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REVIEW ARTICLE

The Acaricidal and Repellent Efficacy of Essential Oils and Their Immunomodulatory Effects against Hyalomma Ticks: A Review Article

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ABSTRACT

Tick and tick-borne diseases significantly affect the global economy by causing huge economic losses in the livestock industry and posing health risks to both animals and humans. Among various tick species, *Hyalomma* ticks are considered to be one of the dangerous blood-sucking ectoparasites of small and large ruminants. Their role in transmitting dangerous pathogens further increases their threat to the veterinary and medical sectors. Various control methods, such as chemical acaricides, biological agents, and antigenic vaccination have been adapted to minimize *Hyalomma* tick infestations. However, these conventional strategies face major challenges, including drug toxicity, the emergence of resistant tick populations, and antigenic mutations, reducing their long-term effectiveness. To overcome these limitations, researchers are shifting towards plant-based alternatives such as botanical extracts and essential oils derived from medicinal plants. These natural compounds have shown promising acaricidal and repellent effects while being eco-friendly and non-toxic to host species. Current reports have published various standardization practices and experimental designs to evaluate the efficacy of essential oils against *Hyalomma* ticks. The bioactive components, such as terpenes and phenolics, disrupt tick physiology, preventing their survival and reproduction. Due to their potent effect and minimal environmental impact, essential oils have gained significant attention worldwide. A thorough investigation has been conducted to demonstrate how different essential oils and their chemical components work as acaricides and repellents against *Hyalomma* ticks.

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INTRODUCTION

Ticks (Acari) are blood-sucking veracious ectoparasites, infesting livestock and humans around the globe (Tan *et al*., 2021; Mannan *et al*., 2022). Ticks preferably attach to the thin skin areas, including rear udder quarters, thighs, abdomen, axilla, neck, inguinal, and inter-scapular regions (Ekman, 2020). Tick saliva contains several pharmacologically active substances that aid in blood feeding by regulating host hemostasis, inflammation, and immunity (Aounallah *et al*., 2020). The hematophagous behavior of ticks causes direct and indirect losses to dairy and meat animals (Rashid *et al*., 2019; Singh *et al*., 2022). The clinical symptoms of infestation include fever, anemia, and irritation, leading to chronic stress, hide damage, and lethargy due to poor feeding. These symptoms contribute to economic losses, which include weight loss, decreased milk production, and, in females, an increased calving interval (Batool *et al*., 2019). Finally, ticks have the potential to depress the host immunity and aid in the attack of other microbes that increase the intensity of infections. Tick infestation poses a threat to an estimated one billion cattle in tropical and subtropical regions (Kasaija *et al*., 2021). They are also known to cause mortality because they are involved in the transmission of various deadly diseases, including theileriosis, babesiosis, anaplasmosis, Lyme disease, rickettsiosis, tularemia, tick-born relapsing fever (TBRF), etc. (Bakheit *et al*., 2012; De la Fuente *et al*., 2017; Perveen *et al*., 2021). Ticks are classified into three families: Ixodidae (hard ticks), Argasidae (soft ticks), and Nuttalliellidae, the recently identified family (Anderson, 2002; Nicholson *et al*., 2019; Johnson, 2023). Among the three, the Ixodidae is the largest and most important family, consisting of 13 genera and almost 670 species, characterized by the sclerotized dorsal shield (Onyiche and MacLeod, 2023). The important genera of Ixodidae family include *Ixodes* (245 species), *Amblyomma* (102 species), *Aponomma* (24 species), *Haemaphysalis* (155 species), *Hyalomma* (30 species), *Dermacentor* (30 species), *Cosmiomma* (1 species), *Nosomma* (1 species), *Rhipicephlus* (30 species), *Anomalohimalaya* (3 species), *Rhipicentor* (2 species), *Boophilus* (5 species), and *Margaropus* (Keve *et al*., 2022; Ledwaba *et al*., 2022; Makwarela *et al*., 2023).

The genus *Hyalomma* (*H.*) of 30 species has significant medical and veterinary importance and includes medium to large-sized ticks (Kumar *et al*., 2020; Kaba, 2022). The majority of *Hyalomma* ticks inhabit xeric habitats, where they parasitize livestock, wild animals, birds, and reptiles of all ages (Ortíz-Giraldo *et al*., 2021; Orlova *et al*., 2023). The *Hyalomma* genus is naturally distributed in three continents, including Asia, Africa, and Europe (Bonnet *et al*., 2022). Five species of *Hyalomma* are widely dispersed and have been documented on all three continents, while seven species are confined to Asia, five to Africa, nine in Asia-Africa, and one in Africa-Europe (Kumar *et al*., 2020). Almost 50% of the *Hyalomma* species act as vectors and are capable of transmitting various pathogens, including bacteria, viruses, and protozoans, to humans and animals (Luan *et al*., 2023). For example, the most abundant and multi-tick host species *H. anatolicum*, infests small and large ruminants and acts as a vector for *Theileria (T.) annulata*, *T. buffeli*, *T. lestocardi*, *Babesia (B.) caballi*, *B. bovis*, and *B. ovis* (Sajid *et al*., 2018). *T. annulata*, vectored by *Hyalomma* ticks worldwide, causes a disease called bovine topical theileriosis, from which about 250 million cattle are at risk (Gharbi *et al*., 2013). Similarly, *H. truncatum* and *H. dromedarii* are responsible for transmitting the Venezuelan equine encephalitis virus and African Horse Sickness virus in horses, respectively (Bonnet *et al*., 2023; Kim *et al*., 2024). *Hyalomma* ticks are also responsible for transmitting other zoonotic pathogens such as the Crimean Congo hemorrhagic fever (CCHF) virus. It is transmitted to humans by the bite of *H. dromedarii*, *H. marginatum*, *H. rufipes*, and *H. truncatum* (Sharma *et al*., 2020; Bonnet *et al*., 2022; Sadeghi *et al*., 2024; Tavassoli *et al*., 2024). The reports from Europe and Africa confirmed that facial and tick paralysis in humans is due to the bite of *H. marginatum* (Deng *et al*., 2024). *Hyalomma* ticks are not only vectors, but they play the role of reservoirs and harbor several pathogenic agents in both humans and animals, such as *Salmonella typhimurium*, *Brucella abortus*, and *Pasteurella multocida* (Jongejan and Uilenberg, 2004).

