaricidal activity is due to the variability of its chemical composition and the relationship between these compounds [25]. Moreover, given their low toxicities and their solubility in water [25] these compounds can contribute to the production of milk and animal meat free from dangerous chemicals which are harmful to humans, animals, and the environment [13]. This review aims to present an overview of tick control methods, tick resistance, essential oils in control of ticks, and their mechanisms of action.

2. Materials and Methods

The data obtained from the following databases were used for the realization of this work: Web of Science (WOS), Science Direct, Scielo, and PubMed (consulted from May to July 2021). We selected articles focusing on the acaricidal effect of EOs against ticks using the following keywords: “Essential oil”, “Ticks”, “Acaricidal”, “Repellent”, “Mode of action”, and “Resistance”.

Therefore, we considered the research items complying with at least one of the following criteria: (1) Stage/specie, (2) bioassay, (3) reproductive efficiency/acaricidal effect, (4) toxicity, (5) repellent effect, and (6) country.

Acaricidal classes were arranged in a table according to the first year of use, containing mode of action, first report of resistance, and mechanisms of resistance.

The plant species were arranged in a table in alphabetical order, also containing the stage and tick specie, bioassay, major compounds concentration, effect, LC₅₀, LC₉₀, and country.

3. Ticks and Synthetic Acaricides

Arsenic and its derivatives were intensively used at the end of the 19th and the beginning of the 20th centuries because they had a short residual effectiveness time, were cheap, stable, and water-soluble [26]. When arsenic use decreased, due to the high toxicity of its residues, its prohibition forced the appearance of the first organochlorines: dichlorodiphenyltrichloroethane (DDT), benzene hexachloride (BHC), lindane, dieldrin, or toxaphene, which were used extensively throughout the twentieth century [27]. Initially, organochlorides were highly effective against ticks showing high residual effectiveness an ease of use, but the majority accumulated residues in the environment and animal tissues [26]. In the 1960s, organophosphates and carbamate derivatives complemented or replaced organochlorides. These new acaricides offered the advantage of being biodegradable and rapidly metabolized, although they also quickly lost their effectiveness [28]. In the 1970s formamidines

appeared, such as amitraz, in an attempt to avoid the fast reduction in effectiveness of the preceding products [29]. From the 1980s, the use of acaricides with low toxicity in mammals proliferated, such as pyrethrins and some biopesticides (macrocyclic lactones: avermectins and milbemycins) [30]. The pyrethrins gave rise to the pyrethroids, synthetic analogs obtained by successive isosteric modifications [31], more stable and with less residual effect. Pyrethroids are classified as first-generation (allethrin), second-generation (tetramethrin, resmethrin, bioresmethrin, biolaethrin, and fontarin), third-generation (fenvalerate and permethrin), and the current fourth-generation, which includes cypermethrin and decamethrin, among others [32]. Finally, in the late twentieth century, mite growth regulators derived from benzoyl-phenyl urea (fluazuron, for example) began to be used [28], along with other chemical acaricides, phenylpyrazoles, such as fipronil. Spinosad is a relatively recent insecticide-acaricide produced from the fermentation of metabolites of the actinomycete bacterium *Saccharopolyspora spinosa* and a mixture of two components A and D spinosyn [33]. In both laboratory and field tests, those products were found to be equally effective against ticks and could therefore be used as an alternative [34,35]. The latest addition to the market for ectoparasitocides for pets is isoxazolines [36–39].

4. Tick Control Methods

Several methods are applied to combat ticks and tick-borne diseases [40]. At first, tick control was based on using a mixture of lard and sulfur, a combination of lard and kerosene, cottonseed oil or fish oil from kerosene mixtures, cottonseed oil and sulfur, 10% kerosene emulsion, a mixture of cottonseed oil and crude petroleum oil, or Beaumont crude oil [8,41]. Thereafter, the treatment of cattle by baths based on mineral oil and “carbolics” by Australian researchers occurred, continuing as recently as 1895 [8,42]. Currently, the main method to control ticks is the use of chemical acaricides [27,41].

Many acaricides are available on the market such as arsenicals, organochlorines, organophosphates, carbamates, formamidines, pyrethroids, macrocyclic lactones, phenylpyrazoles, benzoylphenylurea, spinosad, and isoxazolines (Table 1) [9–11,14,40,41]. The use of these acaricides reduces the tick population, as well as the diseases transmitted by ticks. However, the effectiveness of an acaricide depends on the activity of a product, as well the quality and quantity of active material sprayed or injected [40]. Moreover, inappropriate and long-term application of these acaricides, frequency of treatment, underdosing, and persistent use of a chemical group for tick control enables improvement of tolerance/resistance to the chemical and leads to the evolution of resistance in many tick species [4,14,40,41,43–45].

Several studies recommended an integrated strategy for the control of ticks in cattle based on the house management, slow-burning of the wastes near the walls of the animal sheds, pasture alternation and/or rotation, pasture burning, clearance of vegetation, nutritional management, rotation of acaricides, using combinations of acaricides, immunization via vaccination, improving genetic resistance in cattle, improving resistance diagnostic tests, biological control, and ethnoveterinary practices against ticks [14,41,46–48].

Table 1. Chemical acaricidal class, mode of action, and their mechanisms of resistance.

Acaricidal Class	First Year of Use	Mode of Action	First Report of Resistance	Mechanisms of Resistance	References
Arsenic	1893		1937		[9,41,49]
Organochlorines	1946	GABA-gated chloride channel antagonists Bind at the picrotoxinin site in the γ -aminobutyric acid (GABA) chloride ionophore complex.	1952	Enhanced metabolism and reduced absorption of the chemical	[14,40,41]
Organophosphates	1955	Acetylcholinesterase Inhibits the action of acetylcholinesterase	1965	Target-site insensitivity	[14,40,41]

Table 1. *Conts.*

Acaricidal Class	First Year of Use	Mode of Action	First Report of Resistance	Mechanisms of Resistance	References
Carbamates	1955	Inhibits the action of acetylcholinesterase	1965		[14,40,41]
Formamidines (Amitraz)	1975	Octopamine receptor α -2 agonist Overstimulates the nervous system	1981	Mutations in the octopamine/tyramine receptor Target-site insensitivity in G protein-coupled receptors Amino acid substitution in the beta-2-adrenergic-like octopamine receptor	[4,8,14,40,50]
Pyrethroids	1977	GABA-gated chloride channel antagonists Prolongs opening of sodium channels in nerve, muscle, and other excitable cells.	1989	Mutations in the voltage gated sodium channel gene	[8,40,41,51]
Macrocyclic lactones	1981	Has a toxic effect on ticks by stimulating the release and binding of GABA at nerve endings, which eventually blocks the transmittance of electrical activity in nerves and muscle cells Glutamate-gated Cl channel Blocks nerve signals by interfering with the glutamate gated chloride (GICl)	2001	Insensitivity of the GABA or glutamate gated chloride ion channels	[8,40,41,52]
Phenylpyrazoles (Fipronil)	1993	Blocks the gamma-Aminobutyric acid gated chloride ion-channel (GABA-C)	2003	Mutations in the GABA-Cl gene	[41,53–55]
Benzoylphenyl urea (Fluazuron)	1990	Disturbs cuticle formation Blocks the incorporation of radiola-beled N-acetylglucosamine	2010		[41,56]
Spinosad (Tetracyclic-macrolide compounds)	2001	Nicotinic acetylcholine receptors (nAChRs) γ -amino-butyric acid (GABA) receptors Hyperexcitation and disruption of an insect's nervous system			[41,57–60]
Isoxazolines	2014	Inhibits GABA-gated chloride ion channels			[36,61,62]

5. Tick Resistance

Chemical products used in traditional tick control methods are at the center of eradication and control efforts because they offer relatively rapid and effective control of tick populations. However, resistance is the result of irrational and long-term use of acaricidal drugs. In addition, they are expensive and can be harmful to the environment and dangerous for consumers if the recommended withdrawal times for foods of animal origin are not respected [63–65]. Resistance is broadly defined as a change in the sensitivity of the target species to a drug [66,67]. The concept of drug resistance can be defined as “the ability of a strain of parasite to survive and/or multiply despite the administration and absorption of a drug administered to doses equal to or greater than those usually recommended but within the tolerance of the subject” (World Health Organization, 1965) or “the ability of some parasites to tolerate toxic doses of a drug that would be lethal to most of their congeners” [68,69].

There are several definitions of acaricide resistance and different types of resistance were observed. In parasitology, four types of resistance were defined:

- Natural resistance or tolerance: “present in the external body-part and in all individuals of the species and does not develop as a result of acaricidal use”. This may

be due to the impermeability of the cuticle or behavioral traits. It is not necessarily transmitted to their offspring [47].

- Acquired resistance: is “resistance that results from heritable decreases in sensitivity to drugs over time” [14,40].
- Cross-Resistance: is defined as “the sharing of resistance among different acaricides with a similar mode of action” [14,40].
- Multiple resistances: is defined as “a resistance to more than one drug, even though they have different modes of action” [14,40].

The first report of tick resistance, against arsenic, was due to the indiscriminate use of this product for more than 30 years (1890–1910) to control *Rhipicephalus (Boophilus) microplus* (Wharton 1983), the main tick affecting domestic cattle over the world. There are many reports describing resistances to formamidine, amitraz, permethrin [70–73], and even to the more modern fipronil [53]. Unfortunately, there are instances of resistances to practically all the synthetic acaricides as reviewed by [14]. Although negative consequences of resistances have been partially relieved with the rotation products with different mechanisms of action, it continues to be a major problem in large territories of Africa and America [48,74–77]. This is the main threat given that most of these acaricidal groups are still applied. The development of safe and effective new acaricidal agents is therefore of great interest.

6. Natural Products

Plant products containing bioactive metabolites represent a promising alternative for the control of ticks that are susceptible and/or resistant to conventional acaricides. Studies of the effects of essential oils and plant extracts against different classes of ticks showed efficacies of 5–100% [78]. Following the line of the search for ecological alternatives for effective tick control, products derived from microorganisms or natural products were defined as biopesticides [79]. The products derived from plants are particularly attractive due to their low toxicity, scarce environmental permanence, and the complex chemistry that hinders the development of the resistances. The use of natural products for the control of ticks offers advantages but still has certain limitations. The first disadvantage is the variability of the composition of certain products, such as essential oils, and therefore their effectiveness, for which the identification and subsequent standardization of the fractions and possible effective synergies are required. Another disadvantage could be the characteristics of the product, such as photosensitivity or high volatility, which limit the residual activity depending on the form of presentation [17]. Among the advantages, its role as an alternative in the control of resistant ticks stands out, its environmental innocuousness, and the minimum impact on animal and human health that facilitates its registration and subsequent commercialization [80]. At the beginning of the 19th century, the Caucasian and Persian tribes used pyrethrum flowers as a method of control against body lice [31]. Pyrethrum or Dalmatian pyrethrum (*Tanacetum cinerariifolium* or *Chrysanthemum cinerariifolium*) is an evergreen plant of the Asteraceae family, with insecticidal properties of low toxicity to mammals. Another plant derivative traditionally used is the neem tree (*Azadirachta indica*), belonging to the Meliaceae family that originates in the Indian sub-continent. For centuries, Indians have relied on this tree to strengthen their health and remedy dozens of diseases; in addition, it has been used to protect stored food and as a natural fertilizer and pesticide for the fields, since it intervenes in the feeding of arthropods and the hormonal processes of their development [81,82]. It is now valued throughout the world as an important source of phytochemicals for use in human health and pest control. Neem oil contains at least 100 biologically active compounds [83]. Essential oils are naturally produced by plants as secondary compounds, which are obtained for commercial use by various forms of distillation, and plant extracts are obtained through various forms of solvent extraction; some of them stand out for their pesticide, growth-regulating, and repellent or dissuasive properties [17].