By considering *Hyalomma* ticks as potential threats to livestock and humans various acaricides like arsenicals, organochlorines (OCs), organophosphates, carbamates, synthetic pyrethroids, amitraz, fipronil, spinosad, and fluazuron have been used to control *Hyalomma* ticks (George *et al*., 2004; Reshma and Prakasan, 2020; Arshed *et al*., 2021; Kopsco *et al*., 2021; Mohammed *et al*., 2023). The frequent and inconsistent use of chemical acaricides has led to the development of resistance in various ticks, including *Hyalomma* species (Abbas *et al*., 2014; Nath *et al*., 2018; Dzemo *et al*., 2022; Evans *et al*., 2024; Gupta *et al*., 2024). Three main forms of resistance against acaricides include metabolic resistance (metabolic detoxification caused by esterases, cytochrome P450s, and glutathione S-transferase), target site modification resistance (conformational changes in drug target site), and reduced penetration resistance (decreased access of acaricides to exoskeleton) (De Rouck *et al*., 2023; Gupta *et al*., 2023b; Waldman *et al*., 2023b). Resistance against OCs has been achieved due to nucleotide mutations that alter the channel properties and inhibit the entry of chloride ions into the nerve cells, resulting in the insensitivity of OCs at the target site (Abbasi *et al*., 2023). Similarly, resistance against OPs has been achieved due to frequent interaction with the esterases in the integument layer of ticks, resulting in the overexpression of the enzymes (Gupta *et al*., 2023b). Furthermore, the resistance against amitraz is achieved through conformational changes in octopamine receptors resulting in the insensitivity of octopamine tyramine and β-adrenergic receptors (Obaid *et al*., 2023). On the other hand, amitraz also enhances the overexpression of monoamines that increase the activity of ATP-binding receptors (ABC) that pump acaricides outside, hence reducing the efficiency of acaricidal drugs (İnak *et al*., 2024). Resistance against synthetic pyrethroids is achieved due to mutation in voltage-gated sodium channel genes leading to alteration in the amino acid sequence (Lin *et al*., 2024). Moreover, resistance against macrocyclic lactones and fipronil has been achieved due to the mutations in the second and third transmembrane (TM-2 and TM-3) domains of Glu-Cl genes in the ticks (Molento and Brandão, 2022; Lifschitz *et al*., 2024). Isolates of *H. anatolicum* at 20 locations across three agroclimatic zones in India have also been found to be resistant to acaricides, specifically diazinon, deltamethrin, and cypermethrin (Kumar *et al*., 2021). An adult immersion test conducted in India revealed that *H. anatolicum* exhibited resistance to diazone and deltamethrin (Gaur *et al*., 2017; Shakya, 2020; Shanmuganath *et al*., 2021). Chemical acaricides also pose threats by generating drug residues in meat and milk (Mesfin *et al*., 2024). These chemicals, when accumulated in the human body, cause hormonal imbalance, nerve degeneration, skin rashes, and tumors (Salman *et al*., 2022; Ibrahium *et al*., 2024). Chemical acaricides can linger in the environment and contaminate flora, water, and soil (Mandal *et al*., 2020). Useful insects, aquatic organisms, and animals are among the non-target creatures that may be harmed by this contamination (Zhang *et al*., 2023). Acaricides can destroy beneficial creatures that are not their intended target, such as tick parasites and predators, upsetting natural ecological balances (Rupawate *et al*., 2023). These properties were the main drawbacks of using chemical acaricides as effective agents.

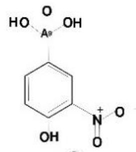
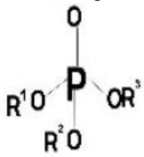
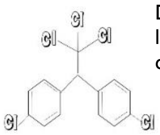
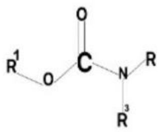
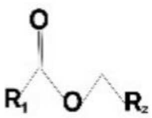
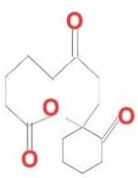
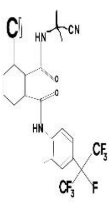
Other than chemical acaricides tick vaccines containing different antigens have undergone trials against several *Hyalomma* species (de la Fuente and Contreras, 2015; Muhanguzi *et al*., 2022; Abbas *et al*., 2023b; Manjunathachar *et al*., 2024). Some vaccines effectively reduce nymph populations, while others show limited efficacy against larvae, nymphs, and adults (Tabor, 2021; de la Fuente and Contreras, 2022). Targeting *Hyalomma* ticks at a particular stage is also difficult because of their complicated life cycles (Parizi *et al*., 2023). For example, in one of the studies, when Hd86 and Bm86 vaccines were used in calves against *H. scupense,* then it was confirmed that Hd86 reduced *H. scupense* larvae, but on the other, it increased the body weight of *H. scupense* females (Said *et al*., 2012). Furthermore, antigenic variation reduces the effectiveness of vaccine-induced protection by changing target proteins, which enables ticks to survive the host's immune response (Orosco, 2023). Because of the above-mentioned reasons, it is a big challenge to create a vaccine that efficiently targets every tick species.