7. Essential Oils in Control of Ticks

Acaricidal Activity of Essential Oils against Ticks

In recent decades, natural products and their compounds have been the most productive source for new drug development. Among them, essential oils and isolated terpenoids have shown activity against diverse stages of several species of ticks [63]. Many studies have reported the ovicidal (inhibited oviposition and inhibited hatchability), effects against all the stages of ticks [3,14,34,84–87].

The variability in the chemical composition of essential oils and the relationship between compounds play an important role in acaricidal activity. It is difficult to attribute the observed biological effects to the major chemical compounds of essential oils. These biological effects can be attributed to a synergistic action between the minority compounds and other minor or major molecules [15]. Additionally, the substances obtained from plants have a low cost, few residual effects, and a low incidence of generating resistance [15,88].

Many researchers have studied the acaricidal effects of essential oils against ticks of the Ixodidae family. Table 2 summarizes the studies carried out on this subject.

Table 2. Essential oils (EOs) tested against ticks. Complete information about major compounds, concentrations, effect, LC50, LC90, and country is provided in the supplementary file (Table S1).

Origin	Stage/Specie	Bioassay	Ref.
<i>Acmella oleracea</i>	L/N <i>A. sculptum</i>	LPT; LIT; NPT; NIT	[89]
<i>Allium sativum</i>	L/R. <i>microplus</i>	LPT	[24]
<i>Aloe rupestris</i>	L/A <i>R. decoloratus</i>	LPT; ACT; AIT	[90,91]
<i>Alpinia zerumbet</i>	L/EF <i>R. microplus</i>	LPT; AIT	[15]
<i>Antizoma angustifolia</i>	L/R. <i>decoloratus</i>	LPT	[90]
<i>Arisaema anurans</i>	L/EF/egg <i>R. microplus</i>	LIT; AIT; EHT	[92]
<i>Artemisia annua</i>	EF/R. <i>microplus</i>	In vivo	[93]
<i>Artemisia dracuncululus</i>	L/H. <i>lusitanicum</i>	LCT	[94]
<i>Artemisia herba alba</i>	Egg/L/N/H. <i>aegyptium</i> ; L/H. <i>lusitanicum</i>	EPT; LPT; NPT; LCT	[94,95]
<i>Calpurnia aurea</i>	L/R. <i>decoloratus</i> ; A/R. <i>turanicus</i>	LPT; ACT; AIT	[90,91,96]
<i>Cananga odorata</i>	N/I. <i>ricinus</i>	OFPM; LETM	[97]
<i>Cedrus atlantica</i>	EF/R. <i>microplus</i>	AIT	[6]
<i>Chenopodium ambrosioides</i>	Egg/L/N <i>H. aegyptium</i>	EPT; LPT; NPT	[95]
<i>Cinnamomum verum</i>	L/EF <i>R. microplus</i>	LPT; AIT	[98]
<i>Cissus quadrangularis</i>	L/R. <i>decoloratus</i> ; A/R. <i>turanicus</i>	LPT; ACT; AIT	[90,91]
<i>Citrus hystrix</i>	L/R. <i>microplus</i>	LIT	[24]
<i>Clematis brachiata</i>	L/R. <i>decoloratus</i> ; A/R. <i>turanicus</i>	LPT; ACT; AIT	[90,91]
<i>Cleome gynandra</i>	L/R. <i>decoloratus</i> ; A/R. <i>turanicus</i>	LPT; ACT; AIT	[90,91]
<i>Cuminum cyminum</i>	L/R. <i>microplus</i>	LPT	[23]
<i>Cymbopogon citratus</i>	EF/L <i>R. microplus</i>	AIT; LIT	[6,24]
<i>Cymbopogon martinii</i>	EF/R. <i>microplus</i>	AIT	[6]
<i>Dorystoechas hastata</i>	L/R. <i>turanicus</i>	LIT	[85]
<i>Eucalyptus camaldulensis</i>	L/A <i>H. scupense</i>	LIT; AIT	[3]
<i>Eucalyptus globulus</i>	L/A/H. <i>scupense</i>	LIT; AIT	[3]
<i>Ficus sycomorus</i>	L/R. <i>decoloratus</i> ; A/R. <i>turanicus</i>	LPT; ACT; AIT	[90,91]
<i>Geranium macrorrhizum</i>	L/H. <i>lusitanicum</i>	LCT	[99]
<i>Homemade ocimum gratissimum</i>	L/R. <i>microplus</i>	LPT	[100]
<i>Hyssopus officinalis</i>	L/H. <i>lusitanicum</i>	LCT	[94,101]
<i>Illicium verum</i>	N/I. <i>ricinus</i> ; A/D. <i>nitens</i>	OFPM; LETM; AIT	[97,102]
<i>Juniperus thurifera var. africana</i>	Egg/L/N <i>H. aegyptium</i>	EPT; LPT; NPT	[95]
<i>Laurus nobilis</i>	L/EF <i>R. microplus</i>	LPT; AIT	[103]
<i>Lavandula angustifolia</i>	L/H. <i>lusitanicum</i>	LCT	[94]
<i>Lavandula intermedia super</i>	L/H. <i>lusitanicum</i>	LCT	[101]
<i>Lavandula luisieri</i>	L/H. <i>lusitanicum</i>	LCT	[104]
<i>Lavandula pedunculata subsp. atlantica</i>	Egg/L/N <i>H. aegyptium</i>	EPT; LPT; NPT	[95]
<i>Lavandula stoechas</i>	L/A <i>H. scupense</i>	LIT; AIT	[3]
<i>Lippia gracilis</i>	L/EF/R. <i>microplus</i>	LIT; AIT; LST	[13]
<i>Lippia graveolens</i>	L/R. <i>microplus</i>	LPT	[24]
<i>Lippia sidoides</i>	L/EF <i>D. nitens</i> ; L/EF <i>R. microplus</i> ; L/N <i>R. sanguineus</i> ; L/N <i>A. cajennense</i>	AIT; NPT	[86,105]

Table 2. Conts.

Origin	Stage/Specie	Bioassay	Ref.
<i>Mangifera indica</i>	L/R. <i>microplus</i> ; L/H. <i>anatolicum</i> ; L/Ha. <i>bispinosa</i>	LPT	[106]
<i>Mentha longifolia</i>	L/R. <i>turanicus</i>	LIT	[85]
<i>Mentha piperita</i>	L/H. <i>lusitanicum</i>	LCT	[94]
<i>Mentha spicata</i>	L/H. <i>lusitanicum</i>	LCT	[94]
<i>Mentha suaveolens</i>	L/H. <i>lusitanicum</i>	LCT	[94]
<i>Mentha suaveolens</i> subsp. <i>timija</i>	Egg/L/N <i>H. aegyptium</i>	EPT; LPT; NPT	[95]
<i>Mesosphaerum suaveolens</i>	L/EF <i>R. microplus</i>	LPT; AIT	[15]
<i>Monsonia angustifolia</i>	L/R. <i>decoloratus</i> ; A/R. <i>turanicus</i>	LPT; ACT; AIT	[90,91]
<i>Nemuaron vieillardii</i>	L/R. <i>microplus</i>	LPT	[107]
<i>Neoglaziovia variegata</i>	EF/R. <i>microplus</i>	AIT	[108]
<i>Ocimum gratissimum</i>	L/EF <i>R. microplus</i> ; L/A. <i>sculptum</i> ; L/R. <i>sanguineus</i>	LPT; AIT; LIT	[15,100,109]
<i>Ocimum urticaefolium</i>	L/R. <i>microplus</i>	LPT	[100]
<i>Ocotea elegans</i>	L/EF <i>R. microplus</i>	LPT; AIT	[110]
<i>Origanum floribundum</i>	L/A <i>H. scupense</i>	LIT; AIT	[3]
<i>Origanum minutiflorum</i>	A/R. <i>turanicus</i>	VPT	[34]
<i>Origanum onites</i>	A/R. <i>turanicus</i>	ACT	[111]
<i>Origanum vulgare</i> subsp. <i>virens</i>	L/H. <i>lusitanicum</i>	LCT	[94]
<i>Pelargonium luridum</i>	L/A <i>R. decoloratus</i>	LPT; ACT; AIT	[90,91]
<i>Pimenta dioica</i>	L/R. <i>microplus</i>	LPT	[23]
<i>Piper amalago</i>	L/R. <i>microplus</i>	LIT	[112]
<i>Piper corcovadensis</i>	L/R. <i>microplus</i>	LPT	[113]
<i>Piper mikanianum</i>	L/R. <i>microplus</i>	LIT	[112]
<i>Piper xylosteoides</i>	L/R. <i>microplus</i>	LIT	[112]
<i>Rosmarinus officinalis</i>	L/R. <i>microplus</i> ; L/A <i>H. scupense</i> ; L/H. <i>lusitanicum</i>	LPT; LIT; AIT; LCT	[3,24,94]
<i>Santolina chamaecyparissus</i>	L/H. <i>lusitanicum</i>	LCT	[100]
<i>Satureja calamintha</i>	Egg/L/N <i>H. aegyptium</i>	EPT; LPT; NPT	[95]
<i>Satureja montana</i>	L/H. <i>lusitanicum</i>	LCT	[94]
<i>Satureja thymbra</i>	A/H. <i>marginatum</i>	VPT	[84]
<i>Schinus molle</i>	L/EF <i>R. sanguineus</i>	LPT; AIT	[114]
<i>Schkuhria pinnata</i>	L/A <i>R. decoloratus</i> ; A/R. <i>turanicus</i>	LPT; ACT; AIT	[90,91]
<i>Sclerocarya birrea</i>	L/R. <i>decoloratus</i> ; A/R. <i>turanicus</i>	LPT; ACT; AIT	[90,91]
<i>Senecio adenotrichius</i>	L/H. <i>lusitanicum</i>	LCT	[115]
<i>Senna italica</i>	L/R. <i>decoloratus</i> ; A/R. <i>turanicus</i>	LPT; ACT; AIT	[90,91]
<i>Syzygium aromaticum</i>	L/A <i>R. microplus</i>	LPT; AIT	[87]
<i>Tabernaemontana elegans</i>	L/R. <i>decoloratus</i> ; A/R. <i>turanicus</i>	LPT; ACT; AIT	[90,91]
<i>Tagetes minuta</i>	EF/R. <i>microplus</i>	In vivo	[116]
<i>Tanacetum vulgare</i>	L/H. <i>lusitanicum</i>	LCT	[94]
<i>Tetradenia riparia</i>	L/EF <i>R. microplus</i>	LPT; AIT	[117]
<i>Thymus capitatus</i>	L/A <i>H. scupense</i>	LIT; AIT	[3]
<i>Thymus mastichina</i>	L/H. <i>lusitanicum</i>	LCT	[94]
<i>Thymus sipyleus</i> subsp. <i>sipyleus</i>	L/R. <i>turanicus</i>	LIT	[85]
<i>Thymus vulgaris</i>	L/H. <i>lusitanicum</i>	LCT	[94]
<i>Thymus zygis</i>	L/H. <i>lusitanicum</i>	LCT	[94]
<i>Zanthoxylum caribaeum</i>	A/R. <i>microplus</i>	AIT	[11]
plant not specified	L/A. <i>sculptum</i> ; L/D. <i>nitens</i> ; L/A <i>R. microplus</i>	LPT;LIT; AIT	[118–120]
Essentria IC3 ©	N/A <i>A. americanum</i>	NPT; APT	[121]
Mosquito Barrier ©	N/A <i>A. americanum</i>	NPT; APT	[121]
Vet's Best ©	N/A <i>A. americanum</i>	NPT; APT	[121]
Wondercide ©	N/A <i>A. americanum</i>	NPT; APT	[121]