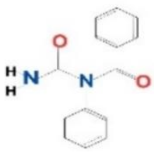
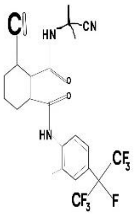
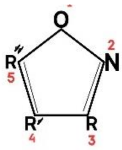
Table 1 summarizes various chemical drugs used to treat *Hyalomma* ticks, including their mode of action, mechanism of resistance, and possible limitations. Because of genuine issues of tick resistance, cost-effectiveness, toxicity, drug residues, poor efficacy of the vaccines, and ecological imbalance scientists and researchers are finding some sustainable, target-specific, non-toxic, economical, and eco-friendly alternatives including organic acids, nanoparticles, and botanicals for the effective control of ticks (Abbas *et al*., 2024; Assadpour *et al*., 2024; Malak *et al*., 2024; Raza *et al*., 2024; Rukh *et al*., 2024). Plant-derived essential oils have drawn the attention of all alternatives because they are biodegradable and present fewer ecological hazards than chemical acaricides (Abd Elgawad *et al*., 2023; Al-Hoshani *et al*., 2023; Eltaly *et al*., 2023; Gonzaga *et al*., 2023; Khater *et al*., 2024). Essential oils are also a safer option for both people and animals, as they lower the possibility of harmful residues in food items and potential hazards at work when applied (Osaili *et al*., 2023; Gholamine et al., 2024). Essential oils are potent and sustainable, providing an effective and innovative approach to tick control while minimizing adverse effects on the environment and human health (Munir *et al*., 2023; Żukowska and Durczyńska, 2024). Moreover, they contain bioactive compounds, such as terpenoids and phenolics, that have specific modes of action as natural acaricides and repellents without posing threats to hosts (Liao *et al*., 2023; Ali *et al*., 2024). These compounds target octopaminergic sites found in insects but absent in mammals, making essential oils logical and selective insecticides (Waldman *et al*., 2023a). Due to their unique behavior, many countries have been using essential oil-based commercial products (Prakash *et al*., 2024). This review paper will explore some key essential oils, their chemical makeup, and their mode of action as natural repellents and acaricides. It will draw attention to the particular bioactive substances that give them their ability to effectively interfere with ticks and generate toxic effects to kill them. The study will also give a summary of the existing obstacles and market gaps that prevent these essential oils from being widely used and commercialized, focusing on problems with product standardization, efficacy, and scalability for large-scale use.

Essential oils: Essential oils (EOs) are aromatic and volatile liquids (Sadgrove *et al*., 2022) obtained through steam distillation, hydro-distillation, cold pressing, solvent extraction, supercritical CO2 extraction, and maceration (Kholiya *et al*., 2023; Naqvi *et al*., 2023; Olalere *et al*., 2024; Tahir *et al*., 2024). Most EOs are obtained through steam distillation and are named after the plant from which they are extracted (Machado *et al*., 2022). EOs can be either products, mixtures of aromatic compounds, or combinations of odorless and aromatic compounds (Liang *et al*., 2023). They are mostly made up of secondary plant metabolites that are very vaporous and lipophilic (Abbas *et al*., 2023a). EOs can be found in glandular hairs, stem ducts, cavities, and oil cells in plants (Negi *et al*., 2024). They may occasionally produce glycosides, and the hydrolysis of glycosidic bonds causes them to release. This is accomplished by permitting enzymatic reactions to occur during the wilting process before fresh plant materials are distilled (Dilworth *et al*., 2024). They are not to be confused with fatty or fixed oils, which are made up of a naturally occurring blend of lipids that may or may not be volatile. As a result, fatty oils and EOs have completely different chemical and physical characteristics (Osaili *et al*., 2023; Zamani *et al*., 2023). Besides higher plants, EOs have also been found in mosses, liverworts, seaweeds, sponges, and fungi (Bajaj and Naaz, 2023). Some rich essential oil-bearing families include Apiaceae, Poaceae, Asteraceae, Lilaceae, Cupressaceae, Burseraceae, Hypericaceae, Annonaceae, Lamiaceae, Fabaceae, Lauraceae, Santalaceae, Myrtaceae, Apocynaceae, Pinaceae, Euphorbiaceae, Piperaceae, Malvaecea, Rutaceae, Santalaceae, Verbenaceae, Zingiberaceae, Cannabaeceae, and Zygophyllaceae (Evergetis *et al*., 2013; Nieto *et al*., 2017; Gladikostić *et al*., 2023; Haas *et al*., 2023; Saber *et al*., 2024). EOs obtained from these families have a variety of uses in perfumery, cosmetics, the food industry, aromatherapy, and agriculture (Butnariu, 2021; Bolouri *et al*., 2022; Vora *et al*., 2024). They have also been used in the medicine and pharmaceutical industry due to their potential therapeutic effects (Amiri *et al*., 2023; Vera-López *et al*., 2024). Consequently, EOs have been used broadly for their antiviral (Bisson, 2024), anti-bacterial (Omran *et al*., 2024; Ricardo-Rodrigues *et al*., 2024), insecticidal (Sarmah *et al*., 2024), anti-parasitic (Jyotsna *et al*., 2024), anticancer (Kiełtyka-Dadasiewicz *et al*., 2024) and antioxidant (Rostaei *et al*., 2024) effects. Some important activities are shown in Fig. 1.

Chemical composition of EOs: EOs are composed of over 300 different compounds, and the majority of these are volatile organic compounds of low molecular weight (Zhao *et al*., 2023a). Partially, they are found in the vapor state because of their high vapor pressure at standard temperature and pressure (Paul *et al*., 2023). In general, EOs include about 20–60 chemical components (de Sousa *et al*., 2023). These oils contain 2-3 major components having 20–70% concentrations, while other components are present in little quantity (Shen *et al*., 2023). The concentration of the chemical components can vary due to some factors which include environmental factors (temperature, humidity, light, CO2, water, drought, pollution, micronutrients, and macronutrients), genetic factors (gene pool), physiological factors (tissue, stem, leaves, and flowers), agronomic factors (fertilizers, crop management, over-irrigation, and under-irrigation), and post-harvest factors (storage methods and processing techniques) (Abakumov *et al*., 2023; Salam *et al*., 2023; Besher *et al*., 2024; Yu *et al*., 2024). EOs are classified into two structural families namely terpenoids and

Table 1: Different synthetic acaricides, their mode of action resistance, and possible limitations

Synthetic acaricides	Chemical structure	Examples	Year of introduction	Mode of action	Site of action	Year of Resistance	Country	Mechanism of resistance	Limitation	References
Arsenicals		Cacodylic acid, sodium arsenate	1893	Oxidative methylation and glutathione S-transferase conjugation	Nervous system	1937	Australia	Increased metabolism and reduced assimilation of the chemicals	Toxic, drug residues, skin lesions, and resistance	(George *et al.*, 2004)
Organophosphate		Chlorpyrifos, diazinon	1955	Inhibition of carboxyl ester hydrolases, particularly N acetylcholinesterase (nAChE)	Nervous system and muscles	1987	Zambia	Sensational loss at the target site	Narrow safety margin, short residual activity, drug residues in meat and milk, toxic to human health, resistance	Li *et al.,* 2003
Organochlorines		DDT, lindane, chlordane	1946	Interfering gamma-aminobutyric acid chloride-gated channels and blocks neurotransmission by blocking specific gamma-aminobutyric acid (GABA) receptors	Peripheral nervous system	1960	Australia	Increased metabolism and reduced assimilation of the chemicals	Environmental persistence, bioaccumulation, toxic to human health, drug residues, resistance	Lawrence and Casida *et al.,*1983
Formamidines		Amitraz	1975	Blocks octopamine receptor α-2 agonist and cause hyperexcitation of CNS	Nervous system and muscles	2001	Mexico	Mutation and alterations in octopamine receptor α-2 , target site insensitivity, Target-site insensitivity, amino acid replacement in β-2-adrenergic octopamine receptors	Toxicity to non-target organisms, narrow safety margin, drug residues, resistance	Ducornez *et al.,* 2005
Carbamates		Carbaryl, propoxur	1956	Cause irreversible phosphorylation of acetylcholine neurotransmitters,	Nervous system and muscles	1968	West Africa	Target site insensitivity	Banned in some countries due to human and environmental toxicity, resistance, drug residues	Li *et al.,* 2005
Synthetic Pyrethroids		Cypermethrin, deltamethrin	1977	Cause the modulation of sodium ion channels	Nervous system and muscles	1979	Australia	Alterations in the voltage-gated sodium (Na) channel genes	Human health risks, toxic to non-targeted organisms, low safety margin, resistance	Narahashi, 1971
Macrocyclic lactones		Ivermectin, moxidectin, doramectin, abamectin	1981	GABA agonists and block the nerve impulse transmission by attaching with glutamate-gated chloride channels	Nervous system and muscles	2001	Mexico	Insensitivity of glutamate-gated chloride channels	Human health risks, toxic to non-targeted organisms, low safety margin, resistance	Clark *et al.,* 1995
Neonicotinoids		Imidacloprid, thiamethoxam, dinotefuran	1991	Agonist of nACh receptors	Nervous system and muscles	1996	Spain	Alterations in acetylcholine receptor genes	Limited efficacy, drug residues, environmental concerns, toxicity to humans	Matsuda *et al.,* 2001
Phenyl pyrazoles		Fipronil	1987	Block the glutamate-activated chloride channels in insects.	Nervous system	2007	Uruguay	Alterations in glutamate-gated chloride channel genes	Limited spectrum against immature stages, environmental hazards, toxicity to non-target organisms, drug resistance	Vasilevich *et al.,* 2013

Benzoylphenyl urea/		Fluazuron	1990	Act on the glutamate-activated chloride ion channels and block them. Blocks chitin synthesis	Growth and development targets	2010	Brazil	Mutation in N-acetylglucosamine (a monomeric unit of polymer chitin) genes	Delayed action, less effective against fully mature stages, costly, resistance	Gomes *et al.,* 2015
Tetracyclic macrolide compounds		Spinosad	2001	Hyperexcitation is caused by blocking nicotinic acetylcholine receptors (nAChRs) and GABA receptors.	Nervous system	-	-		environmental concerns, not effective for all stages, drug residues, not effective for egg inhibition and larval growth	Orr *et al.,* 2009
Isooxazoline		Afoxolaner, fluralaner	2014	Inhibition of GABA or glutamate-gated chloride channels,	Nervous system	-	-	-	Drug residues, environmental concerns, toxicity to non-target organisms, limited spectrum	Jiang *et al.,* 2017

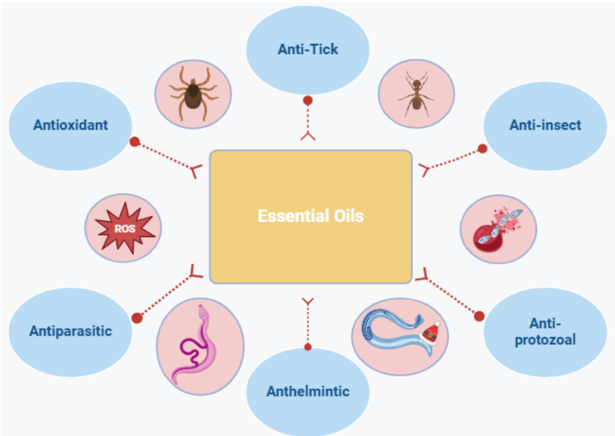


Fig. 1: Different effects of essential oils (www.biorender.com).

phenylpropanoids (Mohammed *et al.*, 2024), as shown in Fig. 2. Terpenoids include monoterpenes (two isoprene units), sesquiterpenes (three isoprene units), and diterpenes (four isoprene units) (Maswal *et al.*, 2023). Both terpenoids and phenylpropanoids obtained from botanicals contain phenolic compounds as primary constituents (Mohammadi-Cheraghabadi and Hazrati, 2023). The EOs and their chemical constituents are biosynthesized by different pathways such as the shikimate pathway is used for phenylpropanoids synthesis, and terpenoids, mevalonate, and mevalonate-independent pathways are used for terpenoids and mevalonate (Zhao *et al.*, 2023c; Hilal *et al.*, 2024; Karimi *et al.*, 2024).

Mode of action of EOs: Various effects of EOs have been studied against ticks including feed inhibition (Gonzaga *et al.*, 2023; Khan *et al.*, 2023b), inhibition of molting or ecdysis (Nollet, 2023), decrease in growth, development, or reproduction (Gonzaga *et al.*, 2023), tick behavior, and most importantly the acaricidal effects (Cao *et al.*, 2023; Luker *et al.*, 2023; Saıfı *et al.*, 2023; Ahmed and Abdelwines, 2024; Rodrigues *et al.*, 2024). The synergistic effect between EOs and their chemical constituents is linked to their high effectiveness. EOs include substances that can improve the absorption and accumulation of harmful substances within cells. Their main advantage is that they affect eggs, larvae, nymphs, and adult stages of economically significant tick species. Different experimental studies have shown that EOs possess different acaricidal modes of action against *Hyalomma* ticks, including neurotoxic effects (Duarte *et al.*, 2024), binding with acetylcholinesterase enzyme (Bi *et al.*, 2023), and binding with octopaminergic receptors (tyramine and β-adrenergic receptors) (Jankowska et al., 2017; Ocampo *et al.*, 2023). Furthermore, they also have cytotoxic, mechanical, and repellent effects (Fahmy *et al.*, 2023; Rahimi *et al.*, 2023; Shehabeldine *et al.*, 2023).