Stage: L: Larvae; N: Nymph; A: Adult; EL: Engorged larvae; EN: Engorged nymph; EF: Engorged females; UEL: Unengorged larvae; UEN: Unengorged nymphs. Specie: A.: Amblyomma; D.: Dermacentor; H.: Hyalomma; I.: Ixodes; Ha.: Haemaphysalis; R.: Rhipicephalus. R.microplus also includes R.(B.) microplus and R. decoloratus includes R.(B.) decoloratus. Bioassay: ACT: Adult contact test; AIT: Adult immersion test; APT: Adult packet test; FIT: Female immersion test; LCT: Larval contact test; LETM: Limited exposure time method; LIT: Larval immersion test; LPT: Larval packet test; LST: Larval sensitivity test; NPT: Nymphal packet test; OFPM: Open filter paper method; VPT: Vapor phase toxicity. Effect: CM Corrected mortality; CR: Control of reproduction; EE: efficiency of the extract; EMR: egg mass reduction; EPI: Egg production index; H: Hatching; IH: Inhibited hatchability; IO: Inhibited ovoposition; IR: Inhibited reproduction; M: Mortality; REI: Reproduction efficiency index.

8. Mechanisms of Action of the Essential Oils and/or Their Components against Ticks

Essential oils are the most studied plant-derived compounds for tick control and prevention [9,16,18,122]. Two effects of essential oils against ticks were observed: acaricidal or repellent effects [9,16,122–127]. They cause various effects against ticks: feeding inhibition [125,128,129], inhibition of chitin synthesis [9,78,129], decrease in growth, development, or reproduction [9,78,125,126,128,130], and affect tick behavior [129].

Several studies have reported that essential oils act against ticks through three modes of action: neurotoxicity effect [16,127,129,131,132], cytotoxicity effect [127,133], and mechanical effects [129,132,134].

8.1. Neurotoxicity Effects

Three mechanisms of the induced action-neurotoxic acaricide effect of essential oils have been described: inhibition of acetylcholinesterase (AChE) [124,127,129,132,135], antagonism with receptors for the neurotransmitter octopamine [124,127,136] and action on GABA [16,124,135,136]. However, there are controversial data on the insecticidal essential oils action on GABA. Some authors have attributed this effect to chloride channel closure by gamma-aminobutyric acid (GABA) [16,135] or to an increase in Cl current induced by the neurotransmitter GABA [124,136].

Salman et al. [127] reported that the neurotoxic effect of essential oils as acaricides acted on motor function. This is due to an increase produced on catecholamines in the central nervous system inhibiting the activity of monoamine oxidase.

8.2. Inhibition of Acetylcholinesterase Activity

Acetylcholine is an important neurotransmitter in both the central nervous system (CNS) and the peripheral nervous system of many organisms including arthropods, whereas, acetylcholinesterase is an enzyme controlling the concentration of the excitatory neurotransmitter acetylcholine (ACh) in the synaptic cleft [124]. This is one of the most important enzymes in the neuron-neuronal and neuromuscular junction [136].

Many works have shown that essential oils as well as several different terpenoid compounds exhibited an anti-AChE activity [124,135–138]. Several components were tested on AChE of arthropods: α -pinene and β -pinene, β -phellandrene, carvacrol, limonene, menthol, menthone, 1,8-cineole, cis-ocimene, niloticin, eucalyptol, pulegone, linalool, citral, bornyl acetate, p-cymene, γ -terpinene. It has been shown that these components are effective with doses varying from nM to μ M concentrations [139–145].

Furthermore, Terpinen-4-ol, a monoterpenoid found at high concentrations in tea tree oil, inhibits arthropod acetylcholinesterase [129]. In addition, Camilo et al. [136] have shown that carvacrol has an AChE inhibitory effect 10-fold higher than its thymol isomer. This effect is linked to the position of the hydroxyl group in its structure that plays a key role.

8.3. Binding-Octopamine Receptors

Octopamine is a multifunctional naturally occurring biogenic amine and plays a key role as a neurotransmitter, neurohormone and neuromodulator in invertebrate systems, with a physiological role analogous to that of noradrenaline in vertebrates [135,146]. In arthropods, the group of biogenic amine messengers consists of five members: dopamine, tyramine, octopamine, serotonin, and histamine [124]. Octopamine and tyramine modulate various functions such as the metabolism and behavior of arthropods [127]. The neurotoxic and cytotoxicity activities of essential oils and/or their purified constituents (eugenol, α -terpineol, and cinnamic alcohol) against arthropods are probably attributable to binding to tyramine and octopamine receptors resulting in lethal effects [124,127,147].

The essential oils act as agonists of octopamine receptors. They cause an increase in both the level of cAMP and the level of intracellular Ca^{2+} . Likewise, they induce the activation of PKA and PKC kinases and the phosphorylation of many proteins (including ion channels, enzymes and receptors) [135,148].

8.4. Mechanical Effects

Several studies have cited the mechanical effects of essential oils on parasites. It is the hydrophobic nature of essential oils that is responsible for this effect. Death from water stress or suffocation is the result of disruption of cuticular waxes and blockage of respiratory stigmas [129,132,134].

Moreover, essential oils are known for their antihistamine [85,132] and anti-inflammatory effect. They reduce inflammation by increasing the production of interleukin-10 [132,149–151].

8.5. Repellent Effects

Many plants and/or their essential oils have a repellent effect against arthropods [122,126,152,153].

The majority of synthetic molecules with repellent effects pose problems for their safety, efficacy, and environmental impacts [153–158]. Therefore, the use of friendly and biodegradable natural acaricides have attracted the attention of researchers [159]. Due of this, plants or their derivatives constitute an interesting alternative to fight against ticks [122,125,153,157,160].

Repellents are substances that act locally or remotely, which prevent the landing, stings, or bites of arthropods. Halos et al. [161] defined repellents as “chemicals which cause arthropods to perform oriented movements away from their source”. There are two types of repulsion, repulsion in the strict sense, where an irritant effect by direct contact can be observed. This effect causes the tick to drop off before attaching itself to the host. The second action is known as sensu lato repellency, which causes attachment inhibition or detachment of already attached ticks [129].

The mechanism of action of the repellent effect of essential oils is poorly understood [162]. These act by producing a vapor barrier that deters the arthropod from coming into contact with the skin or landing on the skin [123,127,162,163].

Several studies reported the repellent activity of essential oil. Essential oils of *Cupressus funebris*, *Juniperus communis*, and *Juniperus chinensis* have an *Amblyomma americanum* nymph repellency with an EC₅₀ of 0.426, 0.508, and 0.917 mg oil/cm² filter paper, respectively. However, the essential oils of *Cupressus funebris* had a repellent effect against *Ixodes scapularis* with an EC₅₀ of 0.103 mg oil/cm² filter paper [164]. Wanzala et al. [152] showed that *Tagetes minuta* essential oil had more repellent activity than that of *Tithonia diversifolia* essential oil against *Rhipicephalus appendiculatus* with a repellent dose at 0.5 probabilities of 0.0021 mg and 0.263 mg, respectively. Likewise, 5% oregano and spearmint essential oils exhibited as natural clothing repellents against *Ixodes ricinus* comparable to 20% DEET for 24 h [153].

Jaenson et al. [165] found that the *Corymbia citriodora* essential oil showed a 100% repellent effect against *Ixodes ricinus* nymphs. Moreover, lavender and geranium essential oil, when diluted to 30% in 1,2-propanediol, had 100% of repellency activity.

Moreover, Kulma et al. [166] noted a moderate to high repellency activity at 65 to 85% against *Ixodes ricinus* females 5 min after the application of *Lavender* and *Eucalyptus* essential oils.

The volatile nature of essential oils is a major drawback because their activities usually dissipate relatively quickly [123,127,162,167]. For this reason, several fixatives are used to improve the duration of repellency of essential oils such as mustard and coconut oils, genapol, ethanol, polyethylene glycol, liquid paraffin petroleum jelly, and salicylic acid [127].

9. Conclusions

The past decade was characterized by a growing interest from researchers to study the effectiveness of essential oils against ticks.

Numerous preclinical studies have documented the acaricidal efficacy of EOs and/or their main compounds, in many cases elucidating their mechanism of action and lethal dose, and their relative biosafety and biodegradability in nature, which may constitute a serious alternative to the use of chemical acaricides.

Unfortunately, there are hardly any clinical studies and more in vivo research is needed to standardize the experimental design, to establish the correct doses to administer in animals, and to determine the synergistic and antagonistic effects, as well as to study the toxicological profile of these EOS in mammals.

Finally, given the volatile nature of many essential oils, it is necessary to further develop their formulation as acaricides (microencapsulation and nanoformulation) to maximize the contact time of these essential oils with ticks, and to avoid problems related to residual activity and the possible phytotoxicity of certain compounds used at high concentrations.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/pathogens10111379/s1>, Table S1: Acaricidal effects of essential oils (EOs) and/or their major compounds against ticks.