Neurotoxic effect: EOs and their derivatives are composed of several bioactive compounds that have their specific function against ectoparasites, particularly ticks (Salman *et al.*, 2020; Selles *et al.*, 2021). It has been experimented that these bioactive ingredients obtained from various EOs have detrimental effects on the nervous systems of different ectoparasites. Some EOs, when given in higher concentrations, bind with gamma-aminobutyric acid (GABA) receptors, inhibiting chloride ion flow intracellularly, thus causing membrane potential to depolarize and paralysis to occur (da Cruz Araujo *et al.*, 2024). Similarly, some EOs and their components bind with acetylcholine receptors responsible for releasing acetylcholine neurotransmitters (Wang and Heinbockel, 2018; Hartley and McLachlan, 2022; Khan *et al.*, 2023a). These neurotransmitters can bind with nicotinic acetylcholine receptors (nAChRs) and muscarinic acetylcholine receptors (mAChRs) and control the normal functions of ticks. EOs have agonistic action and mimic acetylcholine and activate nAChRs, causing more chloride ions to flow inside and potassium ions out of the nerve cell, thus causing neural firing and increased muscle activation (Abbad *et al.*, 2023; Waldman *et al.*, 2023a). Some EOs also block the acetylcholine receptors and cause sedation and paralysis due to the inhibition of nerve impulses. For example, the eugenol obtained from *Syzygium aromaticum* can bind with acetylcholine receptors, inhibit their activity, and cause paralysis of *H. scupense* (Alimi *et al.*, 2023). Similarly, some bioactive compounds of thymol and carvacrol obtained from *Thymus vulgarus*, when interacting with mAChRs, act as agonists and activate the receptors, causing smooth muscle relaxation or modulation of glandular secretions.

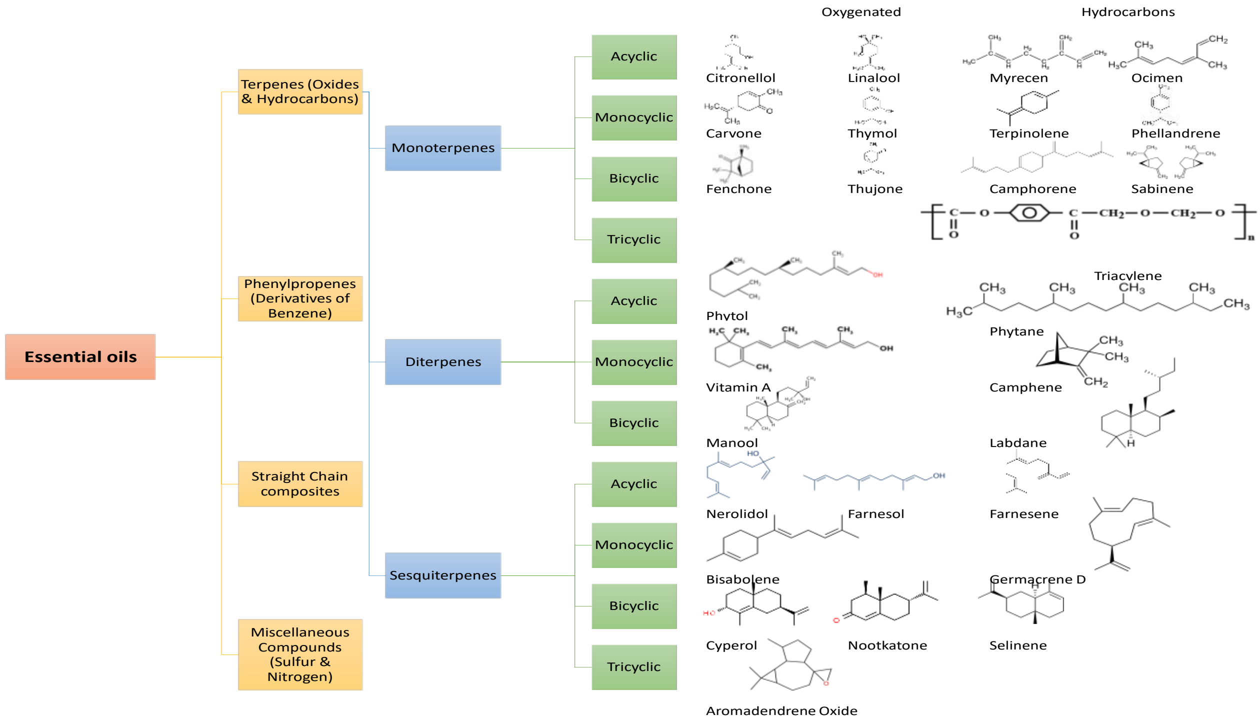


Fig. 2: Chemical composition of essential oils.

They also reduced the fecundity index and increased the mortality of *H. marginatum* (Kaya *et al*., 2024). Some EOs act directly on sodium and potassium ion channels, completely blocking them, resulting in the sedation and paralysis of the ticks (Baptista-Silva *et al*., 2020).

Binding with acetylcholinesterase enzyme (AChE): AChE is a serine hydrolase enzyme embedded in the synaptic cleft of the neuromuscular junction, peripheral, and central nervous systems (Jovičić, 2024). It can hydrolyze the acetylcholine (a neurotransmitter) into nitrogenous base (choline) and acetic acid, which inhibit the nerve signals, thus preventing continuous stimulation at the neuromuscular junction and delaying the functions at the synaptic cleft (Varfolomeev *et al*., 2020). EOs act as reversible inhibitors and block the active site of nAChE temporarily. On the other hand, their bond is irreversible, and they covalently attach to the active site of the enzyme and completely block it. This will lead to the sedation and paralysis of the ticks (Mattar *et al*., 2022; Abdel-Ghany *et al*., 2023; Li *et al*., 2023).

Several substances obtained from various EOs including thymol, carvacrol, α-pinene, β-pinene, limonene, 1,8-cineole, citral, myrcene, caryophyllene, menthone, humulene, niloticin, cinnamaldehyde, terpene 4-ol, linalool, p-cymene, and γ-terpinene were evaluated on arthropod's AChE molecules (Nasreen *et al*., 2020; Tavares *et al*., 2022; de Sena Filho *et al*., 2023; Malak *et al*., 2023). These components have demonstrated efficacy at values ranging from minimum to higher concentrations (de Souza *et al*., 2022). Furthermore, an active component, terpinene-4-ol obtained from *Camella sinensis* inhibits acetylcholinesterase at higher concentrations (Dehsheikh *et al*., 2020). In addition, Alimi *et al*., (2022) have shown that carvacrol has better anti-cholinesterase activity than any other compound against *H. scupense.* This activity is linked with the position of the hydroxyl group present in the structure of carvacrol and plays a key role. Similarly, the main bioactive components α-bisabolene β-farnesene from *Chamaemelum nobile* and terpinene-4-ol and γ-terpinene from *Melaleuca alternifolia* were found to be effective against *H. scupense* due to their acaricidal and repellent effects. These compounds were also found as inhibitors of acetylcholinesterase enzymes (Alimi *et al*., 2024).

Binding with octopaminergic and β-androgens: Octopamine is a multipurpose, naturally occurring biogenic amine that functions similarly to noradrenaline in vertebrates as a neurotransmitter and neuromodulator in invertebrate systems (Georgiades *et al*., 2022). In arthropods including ticks, there are five biogenic amine messengers including octopamine, tyramine, dopamine, serotonin, and histamine (Selles *et al*., 2021). These messengers influence movement, eating, and sensory perceptions by acting as excitatory neurotransmitters in the central nervous system and increasing neuronal activity (Teleanu *et al*., 2022). On the other hand, it improves locomotor activity and increases the contraction of skeletal and visceral muscles, which enables ticks to move effectively. EOs bind with tyramine and octopamine receptors and inhibit the activity of associated enzymes, thus causing sedation and mortality of the parasite (Zargari *et al*., 2022; Ocampo *et al*., 2023). The majority of the constituents of EOs, including terpinene, eugenol, and cinnamaldehyde, bind to octopamine and tyramine receptors and block acetylcholinesterase activity (Ocampo *et al*., 2020). Similarly, when EOs bind with octopamine receptors, they not only raise the intracellular Ca^{2+} levels but also raise cAMP levels. Similarly, they cause the phosphorylation of several proteins (including ion channels, enzymes, and receptors) and the activation of

PKA and PKC kinases (Noel and Adolfo, 2024). Some EOs and their compounds, such as eugenol and carvacrol, present in tea tree oil bind with these receptors and block the activity, which in turn stunts the growth, development, and reproduction of the ticks (Hakami *et al*., 2023). EOs also penetrate the outer walls of eggs, act on androgenic receptors, and inhibit their hatching (Nascimento *et al*., 2023). For example, thymol disrupts hormonal pathways linked with androgen receptors and prevents hatching. The exact mechanism of toxicity is not very clear but they pose lethal effects (Nikolaou *et al*., 2021; Chakraborty *et al*., 2023).

Cytotoxic effect: EOs and their active constituents may lead to the bereavement of various cells by decreasing energy production for example carvacrol extracted from different botanicals leads to ATP deficiency by inhibiting ATP synthetase enzymes present in the cell membrane and at the same time it enhances the permeability of hydrogen ions and as an outcome, the cell's pH lowers (Araniti *et al*., 2020; Makarewicz *et al*., 2021; Hou *et al*., 2022). Additionally, it results in K^+ leakage. Similarly, anethole and eugenol may have the ability to inhibit the activity of cell cytochrome P450 enzyme and block the Krebs cycle during cellular respiration, an energy-producing mechanism (Al-Harrasi *et al*., 2022). Similarly, they also cause the phosphorylation of various proteins by activation of various enzymes such as protein kinase A and protein kinase C (Zhao *et al*., 2023b).

Mechanical effect: EOs are insoluble in water, so they cause water stress by blocking insects' spiracles, leading to suffocation and disruption of the cuticles (Di Stefano, 2017). EOs are also lipophilic, so they can leak into the plasma membranes and act on specific organs (Hou *et al*., 2022). In another study, it was confirmed that exposure of EOs and their bioactive components to ticks may affect the egg-laying mechanism of ticks, making egg-laying tougher. The eggs may become less viable if the oils stick to them. For example, 1, 8-cineol, α-terpinyl acetate, and α-pinene obtained from *Elettaria cardamomum* significantly decreased the number of eggs, egg weight, and hatchability in a dose-dependent manner. Furthermore, EOs are slippery, and when they are applied topically on the skin of large ruminants, ticks may find it more difficult to attach by puncturing their skin with their mouthparts or capitulum (Kamaraj *et al*., 2023). EOs can interfere with sensory organs like Haller's organ used to detect temperature, humidity, and host smells. They can have a harder time finding and clinging to hosts because of this impairment (Nchu *et al*., 2012). For example, cis-ocimene and β-ocimene obtained from *Tagetes minuta* when applied, increased the acaricidal effect of *H. anatolicum* by affecting the Haller's organ (Nchu *et al*., 2012). EOs may interfere with the ecdysis or molting process by weakening the cuticle and disrupting the shedding mechanism (Ghoneim *et al*., 2021). Ticks often die or fail to progress to the subsequent stage of development as a result of ineffective molting. Ticks that come in contact with EOs may experience mechanical and chemical disruptions to their anchoring processes, making it difficult for them to reattach after separating from their host (Çetin *et al*., 2010). The acaricidal effect of some of the important EOs is given in Table 2.