Author Contributions: Conceptualization, S.M.A.S. and F.V.; methodology, M.K. and J.G.; validation, M.G.G. and A.S.O. formal analysis, F.V.; investigation, J.G.; resources, M.S. and J.M.T.; data curation, A.G.-C. and J.S.; writing—original draft preparation, S.M.A.S. and F.V.; writing—review and editing, S.M.A.S., M.K., M.G.G., J.G., M.S., A.G.-C., J.S., L.E., A.S.O., J.M.T. and F.V.; visualization, J.G.; supervision, F.V.; project administration, A.S.O.; funding acquisition, J.M.T. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by Villamagna S.A.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors are especially grateful to his Grace the Duke of Westminster for his financial and human support during all the studies.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Klompen, J.S.H.; Black, W.C., IV; Keirans, J.E.; Oliver, J.H. Evolution of Ticks. *Annu. Rev. Entomol.* **1996**, *41*, 141–161. [[CrossRef](#)] [[PubMed](#)]
2. Barker, S.C.; Murrell, A. Systematics and evolution of ticks with a list of valid genus and species names. *Parasitology* **2004**, *129*, S15–S36. [[CrossRef](#)] [[PubMed](#)]
3. Djebir, S.; Ksouri, S.; Trigui, M.; Tounsi, S.; Boumaaza, A.; Hadeif, Y.; Benakhla, A. Chemical Composition and Acaricidal Activity of the Essential Oils of Some Plant Species of *Lamiaceae* and *Myrtaceae* against the Vector of Tropical Bovine Theileriosis: *Hyalomma scupense* (syn. *Hyalomma detritum*). *BioMed Res. Int.* **2019**, *2019*, 1–9. [[CrossRef](#)] [[PubMed](#)]
4. Alota, S.L.; Edquiban, T.R.J.; Galay, R.L.; Bernardo, J.M.G.; Sandalo, K.A.C.; Divina, B.P.; Tanaka, T. Determination of resistance status to amitraz in the cattle tick *Rhipicephalus (Boophilus) microplus* from Luzon, Philippines, through bioassay and molecular analysis. *Exp. Appl. Acarol.* **2021**, *83*, 399–409. [[CrossRef](#)] [[PubMed](#)]
5. Abbas, A.; Abbas, R.Z.; Masood, S.; Iqbal, Z.; Khan, M.K.; Saleemi, M.K.; Raza, M.A.; Mahmood, M.S.; Khan, J.A.; Sindhu, Z.D. Acaricidal and insecticidal effects of essential oils against ectoparasites of veterinary importance. *Bol. Latinoam. Caribe Plant. Med. Aromat.* **2018**, *17*, 441–452.
6. Pazinato, R.; Volpato, A.; Baldissera, M.D.; Santos, R.C.V.; Baretta, D.; Vaucher, R.A.; Giongo, J.L.; Boligon, A.A.; Stefani, L.M.; Da Silva, A.S. In vitro effect of seven essential oils on the reproduction of the cattle tick *Rhipicephalus microplus*. *J. Adv. Res.* **2016**, *7*, 1029–1034. [[CrossRef](#)]
7. Luns, D.A.R.; Martins, R.; Pombal, S.; Rodilla, J.M.L.; Githaka, N.W.; Vaz, I.D.S., Jr.; Logullo, C. Effect of essential oils against acaricide-susceptible and acaricide-resistant *Rhipicephalus* ticks. *Exp. Appl. Acarol.* **2021**, *83*, 597–608. [[CrossRef](#)] [[PubMed](#)]
8. George, J.E.; Pound, J.M.; Davey, R.B. Chemical control of ticks on cattle and the resistance of these parasites to acaricides. *Parasitology* **2004**, *129*, S353–S366. [[CrossRef](#)] [[PubMed](#)]
9. Adenubi, O.; Fasina, F.; McGaw, L.; Eloff, J.; Naidoo, V. Plant extracts to control ticks of veterinary and medical importance: A review. *S. Afr. J. Bot.* **2016**, *105*, 178–193. [[CrossRef](#)]
10. Furtado, F.N.; Silva, V.A.R.; Pereira, J.R.G.; Kisue, A.; Coêlho, F.A.S.; Coêlho, M.D.G. Avaliação in vitro do potencial acaricida do óleo essencial de *Tagetes minuta* frente a *Rhipicephalus (Boophilus) microplus* (Canestrini, 1887). *Rev. Biociênc.* **2013**, *19*, 104–110.

11. Nogueira, J.; Vinturelle, R.; Mattos, C.; Tietbohl, L.A.C.; Santos, M.G.; Vaz, J.I.D.S.; Mourão, S.C.; Rocha, L.; Folly, E. Acaricidal Properties of the Essential Oil from *Zanthoxylum caribaeum* against *Rhipicephalus microplus*. *J. Med. Entomol.* **2014**, *51*, 971–975. [[CrossRef](#)] [[PubMed](#)]
12. Habeeb, S.M.; El-Namaky, A.H.; Kamel, R.O. In vivo evaluation of xic effects of avermectin, *Citrus sinensis* var. balady and *C. limon* on female *Hyalomma dromedarii* (Acari: Ixodidae). *Acarologia* **2009**, *49*, 13–22.
13. Cruz, E.M.D.O.; Costa-Junior, L.; Pinto, J.A.O.; Santos, D.; de Araujo, S.A.; Arrigoni-Blank, M.D.F.; Bacci, L.; Alves, P.; Cavalcanti, S.C.D.H.; Blank, A.F. Acaricidal activity of *Lippia gracilis* essential oil and its major constituents on the tick *Rhipicephalus (Boophilus) microplus*. *Vet. Parasitol.* **2013**, *195*, 198–202. [[CrossRef](#)]
14. Abbas, R.Z.; Zaman, M.A.; Colwell, D.D.; Gilleard, J.; Iqbal, Z. Acaricide resistance in cattle ticks and approaches-its management: The state of play. *Vet. Parasitol.* **2014**, *203*, 6–20. [[CrossRef](#)] [[PubMed](#)]
15. Castro, K.N.D.C.; Canuto, K.M.; de Brito, E.S.; Costa-Junior, L.; De Andrade, I.M.; Magalhães, J.A.; Barros, D.M.A. In vitro efficacy of essential oils with different concentrations of 1,8-cineole against *Rhipicephalus (Boophilus) microplus*. *Rev. Bras. Parasitol. Vet.* **2018**, *27*, 203–210. [[CrossRef](#)] [[PubMed](#)]
16. Quadros, D.; Johnson, T.; Whitney, T.; Oliver, J.; Chávez, A.O. Plant-Derived Natural Compounds for Tick Pest Control in Livestock and Wildlife: Pragmatism or Utopia? *Insects* **2020**, *11*, 490. [[CrossRef](#)] [[PubMed](#)]
17. George, D.R.; Finn, R.D.; Graham, K.M.; Sparagano, O.A. Present and future potential of plant-derived products to control arthropods of veterinary and medical significance. *Parasites Vectors* **2014**, *7*, 28. [[CrossRef](#)] [[PubMed](#)]
18. Ellse, L.; Wall, R. The use of essential oils in veterinary ectoparasite control: A review. *Med. Veter.-Entomol.* **2013**, *28*, 233–243. [[CrossRef](#)] [[PubMed](#)]
19. Kolaczinski, J.; Curtis, C. Chronic illness as a result of low-level exposure to synthetic pyrethroid insecticides: A review of the debate. *Food Chem. Toxicol.* **2004**, *42*, 697–706. [[CrossRef](#)] [[PubMed](#)]
20. Freitas, D.R.J.; Pohl, P.C.; Vaz, I.S., Jr. Caracterização da resistência para acaricidas no carrapato *Boophilus microplus*. *Acta Sci. Vet.* **2005**, *33*, 109–117. [[CrossRef](#)]
21. Ramwell, C.T.; Sinclair, C.J.; Van Beinum, G.W.; Bryning, G. Management of the environmental inputs and risks of cypermethrin based sheep dips. *Central. Sci. Lab. Rep.* **2009**, *1*, 35–43.
22. Pinto, Z.T.; Carneiro, J.F.; Carriço, C.; Caetano, R.L.; Ferreira, V.D.S.B.; Mendonça, P.M.; Berenger, A.L.R.; Figueiredo, M.R. Acaricidal effects of seven Brazilian plant extracts. *Rev. Colomb. Entomol.* **2018**, *44*, 44–47. [[CrossRef](#)]
23. Martinez-Velazquez, M.; Castillo-Herrera, G.A.; Rosario-Cruz, R.; Flores-Fernandez, J.M.; Lopez-Ramirez, J.; Hernandez-Gutierrez, R.; Lugo-Cervantes, E.D.C.; Rosario-Cruz, R. Acaricidal effect and chemical composition of essential oils extracted from *Cuminum cyminum*, *Pimenta dioica* and *Ocimum basilicum* against the cattle tick *Rhipicephalus (Boophilus) microplus* (Acari: Ixodidae). *Parasitol. Res.* **2010**, *108*, 481–487. [[CrossRef](#)]
24. Martinez-Velazquez, M.; Rosario-Cruz, R.; Castillo-Herrera, G.; Flores-Fernandez, J.M.; Alvarez, A.H.; Lugo-Cervantes, E.; Rosario-Cruz, R. Acaricidal Effect of Essential Oils from *Lippia graveolens* (Lamiales: Verbenaceae), *Rosmarinus officinalis* (Lamiales: Lamiaceae), and *Allium sativum* (Liliales: Liliaceae) against *Rhipicephalus (Boophilus) microplus* (Acari: Ixodidae). *J. Med. Entomol.* **2011**, *48*, 822–827. [[CrossRef](#)] [[PubMed](#)]
25. Shezryna, S.; Anisah, N.; Saleh, I.; A Syamsa, R. Acaricidal activity of the essential oils from *Citrus hystrix* (Rutaceae) and *Cymbopogon citratus* (Poaceae) on the cattle tick *Rhipicephalus (Boophilus) microplus* larvae (Acari: Ixodidae). *Trop. Biomed.* **2020**, *37*, 433–442.
26. Drummond, R.O.; Ernst, S.E.; Trevino, J.L.; Gladney, W.J.; Graham, O.H. *Boophilus annulatus* and *B. microplus*: Laboratory Tests of Insecticides 13. *J. Econ. Entomol.* **1973**, *66*, 130–133. [[CrossRef](#)] [[PubMed](#)]
27. George, J.E. Present and Future Technologies for Tick Control. *Ann. N. Y. Acad. Sci.* **2006**, *916*, 583–588. [[CrossRef](#)]
28. Graf, J.-F.; Gogolewski, R.; Leach-Bing, N.; Sabatini, G.A.; Molento, M.B.; Bordin, E.L.; Arantes, G.J. Tick control: An industry point of view. *Parasitology* **2004**, *129*, S427–S442. [[CrossRef](#)] [[PubMed](#)]
29. Wharton, R.H. Acaricide Resistance and Alternative Methods of Tick Control. *World Anim. Rev.* **1983**, *36*, 34–41.
30. Sonenshine, D.E. Tick pheromones and their use in tick control. *Annu. Rev. Entomol.* **2006**, *51*, 557–580. [[CrossRef](#)] [[PubMed](#)]
31. Casida, J.E. Pyrethrum flowers and pyrethroid insecticides. *Environ. Health Perspect.* **1980**, *34*, 189–202. [[CrossRef](#)]
32. ATSDR. Piretrinas y piretroides (Pyrethrins and Pyrethroids) | -xFAQ ATSDR. Available online: https://www.atsdr.cdc.gov/es/toxfaqs/es_tfacts155.html (accessed on 1 October 2019).
33. Davey, R.B.; George, J.E.; Snyder, D.E. Efficacy of a single whole-body spray treatment of spinosad, against *Boophilus microplus* (Acari: Ixodidae) on cattle. *Vet. Parasitol.* **2001**, *99*, 41–52. [[CrossRef](#)]
34. Cetin, H.; Cilek, J.E.; Aydin, L.; Yanikoglu, A. Acaricidal effects of the essential oil of *Origanum minutiflorum* (Lamiaceae) against *Rhipicephalus turanicus* (Acari: Ixodidae). *Vet. Parasitol.* **2009**, *160*, 359–361. [[CrossRef](#)] [[PubMed](#)]
35. Brito, L.G.; Barbieri, F.S.; Rocha, R.B.; Oliveira, M.C.S.; Ribeiro, E.S. Evaluation of the Efficacy of Acaricides Used- Control the Cattle Tick, *Rhipicephalus microplus*, in Dairy Herds Raised in the Brazilian Southwestern Amazon. *Vet. Med. Int.* **2011**, *2011*, 806093. [[CrossRef](#)] [[PubMed](#)]
36. Shoop, W.L.; Hartline, E.J.; Gould, B.R.; Waddell, M.E.; McDowell, R.G.; Kinney, J.B.; Lahm, G.P.; Long, J.K.; Xu, M.; Wagerle, T.; et al. Discovery and mode of action of afoxolaner, a new isoxazoline parasiticide for dogs. *Vet. Parasitol.* **2014**, *201*, 179–189. [[CrossRef](#)] [[PubMed](#)]