Repellent effects: Repellants are chemical compounds that are topically applied to the skin and used to prevent humans and animals from biting harmful arthropods (Chinthaka *et al*., 2023). Synthetic chemicals are not used these days because they produce environmental hazards, are less efficacious, and are too expensive. Therefore, the natural biodegradable acaricides attracted researchers to use them against arthropods (Mishra *et al*., 2023). The exact mechanism of these is not known, but they usually produce vapor barriers and prevent mosquitoes and ticks from coming in contact with the skin (Luker *et al*., 2023; Utami *et al*., 2023). EOs are organic and volatile, so their repellant potential depends upon the duration of application (Gupta *et al*., 2023a). The freshly applied EOs have shown excellent results. Repellency also depends upon the composition of EOs as polymer mixtures, creams, and microcapsules. Some fixatives like liquid paraffin, salicylic acid, ethanol, genapol, polyethylene glycol, vanillin, and petroleum jelly can also be used to increase the repellency duration of EOs like mustard and coconut oils (Abdel-Ghany *et al*., 2023; Uçkun and Karakoyun, 2023). Strict sense repulsion and sensu lato repulsion of different EOs have been studied which cause the ticks to drop off just after attachment and attachment inhibition of already attached ticks respectively (Selles *et al*., 2021). EOs of *Ammi majus and Ammi visnaga* (Apiaceae) have shown 68.2 and 62.4% repellency when used at $0.15 mg/cm^2$ concentration each, respectively (Szöke *et al*., 2023). Similarly, a filter-paper arena test was performed to check the anti-tick potential of *A. vulgaris* oil, which showed very strong repellant potential in adults when 0.6μL/mL (v/v) of oil was used (Khater *et al*., 2024). The specific mode of action of EOs is given in Fig. 3, and there is a tonne of information available on the acaricidal and repellant properties of several EOs against *Hyalomma* ticks, which has been condensed in the accompanying tables with all important information. The repellent effect of some of the important essential oils is given in Table 3.

Limitations and future prospective: Several future challenges and limitations are there while using EOs against ticks and those challenges must be addressed to ensure effective implementation. The most important challenge is the variability in the chemical composition of EOs, which heavily relies on plant species, cultivation conditions of particular areas, and their extraction methods, which leads to inconsistent efficacy and difficulties in standardization (Aljaafari *et al*., 2021; Ni *et al*., 2021; Hechachna *et al*., 2023; Etri and Pluhár, 2024). Furthermore, they are highly volatile and degrade rapidly when they are exposed to light, oxygen, or heat, which results in the need for the reapplication of EOs (Maurya *et al*., 2021). No doubt, in general, they are considered safe, while some EOs can harm non-target organisms such as pollinators and cause skin irritation in livestock when not applied carefully (Dar *et al*., 2021). Large-scale production of EOs raises some serious concerns about the

Table 2: Acaricidal potential of different botanicals, EOs, and their bioactive compounds against different stages of *Hyalomma* species

Plant	Common names	Family	Major Components	Concentration used	Extraction Method	Mortality and inhibition Against	Efficacy	Methodology	Tick species	References
Mentha suaveolens	Apple mint	Lamiaceae	Menthone, piperitone oxide,	0.91 µL/mL	Steam distillation	Eggs	Excellent	Filter paper/petri dish method	*Hyalomma (H) agypticum*	(El-Mustapha *et al*., 2021)
Chenopodium ambrosioides	Wormseed	Chenopodiaceae	α-terpinene, isoascaridol, cymene	0.44 µL/mL	Hydro-distillation	Larvae	Excellent	Filter paper/petri dish method	*H. agypticum*	(Laghzaoui *et al*., 2018)
Lavandula pedunculata	Butterfly lavender	Lamiaceae	1,8-cineol, camphor	3.6 µL/100mL	Hydro-distillation	Nymphs	Moderate	Filter paper /petri dish method	*H. agypticum*	(Laghzaoui *et al*., 2018)
Cannabis sativa	Marijuana	Cannabaceae	Cannabidiol, cannabinol	10-50 µg/mL	Steam distillation	Eggs and larvae	Excellent	Spray method and packet test	*H. dromedarri*	(Tabari *et al*., 2020)
Laurus nobilis	Sweet bay	Lauraceae	β-pinene, linalool, sabinene	100 mg/mL	Water distillation	Larvae	Excellent	Packet test	*H. scupense*	(Alimi *et al*., 2021)
Piper longum	Pepper	Piperaceae	Piper longuminine	0.07-0.1µL	Hydrodistillation	Larvae	Excellent	Immersion test	*H. anatolicum*	(Singh *et al*., 2017)
Artemisia absinthium	wormwood	Asteraceae	Artemisinin, terpenes	2.5-20 mL	Hydrodistillation	Eggs, Larvae and Adults	Excellent	Immersion test, packet method	*H. anatolicum*	(Godara *et al*., 2015)
Piper nigrum	Black pepper	Piperaceae	Piperine	0.07-0.1 µL	Hydrodistillation	Larvae	Moderate	Packet test	*H. anatolicum*	(Singh *et al*., 2017)
Artemisia herba-alba	White wormwood	Asteraceae	Artemisinin	Minute quantities	Steam distillation	Eggs and nymphs	Excellent	Immersion test	*H. dromedarri*	(Abdel-Ghany *et al*., 2019)
Melia azedarach	Bead tree	Meliaceae	Triterpenoids, steroids	3.14%	Steam distillation	Eggs and nymphs	Excellent	Immersion test	*H. dromedarri*	(Abdel-Ghany *et al*., 2019)
Colchicum autumnale	Meadow saffron	Colchicaceae	Carbamodithioic acid, colchicines	50 mg/mL	Hydrodistillation	Adults	Poor	Petri dish and spray method	*Hyalomma* spp.	(Norouzi *et al*., 2021)
Annona squamosa	Sugar apple	Annonaceae	Annotemoyin-1, annotemoyin-2, squamocin	75-150 mg/mL	Steam distillation	Larvae and adults	Moderate	Immersion test	*H. anatolicum*	(Ilham *et al*., 2014)
Alstonia scholaris	White cheese wood	Apocynaceae	Lupeol, lupeol acetate	0.25–8.0%	Steam distillation	Larvae	Moderate	Immersion test	*H. anatolicum*	(Godara *et al*., 2020)
Sida cordifolia	Ballon vine	Malvaceae	Rosmerinic acid, palmitic acid, phytol	0.25–8.0%	Steam distillation	Larvae	Excellent	Immersion test	*H. anatolicum*	(Godara *et al*., 2020)
Guiera senegalensis	Senegal tea	Combretaceae	Guieranone	150 mg/mL	Steam distillation	Larvae	Excellent	Immersion test	*H. anatolicum*	(Osman *et al*., 2014)
Lavendula augustifolia	English lavender	Lamiaceae	Camphor, 1,8-cineole	200 mg/mL	Hydrodistillation	Adults	Moderate e	Immersion test	*H.dromedarri*	(Noaman and Bahreinineja d, 2024)
Tagetes minuta	Marigold	Asteraceae	Dihydrotagetone, tagetone, piperitone	0.070-0.072 mg/mL	Hydrodistillation	Nymphs	Excellent	Immersion test	*H. rufipes*	(Nchu *et al*., 2012)
Thymus capitatus	Spanish thyme	Lamiaceae	Carvacrol, p-cymene, γ-terpinene	1.6 µL/mL	Hydrodistillation	Larvae and adults	Moderate against adults and excellent against larvae	Immersion test	*H. scupense*	(Djebir *et al*., 2019)
Lavandula stoechas	Fridged lavender	Lamiaceae	α-pinene, α-thujone, camphor	3.13 µL/mL	Hydrodistillation	Larvae and adults	Moderate	Immersion test	*H. scupense*	(Djebir *et al*., 2019)
Cymbopogon winterianus	Citronella grass	Poaceae	Citronellal, eugenol, geraniol	0.1-5.0%	Hydrodistillation	Larvae	Moderate	Packet test	*H. anatolicum*	(Singh *et al*., 2014)
Withania somnifera	Indian ginseng	Solanaceae	Isopelletierine, anaferine	0.1-5.0%	Hydrodistillation	Larvae	Moderate	Packet test	*H. anatolicum*	(Singh *et al*., 2014)
Rosmarinus officinalis	Rosemary	Lamiaceae	l-camphor, 1,8-cineole	0.78 µL/mL	Hydrodistillation	Larvae and adults	Excellent	Immersion test	*H. scupense*	(Djebir *et al*., 2019)
Vitex negundo	Nirgundi	Verbenaceae	Aliphatic alcohol, phenolic compounds, steroids, terpenoids	0.1-5.0%	Steam distillation	Larvae	Moderate	Packet test	*H. anatolicum*	(Singh *et al*., 2014)
Origanum floribundum	Oregano	Lamiaceae	α -pinene, α-terpinene, β-myrcene	3.125 µL/mL	Hydrodistillation	Larvae and adults	Moderate	Immersion test	*H. scupense*	Djebir *et al*., 2019
Eucalyptus globulus	Blue gum	Myrtaceae	Aromadendrene, α-pinene, camphene	6.250 µL/mL	Hydrodistillation	Larvae and adults	Excellent	Immersion test	*H. scupense*	Djebir *et al*., 2019
Artemisia monosperma	Sagebrush	Fabaceae	Phenolic compounds, terpenoids	0.095 µg/µL	Hydrodistillation	Larvae	Moderate	Immersion test	*H. dromedarri*	(Habeeb, 2010)
Euphorbia	Egyptian	Euphor-	Jatrophanes, lathyranes	0.259	Hydrodistillation	Larvae	Excellent	Immersion test	*H.*	(Abdel-Shafy