37. Weber, T.; Selzer, P.M. Isoxazolines: A Novel Chemotype Highly Effective on Ectoparasites. *ChemMedChem* **2016**, *11*, 270–276. [[CrossRef](#)]
38. McTier, T.L.; Chubb, N.; Curtis, M.P.; Hedges, L.; Inskeep, G.A.; Knauer, C.S.; Menon, S.; Mills, B.; Pullins, A.; Zinser, E.; et al. Discovery of sarolaner: A novel, orally administered, broad-spectrum, isoxazoline ectoparasiticide for dogs. *Vet. Parasitol.* **2016**, *222*, 3–11. [[CrossRef](#)]
39. Little, S.E. Lotilaner—A novel systemic tick and flea control product for dogs. *Parasites Vectors* **2017**, *10*, 539. [[CrossRef](#)] [[PubMed](#)]
40. Abebe, D.; Kebede, A. Review on Acaricide Resistant Bovine Ticks and Alternative Solutions. *Eur. J. Biol. Sci.* **2018**, *10*, 86–94. [[CrossRef](#)]
41. Reshma, K.R.; Prakasan, K. Synthetic Acaricides as A Promising-ol in Tick Control Program-The Present Scenario. *Entomol. Appl. Sci. Lett.* **2020**, *7*, 58–69.
42. Angus, B.M. The history of the cattle tick *Boophilus microptus* in Australia and achievements in its control. *Int. J. Parasitol.* **1996**, *26*, 1341–1355. [[CrossRef](#)]
43. Harris, R.L.; George, J.E.; Ahrens, E.H.; Davey, R.B.; Bazan, H.O. Selection for Resistance to Coumaphos in a Strain of Southern Cattle Tick (Acari: Ixodidae). *J. Econ. Entomol.* **1988**, *81*, 545–548. [[CrossRef](#)] [[PubMed](#)]
44. Hemingway, J.; Field, L.; Vontas, J. An Overview of Insecticide Resistance. *Science* **2002**, *298*, 96–97. [[CrossRef](#)]
45. Raynal, J.T.; Da Silva, A.A.B.; Sousa, T.D.J.; Bahiense, T.C.; Meyer, R.; Portela, R.W. Acaricides efficiency on *Rhipicephalus (Boophilus) microplus* from Bahia state North-Central region. *Rev. Bras. Parasitol. Vet.* **2013**, *22*, 71–77. [[CrossRef](#)] [[PubMed](#)]
46. Muhammad, G.; Naureen, A.; Firyal, S.; Saqib, M. Tick control strategies in dairy production medicine. *Pakistan. Vet. J.* **2008**, *28*, 43–50.
47. Nath, S.; Mandal, S.; Pal, S.; Jadhao, S.; Ottalwar, N.; Sanyal, P. Impact and Management of Acaricide Resistance-Pertaining to Sustainable Control of Ticks. *Int. J. Livest. Res.* **2018**, *8*, 46. [[CrossRef](#)]
48. Rodriguez-Vivas, R.I.; Jonsson, N.; Bhushan, C. Strategies for the control of *Rhipicephalus microplus* ticks in a world of conventional acaricide and macrocyclic lactone resistance. *Parasitol. Res.* **2017**, *117*, 3–29. [[CrossRef](#)] [[PubMed](#)]
49. Shaw, R.D. Tick control on domestic animals. 1. A brief history of economic significance of tick infestations. *Trop. Sci.* **1969**, *11*, 113.
50. Catterall, W.A. Structural biology: A 3D view of sodium channels. *Nature* **2001**, *409*, 988–991. [[CrossRef](#)] [[PubMed](#)]
51. Schnitzerling, H.J.; Nolan, J.; Hughes, S. Toxicology and metabolism of isomers of flumethrin in larvae of pyrethroid susceptible and resistant strains of the cattle tick *Boophilus microplus* (Acari: Ixodidae). *Exp. Appl. Acarol.* **1989**, *6*, 47–54. [[CrossRef](#)]
52. Lovis, L.; Reggi, J.; Berggoetz, M.; Betschart, B.; Sager, H. Determination of Acaricide Resistance in *Rhipicephalus (Boophilus) microplus* (Acari: Ixodidae) Field Populations of Argentina, South Africa, and Australia with the Larval Tarsal Test. *J. Med. Entomol.* **2013**, *50*, 326–335. [[CrossRef](#)] [[PubMed](#)]
53. Castro-Janer, E.; Rifran, L.; Piaggio, J.; Gil, A.; Miller, R.; Schumaker, T. In vitro tests to establish LC50 and discriminating concentrations for fipronil against *Rhipicephalus (Boophilus) microplus* (Acari: Ixodidae) and their standardization. *Vet. Parasitol.* **2009**, *162*, 120–128. [[CrossRef](#)] [[PubMed](#)]
54. Janer, E.C.; Klafke, G.; Fontes, F.; Capurro, M.; Schumaker, T. Mutations in *Rhipicephalus microplus* GABA gated chloride channel gene associated with fipronil resistance. *Ticks Tick-borne Dis.* **2019**, *10*, 761–765. [[CrossRef](#)] [[PubMed](#)]
55. Simon-Delso, N.; Amaral-Rogers, V.; Belzunces, L.P.; Bonmatin, J.M.; Chagnon, M.; Downs, C.; Furlan, L.; Gibbons, D.W.; Giorio, C.; Girolami, V.; et al. Systemic insecticides (neonicotinoids and fipronil): Trends, uses, mode of action and metabolites. *Environ. Sci. Pollut. Res.* **2014**, *22*, 5–34. [[CrossRef](#)]
56. Junquera, P.; Hosking, B.; Gameiro, M.; Macdonald, A. Benzoylphenyl ureas as veterinary antiparasitics. An overview and outlook with emphasis on efficacy, usage and resistance. *Parasite* **2019**, *26*, 26. [[CrossRef](#)] [[PubMed](#)]
57. Sparks, T.C.; Crouse, G.D.; Durst, G. Natural products as insecticides: The biology, biochemistry and quantitative structure—Activity relationships of spinosyns and spinosoids. *Pest. Manag. Sci.* **2001**, *57*, 896–905. [[CrossRef](#)] [[PubMed](#)]
58. Salgado, V.L. Studies on the Mode of Action of Spinosad: Insect Symptoms and Physiological Correlates. *Pestic. Biochem. Physiol.* **1998**, *60*, 91–102. [[CrossRef](#)]
59. Snyder, D.E.; Cruthers, L.R.; Slone, R.L. Preliminary study on the acaricidal efficacy of spinosad administered orally to dogs infested with the brown dog tick, *Rhipicephalus sanguineus* (Latreille, 1806) (Acari: Ixodidae). *Vet. Parasitol.* **2009**, *166*, 131–135. [[CrossRef](#)]
60. A Kirst, H. The spinosyn family of insecticides: Realizing the potential of natural products research. *J. Antibiot.* **2010**, *63*, 101–111. [[CrossRef](#)] [[PubMed](#)]
61. Ozoe, Y.; Asahi, M.; Ozoe, F.; Nakahira, K.; Mita, T. The antiparasitic isoxazoline A1443 is a potent blocker of insect ligand-gated chloride channels. *Biochem. Biophys. Res. Commun.* **2010**, *391*, 744–749. [[CrossRef](#)]
62. Gassel, M.; Wolf, C.; Noack, S.; Williams, H.; Ilg, T. The novel isoxazoline ectoparasiticide fluralaner: Selective inhibition of arthropod γ -aminobutyric acid- and l-glutamate-gated chloride channels and insecticidal/acaricidal activity. *Insect Biochem. Mol. Biol.* **2014**, *45*, 111–124. [[CrossRef](#)]
63. Ribeiro, V.L.S.; Dos Santos, J.C.; Bordignon, S.A.; Apel, M.A.; Henriques, A.T.; Von Poser, G.L. Acaricidal properties of the essential oil from *Hesperozygis ringens* (Lamiaceae) on the cattle tick *Rhipicephalus (Boophilus) microplus*. *Bioresour. Technol.* **2010**, *101*, 2506–2509. [[CrossRef](#)]

64. De Meneghi, D.; Stachurski, F.; Adakal, H. Experiences in Tick Control by Acaricide in the Traditional Cattle Sector in Zambia and Burkina Faso: Possible Environmental and Public Health Implications. *Front. Public Health* **2016**, *4*, 239. [[CrossRef](#)] [[PubMed](#)]
65. Singh, N.K.; Abhijit, N.; Harkirat, S. Detection of multi-acaricide resistance in *Rhipicephalus (Boophilus) microplus* (Acari: Ixodidae). *Explor. Anim. Med. Res.* **2019**, *9*, 24–28.
66. Sangster, N. Managing parasiticide resistance. *Vet. Parasitol.* **2001**, *98*, 89–109. [[CrossRef](#)]
67. Corley, S.W.; Jonsson, N.N.; Piper, E.K.; Cutullé, C.; Stear, M.; Seddon, J. Mutation in the Rm AOR gene is associated with amitraz resistance in the cattle tick *Rhipicephalus microplus*. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 16772–16777. [[CrossRef](#)] [[PubMed](#)]
68. Stone, B.F. The Genetics of Resistance by Ticks- Acaricides. *Aust. Vet. J.* **1972**, *48*, 345–350. [[CrossRef](#)]
69. Benavides, E. Control de Las Pérdidas Ocasionadas Por Los Parásitos Del Ganado. *Carta Fedegan* **2001**, *69*, 52–63.
70. Nolan, J. *Acaricide Resistance in the Cattle Tick Boophilus microplus, Report of Workshop Leader-FAO/UN Consultant, Porto Alegre, RS, Brazil*; Food and Agriculture Organization of the United Nations Publishing Services: Rome, Italy, 1994.
71. Chen, A.C.; He, H.; Davey, R.B. Mutations in a putative octopamine receptor gene in amitraz-resistant cattle ticks. *Vet. Parasitol.* **2007**, *148*, 379–383. [[CrossRef](#)] [[PubMed](#)]
72. Davey, R.B.; Miller, R.J.; George, J.E. Efficacy of amitraz applied as a dip against an amitraz-resistant strain of *Rhipicephalus (Boophilus) microplus* (Acari: Ixodidae) infested on cattle. *Vet. Parasitol.* **2008**, *152*, 127–135. [[CrossRef](#)]
73. Miller, R.J.; Davey, R.B.; White, W.H.; George, J.E. A comparison of three bioassay techniques- determine amitraz susceptibility in *Boophilus microplus* (Acari: Ixodidae). *J. Med. Entomol.* **2007**, *44*, 283–294. [[CrossRef](#)]
74. Mekonnen, S.; Bryson, N.R.; Fourie, L.J.; Peter, R.J.; Spickett, A.M.; Taylor, R.J.; Strydom, T.; Horak, I.G. Acaricide resistance profiles of single- and multi-host ticks from communal and commercial farming areas in the Eastern Cape and North-West Provinces of South Africa. *Onderstepoort J. Vet. Res.* **2002**, *69*, 99–105.
75. Jongejan, F.; Uilenberg, G. The global importance of ticks. *Parasitology* **2004**, *129*, S3–S14. [[CrossRef](#)] [[PubMed](#)]
76. A Alonso-Díaz, M.; I Rodríguez-Vivas, R.; Fragoso-Sánchez, H.; Rosario-Cruz, R. Resistencia de la garrapata *Boophilus microplus* a los ixodicidas. *Arch. Med. Vet.* **2006**, *38*, 105–113. [[CrossRef](#)]
77. Yessinou, R.E.; Akpo, Y.; Sidick, A.; Adoligbe, C.; Karim, I.Y.A.; Akogbeto, M.; Farougou, S. Evidence of multiple mechanisms of alphacypermethrin and deltamethrin resistance in ticks *Rhipicephalus microplus* in Benin, West Africa. *Ticks Tick-Borne Dis.* **2018**, *9*, 665–671. [[CrossRef](#)]
78. Rosado-Aguilar, J.; Arjona-Cambranes, K.; Torres-Acosta, J.; Rodríguez-Vivas, R.; Bolio-González, M.; Ortega-Pacheco, A.; Alzina-López, A.; Gutiérrez-Ruiz, E.; Gutiérrez-Blanco, E.; Aguilar-Caballero, A. Plant products and secondary metabolites with acaricide activity against ticks. *Vet. Parasitol.* **2017**, *238*, 66–76. [[CrossRef](#)] [[PubMed](#)]
79. European Commission. Encouraging Innovation in Biopesticide Development. (New Alert Issue). Science for Environment Policy. European Commission. 2008. Available online: https://ec.europa.eu/environment/integration/research/newsalert/pdf/134na5_en.pdf. (accessed on 16 June 2021).
80. Natural Tick Repellents and Pesticides | Lyme Disease CDC. 2018. Available online: <https://www.cdc.gov/lyme/prev/natural-repellents.html>. (accessed on 13 August 2018).
81. Schmutterer, H. Properties and Potential of Natural Pesticides from the Neem Tree, *Azadirachta indica*. *Annu. Rev. Entomol.* **1990**, *35*, 271–297. [[CrossRef](#)]
82. Neem Foundation. Neem. History of Usage. 2018. Available online: <https://neemfoundation.org/about-neem/history-of-usage/> (accessed on 13 June 2021).
83. Campos, E.V.R.; de Oliveira, J.L.; Pascoli, M.; de Lima, R.; Fraceto, L.F. Neem Oil and Crop Protection: From Now- the Future. *Front. Plant. Sci.* **2016**, *7*, 1494. [[CrossRef](#)]
84. Cetin, H.; Cilek, J.; Oz, E.; Aydin, L.; Deveci, O.; Yanikoglu, A. Acaricidal activity of *Satureja thymbra* L. essential oil and its major components, carvacrol and γ -terpinene against adult *Hyalomma marginatum* (Acari: Ixodidae). *Vet. Parasitol.* **2010**, *170*, 287–290. [[CrossRef](#)] [[PubMed](#)]
85. Koç, S.; Oz, E.; Aydin, L.; Cetin, H. Acaricidal activity of the essential oils from three Lamiaceae plant species on *Rhipicephalus turanicus* Pom. (Acari: Ixodidae). *Parasitol. Res.* **2012**, *111*, 1863–1865. [[CrossRef](#)]
86. Gomes, G.A.; Monteiro, C.M.O.; Julião, L.D.S.; Maturano, R.; Senra, T.O.S.; Zeringóta, V.; Calmon, F.; Matos, R.; Daemon, E.; de Carvalho, M.G. Acaricidal activity of essential oil from *Lippia sidoides* on unengorged larvae and nymphs of *Rhipicephalus sanguineus* (Acari: Ixodidae) and *Amblyomma cajennense* (Acari: Ixodidae). *Exp. Parasitol.* **2014**, *137*, 41–45. [[CrossRef](#)] [[PubMed](#)]
87. Ferreira, F.M.; Delmonte, C.C.; Novato, T.L.P.; Monteiro, C.M.O.; Daemon, E.; Vilela, F.M.P.; Amaral, M.P.H. Acaricidal activity of essential oil of *Syzygium aromaticum*, hydrolate and eugenol formulated or free on larvae and engorged females of *Rhipicephalus microplus*. *Med. Vet. Entomol.* **2017**, *32*, 41–47. [[CrossRef](#)]
88. Rosado-Aguilar, J.; Aguilar-Caballero, A.J.; Rodriguez-Vivas, R.; Borges-Argaez, R.; Garcia-Vazquez, Z.; Mendez-Gonzalez, M. Acaricidal activity of extracts from *Petiveria alliacea* (Phytolaccaceae) against the cattle tick, *Rhipicephalus (Boophilus) microplus* (Acari: Ixodidae). *Vet. Parasitol.* **2010**, *168*, 299–303. [[CrossRef](#)]
89. Marchesini, P.; Barbosa, A.F.; Franco, C.; Novato, T.; Sanches, M.N.G.; de Carvalho, M.G.; Fabri, R.L.; Daemon, E.; Monteiro, C.M.O. Activity of the extract of *Acmella oleracea* on immature stages of *Amblyomma sculptum* (Acari: Ixodidae). *Vet. Parasitol.* **2018**, *254*, 147–150. [[CrossRef](#)]

90. Fouche, G.; Ramafuthula, M.; Maselela, V.; Mokoena, M.; Senabe, J.; Leboho, T.; Sakong, B.M.; Adenubi, O.T.; Eloff, J.N.; Wellington, K.W. Acaricidal activity of the organic extracts of thirteen South African plants against *Rhipicephalus (Boophilus) decoloratus* (Acari: Ixodidae). *Vet. Parasitol.* **2016**, *224*, 39–43. [[CrossRef](#)] [[PubMed](#)]
91. Fouche, G.; Sakong, B.M.; Adenubi, O.T.; Dzoyem, J.P.; Naidoo, V.; Leboho, T.; Wellington, K.W.; Eloff, J.N. Investigation of the acaricidal activity of the acetone and ethanol extracts of 12 South African plants against the adult ticks of *Rhipicephalus turanicus*. *Onderstepoort J. Vet. Res.* **2017**, *84*. [[CrossRef](#)] [[PubMed](#)]
92. Jia, M.; He, Q.; Wang, W.; Dai, J.; Zhu, L. Chemical composition and acaricidal activity of *Arisaema anurans* essential oil and its major constituents against *Rhipicephalus microplus* (Acari: Ixodidae). *Vet. Parasitol.* **2018**, *261*, 59–66. [[CrossRef](#)] [[PubMed](#)]
93. Charlie-Silva, I.; Giglioti, R.; Magalhães, P.M.; Sousa, I.M.; Foglio, M.A.; Oliveira, M.C.; Chagas, A.C.S. Lack of impact of dietary inclusion of dried *Artemisia annua* leaves for cattle on infestation by *Rhipicephalus (Boophilus) microplus* ticks. *Ticks Tick-Borne Dis.* **2018**, *9*, 1115–1119. [[CrossRef](#)]
94. Valcárcel, F.; Olmeda, A.S.; González, M.G.; Andrés, M.F.; Navarro-Rocha, J.; González-Coloma, A. Acaricidal and Insect Antifeedant Effects of Essential Oils From Selected Aromatic Plants and Their Main Components. *Front. Agron.* **2021**, *3*, 22. [[CrossRef](#)]
95. Laghzaoui, E.-M.; Kasrati, A.; Abbad, A.; Leach, D.; Spooner-Hart, R.; El Mouden, E.H. Acaricidal properties of essential oils from Moroccan plants against immature ticks of *Hyalomma aegyptium* (Linnaeus, 1758); an external parasite of the spur-thighed tortoise (*Testudo graeca*). *Int. J. Acarol.* **2018**, *44*, 315–321. [[CrossRef](#)]
96. Adenubi, O.T.; Abdalla, M.A.; Ahmed, A.S.; Njoya, E.M.; McGaw, L.J.; Eloff, J.N.; Naidoo, V. Isolation and characterization of two acaricidal compounds from *Calpurnia aurea* subsp. *aurea* (Fabaceae) leaf extract. *Exp. Appl. Acarol.* **2018**, *75*, 345–354. [[CrossRef](#)]
97. Elmhalli, F.; Pålsson, K.; Öberg, J.; Grandi, G. Acaricidal properties of ylang-ylang oil and star anise oil against nymphs of *Ixodes ricinus* (Acari: Ixodidae). *Exp. Appl. Acarol.* **2018**, *76*, 209–220. [[CrossRef](#)] [[PubMed](#)]
98. Monteiro, I.N.; Monteiro, O.D.S.; Costa-Junior, L.M.; Lima, A.D.S.; Andrade, E.H.D.A.; Maia, J.G.S.; Filho, V.E.M. Chemical composition and acaricide activity of an essential oil from a rare chemotype of *Cinnamomum verum* Presl on *Rhipicephalus microplus* (Acari: Ixodidae). *Vet. Parasitol.* **2017**, *238*, 54–57. [[CrossRef](#)] [[PubMed](#)]
99. Navarro-Rocha, J.; Barrero, A.F.; Burillo, J.; Olmeda, A.S.; González-Coloma, A. Valorization of essential oils from two populations (wild and commercial) of *Geranium macrorrhizum* L. *Ind. Crop. Prod.* **2018**, *116*, 41–45. [[CrossRef](#)]
100. Hue, T.; Cauquil, L.; Fokou, J.B.H.; Dongmo, P.M.J.; Bakarnga-Via, I.; Menut, C. Acaricidal activity of five essential oils of *Ocimum* species on *Rhipicephalus (Boophilus) microplus* larvae. *Parasitol. Res.* **2014**, *114*, 91–99. [[CrossRef](#)] [[PubMed](#)]
101. Ortiz de Elguea-Culebras, G.; Sánchez-Vioque, R.; Berruga, M.I.; Herraiz-Peñalver, D.; González-Coloma, A.; Andrés, M.F.; Santana-Méridas, O. Biocidal Potential and Chemical Composition of Industrial Essential Oils from *Hyssopus officinalis*, *Lavandula × intermedia* var. Super, and *St. chamaecyparissus*. *Chem. Biodivers.* **2018**, *15*, e1700313. [[CrossRef](#)] [[PubMed](#)]
102. Junior, G.D.S.L.; Campos, J.P.; Monteiro, C.M.D.O.; Fiorotti, J.; Júnior, F.E.A.C.; Tomé, A.L.; Perinotto, W.M.D.S. Chemical composition and acaricidal activity of essential oils from fruits of *Illicium verum* and rhizomes of *Curcuma zedoaria* against *Dermacentor nitens* (Acari: Ixodidae). *J. Essent. Oil Res.* **2020**, *32*, 571–576. [[CrossRef](#)]
103. Fernandez, C.M.M.; Da Rosa, M.F.; Fernandez, A.C.A.M.; Bortolucci, W.D.C.; Ferreira, F.B.P.; Linde, G.A.; Colauto, G.A.L.; Simões, M.R.; Lobo, V.D.S.; Gazim, Z.C. Essential oil and fractions isolated of Laurel to control adults and larvae of cattle ticks. *Nat. Prod. Res.* **2018**, *34*, 731–735. [[CrossRef](#)] [[PubMed](#)]
104. Julio, L.F.; Díaz, C.E.; Aissani, N.; Valcarcel, F.; Burillo, J.; Olmeda, S.; González-Coloma, A. Ixodicidal compounds from pre-domesticated *Lavandula luisieri*. *Ind. Crop. Prod.* **2017**, *110*, 83–87. [[CrossRef](#)]
105. Gomes, G.A.; Monteiro, C.M.D.O.; Senra, T.D.O.S.; Zeringota, V.; Calmon, F.; Matos, R.; Daemon, E.; Gois, R.W.D.S.; Santiago, G.M.P.; de Carvalho, M.G. Chemical composition and acaricidal activity of essential oil from *Lippia sidoides* on larvae of *Dermacentor nitens* (Acari: Ixodidae) and larvae and engorged females of *Rhipicephalus microplus* (Acari: Ixodidae). *Parasitol. Res.* **2012**, *111*, 2423–2430. [[CrossRef](#)] [[PubMed](#)]
106. Rajakumar, G.; Rahuman, A.A.; Roopan, S.M.; Chung, I.-M.; Anbarasan, K.; Karthikeyan, V. Efficacy of larvicidal activity of green synthesized titanium dioxide nanoparticles using *Mangifera indica* extract against blood-feeding parasites. *Parasitol. Res.* **2014**, *114*, 571–581. [[CrossRef](#)]
107. Lebouvier, N.; Hue, T.; Brophy, J.; Hnawia, E.; Nour, M. Chemical Composition and Acaricidal Activity of *Nemuaron vieillardii* Essential Oil against the Cattle Tick *Rhipicephalus (Boophilus) microplus*. *Nat. Prod. Commun.* **2016**, *11*, 1934578X1601101235. [[CrossRef](#)]
108. Dantas, A.; Machado, D.; Araujo, A.; Oliveira-Junior, R.; Lima-Saraiva, S.; Ribeiro, L.; Almeida, J.; Horta, M. Acaricidal activity of extracts from the leaves and aerial parts of *Neoglaziovia variegata* (Bromeliaceae) on the cattle tick *Rhipicephalus (Boophilus) microplus*. *Res. Vet. Sci.* **2015**, *100*, 165–168. [[CrossRef](#)]
109. Ferreira, T.P.; Cid, Y.P.; Cardilo, M.A.; Dos Santos, G.C.M.; Avelar, B.R.; Freitas, J.P.; Ożarowski, M.; Souza, M.; Chaves, D. In vitro Acaricidal Activity of *Ocimum gratissimum* Essential Oil on *Rhipicephalus sanguineus*, *Amblyomma sculptum* and *Rhipicephalus microplus* Larvae. *Rev. Virtual De Quim.* **2019**, *11*, 1604–1613. [[CrossRef](#)]
110. Figueiredo, A.; Nascimento, L.M.; Lopes, L.G.; Giglioti, R.; Albuquerque, R.D.; Santos, M.G.; Falcão, D.Q.; Nogueira, J.A.; Rocha, L.; Chagas, A.C.S. First report of the effect of *Ocotea elegans* essential oil on *Rhipicephalus (Boophilus) microplus*. *Vet. Parasitol.* **2018**, *252*, 131–136. [[CrossRef](#)]
111. Coskun, S.; Girisgin, O.; Kürkcüoğlu, M.; Malyer, H.; Girisgin, A.O.; Kirimer, N.; Baser, K.H.C. Acaricidal efficacy of *Origanum onites* L. essential oil against *Rhipicephalus turanicus* (Ixodidae). *Parasitol. Res.* **2008**, *103*, 259–261. [[CrossRef](#)] [[PubMed](#)]

112. Ferraz, A.; Balbino, J.M.; Zini, C.A.; Ribeiro, V.L.S.; Bordignon, S.A.L.; Von Poser, G. Acaricidal activity and chemical composition of the essential oil from three Piper species. *Parasitol. Res.* **2010**, *107*, 243–248. [[CrossRef](#)] [[PubMed](#)]
113. Fernandez, C.M.M.; Lorenzetti, F.B.; Bernuci, K.Z.; Iwanaga, C.C.; Bortolucci, W.D.C.; Romagnolo, M.B.; Simões, M.R.; Cortez, D.A.G.; Scodro, R.B.D.L.; Gazim, Z.C.; et al. Larvicidal potential of piperovatine in the control of cattle tick. *Vet. Parasitol.* **2018**, *263*, 5–9. [[CrossRef](#)]
114. Rey-Valeirón, C.; Pérez, K.; Guzmán, L.; López-Vargas, J.; Valarezo, E. Acaricidal effect of *Schinus molle* (Anacardiaceae) essential oil on unengorged larvae and engorged adult females of *Rhipicephalus sanguineus* (Acari: Ixodidae). *Exp. Appl. Acarol.* **2018**, *76*, 399–411. [[CrossRef](#)] [[PubMed](#)]
115. Vasquez, L.R.; Olmeda, A.S.; Zuñiga, G.; Villarroel, L.; Echeverri, L.F.; Gonzalez-Coloma, A.; Reina, M. Insect Antifeedant and Ixodidical Compounds from *Senecio adenotrichius*. *Chem. Biodivers.* **2016**, *14*, e1600155. [[CrossRef](#)]
116. Andreotti, R.; Garcia, M.V.; Cunha, R.C.; Barros, J.C. Protective action of *Tagetes minuta* (Asteraceae) essential oil in the control of *Rhipicephalus microplus* (Canestrini, 1887) (Acari: Ixodidae) in a cattle pen trial. *Vet. Parasitol.* **2013**, *197*, 341–345. [[CrossRef](#)] [[PubMed](#)]
117. Gazim, Z.C.; Demarchi, I.G.; Lonardon, M.V.C.; Amorim, A.C.L.; Hovell, A.M.C.; Rezende, C.M.; Ferreira, G.A.; de Lima, E.L.; de Cosmo, F.A.; Cortez, D.A.G. Acaricidal activity of the essential oil from *Tetradenia riparia* (Lamiaceae) on the cattle tick *Rhipicephalus (Boophilus) microplus* (Acari: Ixodidae). *Exp. Parasitol.* **2011**, *129*, 175–178. [[CrossRef](#)] [[PubMed](#)]
118. Novato, T.P.L.; Araújo, L.X.; de Monteiro, C.M.O.; Maturano, R.; Senra, T.D.O.S.; Matos, R.; Gomes, G.A.; de Carvalho, M.G.; Daemon, E. Evaluation of the combined effect of thymol, carvacrol and (E)-cinnamaldehyde on *Amblyomma sculptum* (Acari: Ixodidae) and *Dermacentor nitens* (Acari: Ixodidae) larvae. *Vet. Parasitol.* **2015**, *212*, 331–335. [[CrossRef](#)] [[PubMed](#)]
119. Ramírez, C.; Ibarra, F.; Pérez, H.I.; Manjarrez, N.; Salgado, H.J.; Ortega, L. Assessment and determination of LC 50 of carvacrol and salicylic acid analogues with acaricide activity in larvae and adult ticks of *Rhipicephalus (Boophilus) microplus*. *Parasite Epidemiol. Control* **2016**, *1*, 72–77. [[CrossRef](#)] [[PubMed](#)]
120. Novato, T.; Gomes, G.A.; Zeringóta, V.; Franco, C.T.; de Oliveira, D.R.; Melo, D.; de Carvalho, M.G.; Daemon, E.; Monteiro, C.M.D.O. In vitro assessment of the acaricidal activity of carvacrol, thymol, eugenol and their acetylated derivatives on *Rhipicephalus microplus* (Acari: Ixodidae). *Vet. Parasitol.* **2018**, *260*, 1–4. [[CrossRef](#)] [[PubMed](#)]
121. Machtiger, E.T.; Li, A.Y. Evaluation of four commercial natural products for repellency and toxicity against the lone star tick, *Amblyomma americanum* (Acari: Ixodidae). *Exp. Appl. Acarol.* **2017**, *73*, 451–460. [[CrossRef](#)] [[PubMed](#)]
122. Benelli, G.; Pavela, R. Repellence of essential oils and selected compounds against ticks—A systematic review. *Acta Trop.* **2018**, *179*, 47–54. [[CrossRef](#)]
123. Nerio, L.S.; Olivero-Verbel, J.; Stashenko, E. Repellent activity of essential oils: A review. *Bioresour. Technol.* **2010**, *101*, 372–378. [[CrossRef](#)] [[PubMed](#)]
124. Blenau, W.; Rademacher, E.; Baumann, A. Plant essential oils and formamidines as insecticides/acaricides: What are the molecular targets? *Apidologie* **2011**, *43*, 334–347. [[CrossRef](#)]
125. Benelli, G.; Pavela, R.; Canale, A.; Mehlhorn, H. Tick repellents and acaricides of botanical origin: A green roadmap to control tick-borne diseases? *Parasitol. Res.* **2016**, *115*, 2545–2560. [[CrossRef](#)]
126. Elmhalli, F.; Garboui, S.S.; Borg-Karlson, A.-K.; Mozūraitis, R.; Baldauf, S.L.; Grandi, G. The repellency and toxicity effects of essential oils from the Libyan plants *Salvadora persica* and *Rosmarinus officinalis* against nymphs of *Ixodes ricinus*. *Exp. Appl. Acarol.* **2019**, *77*, 585–599. [[CrossRef](#)] [[PubMed](#)]
127. Salman, M.; Abbas, R.Z.; Israr, M.; Abbas, A.; Mehmood, M.K.; Khan, M.K.; Sindhu, Z.U.D.; Hussain, R.; Saleemi, M.K.; Shah, S. Repellent and acaricidal activity of essential oils and their components against *Rhipicephalus* ticks in cattle. *Vet. Parasitol.* **2020**, *283*, 109178. [[CrossRef](#)]
128. Kaaya, G.P. The potential for antitick plants as components of an integrated tick control strategy. *Ann. N. Y. Acad. Sci.* **2000**, *916*. [[CrossRef](#)]
129. Goode, P.; Ellse, L.; Wall, R. Preventing tick attachment to dogs using essential oils. *Ticks Tick-Borne Dis.* **2018**, *9*, 921–926. [[CrossRef](#)] [[PubMed](#)]
130. Ribeiro, V.L.S.; Avancini, C.; Gonçalves, K.; Toigo, E.; von Poser, G. Acaricidal activity of *Calea serrata* (Asteraceae) on *Boophilus microplus* and *Rhipicephalus sanguineus*. *Vet. Parasitol.* **2008**, *151*, 351–354. [[CrossRef](#)]
131. Ribeiro, V.L.S.; Toigo, E.; Bordignon, S.A.; Gonçalves, K.; von Poser, G. Acaricidal properties of extracts from the aerial parts of *Hypericum polyanthemum* on the cattle tick *Boophilus microplus*. *Vet. Parasitol.* **2007**, *147*, 199–203. [[CrossRef](#)]
132. Amer, A.M.; Amer, M.M. Efficacy and Safety of Natural Essential Oils Mixture on Tick Infestation in Dogs. *Adv. Anim. Vet. Sci.* **2020**, *8*, 398–407. [[CrossRef](#)]
133. Powers, C.N.; Osier, J.L.; McFeeters, R.L.; Brazell, C.B.; Olsen, E.L.; Moriarity, D.M.; Satyal, P.; Setzer, W.N. Antifungal and Cytotoxic Activities of Sixty Commercially-Available Essential Oils. *Molecules* **2018**, *23*, 1549. [[CrossRef](#)]
134. Burgess, I.F. The mode of action of dimeticone 4% lotion against head lice, *Pediculus capitis*. *BMC Pharmacol.* **2009**, *9*, 3. [[CrossRef](#)] [[PubMed](#)]
135. Jankowska, M.; Rogalska, J.; Wyszowska, J.; Stankiewicz, M. Molecular Targets for Components of Essential Oils in the Insect Nervous System—A Review. *Molecules* **2017**, *23*, 34. [[CrossRef](#)]
136. Camilo, C.J.; Alves Nonato, C.D.F.; Galvão-Rodrigues, F.F.; Costa, W.D.; Clemente, G.G.; Sobreira Macedo, M.A.C.; Galvão Rodrigues, F.F.; Da Costa, J.G.M. Acaricidal activity of essential oils: A review. *Trends Phytochem. Res.* **2017**, *1*, 183–198.

137. López, M.D.; Pascual-Villalobos, M. Mode of inhibition of acetylcholinesterase by monoterpenoids and implications for pest control. *Ind. Crop. Prod.* **2010**, *31*, 284–288. [[CrossRef](#)]
138. Anderson, J.; Coats, J. Acetylcholinesterase inhibition by nootkatone and carvacrol in arthropods. *Pestic. Biochem. Physiol.* **2012**, *102*, 124–128. [[CrossRef](#)]
139. Keane, S.; Ryan, M.F. Purification, characterisation, and inhibition by monoterpenes of acetylcholinesterase from the waxmoth, *Galleria mellonella* (L.). *Insect Biochem. Mol. Biol.* **1999**, *29*, 1097–1104. [[CrossRef](#)]
140. Lee, S.E.; Lee, B.H.; Choi, W.S.; Park, B.S.; Kim, J.G.; Campbell, B.C. Fumigant-activity of volatile natural products from Korean spices and medicinal plants-wards the rice weevil, *Sitophilus oryzae* (L.). *Pest Manag. Sci.* **2001**, *57*, 548–553. [[CrossRef](#)]
141. Picollo, M.I.; Toloza, A.C.; Cueto, G.M.; Zygadlo, J.; Zerba, E. Anticholinesterase and pediculicidal activities of monoterpenoids. *Fitoterapia* **2008**, *79*, 271–278. [[CrossRef](#)] [[PubMed](#)]
142. Abdelgaleil, S.A.M.; Mohamed, M.I.E.; Badawy, M.; El-Arabi, S.A.A. Fumigant and Contact Toxicities of Monoterpenes to *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbst) and their Inhibitory Effects on Acetylcholinesterase Activity. *J. Chem. Ecol.* **2009**, *35*, 518–525. [[CrossRef](#)]
143. Siramon, P.; Ohtani, Y.; Ichiura, H. Biological performance of *Eucalyptus camaldulensis* leaf oils from Thailand against the subterranean termite *Coptotermes formosanus* Shiraki. *J. Wood Sci.* **2009**, *55*, 41–46. [[CrossRef](#)]
144. Seo, S.M.; Kim, J.; Kang, J.S.; Koh, S.H.; Ahn, Y.J.; Kang, K.S.; Park, I.K. Fumigant-activity and acetylcholinesterase inhibitory activity of 4 Asteraceae plant essential oils and their constituents against Japanese termite (*Reticulitermes speratus* Kolbe). *Pestic. Biochem. Physiol.* **2014**, *113*, 55–61. [[CrossRef](#)]
145. Yeom, H.-J.; Jung, C.-S.; Kang, J.; Kim, J.; Lee, J.-H.; Kim, D.-S.; Kim, H.-S.; Park, P.-S.; Kang, K.-S.; Park, I.-K. Insecticidal and Acetylcholine Esterase Inhibition Activity of Asteraceae Plant Essential Oils and Their Constituents against Adults of the German Cockroach (*Blattella germanica*). *J. Agric. Food Chem.* **2015**, *63*, 2241–2248. [[CrossRef](#)] [[PubMed](#)]
146. Kostyukovsky, M.; Rafaeeli, A.; Gileadi, C.; Demchenko, N.; Shaaya, E. Activation of octopaminergic receptors by essential oil constituents isolated from aromatic plants: Possible mode of action against insect pests. *Pest Manag. Sci.* **2002**, *58*, 1101–1106. [[CrossRef](#)]
147. Enan, E. Insecticidal activity of essential oils: Octopaminergic sites of action. *Comp. Biochem. Physiol. Part C Toxicol. Pharmacol.* **2001**, *130*, 325–337. [[CrossRef](#)]
148. Grifman, M.; Arbel, A.; Ginzberg, D.; Glick, D.; Elgavish, S.; Shaanan, B.; Soreq, H. In vitro phosphorylation of acetylcholinesterase at non-consensus protein kinase sites enhances the rate of acetylcholine hydrolysis. *Brain. Res. Mol. Brain Res.* **1997**, *51*, 179–187. [[CrossRef](#)]
149. Aazza, S.; Lyoussi, B.; Megías, C.; Cortés-Giraldo, I.; Vioque, J.; Figueiredo, A.C.; Miguel, M.G. Anti-oxidant, Anti-inflammatory and Anti-proliferative Activities of Moroccan Commercial Essential Oils. *Nat. Prod. Commun.* **2014**, *9*, 587–594. [[CrossRef](#)] [[PubMed](#)]
150. Ali, B.; Al-Wabel, N.A.; Shams, S.; Ahamad, A.; Khan, S.; Anwar, F. Essential oils used in aromatherapy: A systemic review. *Asian Pac. J. Trop. Biomed.* **2015**, *5*, 601–611. [[CrossRef](#)]
151. Andrade, B.F.M.T.; Conti, B.J.; Santiago, K.; Fernandes, A.; Sforcin, J.M. Cymbopogon martinii essential oil and geraniol at noncytotoxic concentrations exerted immunomodulatory/anti-inflammatory effects in human monocytes. *J. Pharm. Pharmacol.* **2014**, *66*, 1491–1496. [[CrossRef](#)]
152. Wanzala, W.; Hassanal, A.; Mukabana, W.R.; Takken, W. Repellent Activities of Essential Oils of Some Plants Used Traditionally to Control the Brown Ear Tick, *Rhipicephalus appendiculatus*. *J. Parasitol. Res.* **2014**, *2014*, 1–10. [[CrossRef](#)]
153. Soutar, O.; Cohen, F.; Wall, R. Essential oils as tick repellents on clothing. *Exp. Appl. Acarol.* **2019**, *79*, 209–219. [[CrossRef](#)]
154. Aquino, M.; Fyfe, M.; MacDougall, L.; Remple, V. West Nile virus in British Columbia. *Emerg. Infect. Dis.* **2004**, *10*, 1499–1501. [[CrossRef](#)] [[PubMed](#)]
155. Herrington, J. Risk perceptions regarding ticks and Lyme disease: A national survey. *Am. J. Prev. Med.* **2004**, *26*, 135–140. [[CrossRef](#)] [[PubMed](#)]
156. Katz, T.M.; Miller, J.H.; Hebert, A.A. Insect repellents: Historical perspectives and new developments. *J. Am. Acad. Dermatol.* **2008**, *58*, 865–871. [[CrossRef](#)] [[PubMed](#)]
157. Bissinger, B.W.; Roe, R.M. Tick repellents: Past, present, and future. *Pestic. Biochem. Physiol.* **2009**, *96*, 63–79. [[CrossRef](#)]
158. Osimitz, T.; Murphy, J.; Fell, L.; Page, B. Adverse events associated with the use of insect repellents containing *N,N*-diethyl-m-toluamide (DEET). *Regul. Toxicol. Pharmacol.* **2010**, *56*, 93–99. [[CrossRef](#)]
159. Geetha, R.V.; Roy, A. Essential oil repellents—a short review. *Int. J. Drug Dev. Res.* **2014**, *6*, 20–27.
160. Del Fabbro, S.; Nazzi, F. From chemistry- behavior molecular structure and bioactivity of repellents against *Ixodes ricinus* ticks. *PLoS ONE* **2013**, *8*, e67832. [[CrossRef](#)]
161. Halos, L.; Baneth, G.; Beugnet, F.; Bowman, A.S.; Chomel, B.; Farkas, R.; Franc, M.; Guillot, J.; Inokuma, H.; Kaufman, R.; et al. Defining the concept of ‘tick repellency’ in veterinary medicine. *Parasitology* **2012**, *139*, 419–423. [[CrossRef](#)] [[PubMed](#)]
162. Lee, M.Y. Essential Oils as Repellents against Arthropods. *BioMed Res. Int.* **2018**, *2018*, 1–9. [[CrossRef](#)]
163. Brown, M.; Hebert, A.A. Insect repellents: An overview. *J. Am. Acad. Dermatol.* **1997**, *36*, 243–249. [[CrossRef](#)]
164. Carroll, J.F.; Tabanca, N.; Kramer, M.; Elejalde, N.M.; Wedge, D.E.; Bernier, U.R.; Coy, M.; Becnel, J.J.; Demirci, B.; Başer, K.H.C.; et al. Essential oils of *Cupressus funebris*, *Juniperus communis*, and *J. chinensis* (Cupressaceae) as repellents against ticks (Acari: Ixodidae) and mosquitoes (Diptera: Culicidae) and as toxicants against mosquitoes. *J. Vector Ecol.* **2011**, *36*, 258–268. [[CrossRef](#)] [[PubMed](#)]

165. Jaenson, T.G.T.; Garboui, S.; Pålsson, K. Repellency of Oils of Lemon Eucalyptus, Geranium, and Lavender and the Mosquito Repellent MyggA Natural to *Ixodes ricinus* (Acari: Ixodidae) in the Laboratory and Field. *J. Med. Entomol.* **2006**, *43*, 731–736. [[CrossRef](#)] [[PubMed](#)]
166. Kulma, M.; Bubová, T.; Kopecký, O.; Rettich, F. Lavender, Eucalyptus, and Orange Essential Oils as Repellents against *Ixodes Ricinus* Females. *Sci. Agric. Bohem.* **2017**, *48*, 76–81. [[CrossRef](#)]
167. Trongtokit, Y.; Rongsriyam, Y.; Komalamisra, N.; Apiwathnasorn, C. Comparative repellency of 38 essential oils against mosquito bites. *Phytother. Res.* **2005**, *19*, 303–309. [[CrossRef](#)] [[PubMed](#)]