aegyptiaca	spurge	biaceae		µg/µL	llation				*dromedarii*	*et al.*, 2006)
Francoeuria crispa	francoeuria	Asteraceae	Caryophyllene, carvone	0.849 µg/µL	Hydrodistillation	Larvae	Moderate	Immersion test	*H. dromedarri*	(Abdel-Shafy *et al.*, 2006)
Geranium macrorrhizum	cranesbill	Geraniaceae	β-elemenone, thymol, germacrene	2.87 mg/mL	Hydrodistillation	Larvae	Excellent	Immersion test	*H. lusitanicum*	(Navarro-Rocha *et al.*, 2018)
Haplophyllum tuberculatum	Haplophyllum	Rutaceae	Caryophyllene	0.5%	Hydrodistillation	Larvae	Excellent	Immersion test	*H. dromedarri*	(Abdel-Shafy *et al.*, 2006)
Mesembryanthemus forsskale	Screw plant	Aizoaceae	β-sitosterol	1.646 µg/µL	Hydrodistillation	Larvae	Excellent	Immersion test	*H. dromedarri*	(Abdel-Shafy *et al.*, 2006)
Satureja thymbra	Savory	Lamiaceae	Thymol, carvacrol	40 µL/L each	Hydrodistillation	Adults	Moderate	Vapor Phase Toxicity Test	*H. marginatum*	(Çetin *et al.*, 2010)
Cupressus sempervirens	Italian cypress	Cupressaceae	α-pinene and δ-3-Carene	20 mg/mL	Hydrodistillation	Larvae and adults	Moderate	Packet test, immersion test	*H. scupense*	(Alimi *et al.*, 2022)
Mentha pulegium	Pennyroyal	Lamiaceae	δ-3-Carene, α-pinene	20 mg/mL	Hydrodistillation	Larvae and adults	Moderate	Packet test, immersion test	*H. scupense*	(Alimi *et al.*, 2022)
Mentha pulegium plus Cupressus sempervirens	-	-	α-pinene and δ-3-Carene	1.76 mg/mL	Hydrodistillation	Larvae and adults	Moderate	Packet test, immersion test	*H. scupense*	(Alimi *et al.*, 2022)
Artemisia dracunculus	Tarragon	Asteraceae	Estragole, *p*-ally anisole, sabinene	40 µg/mg	Hydrodistillation	Larvae	Excellent	Immersion test	*Hyalomma* spp.	(Valcárcel *et al.*, 2021)
Mentha spicata	Spearmint	Lamiaceae	β-pinene, *cis*-dihydro carvone	40 µg/mg	Hydrodistillation	Larvae	Excellent	Immersion test	*Hyalomma* spp.	(Valcárcel *et al.*, 2021)
Origanum vulgare	Oregano	Lamiaceae	α-terpineol, Terpinen-4-ol, 1, 8-cineol	40 µg/mg	Hydrodistillation	Larvae	Excellent	Immersion test	*Hyalomma* spp.	(Valcárcel *et al.*, 2021)
Satureja montana	Winter savory	Labiatae	P-cymene, Carvacrol Terpinene	40 µg/mg	Hydrodistillation	Larvae	Moderate	Immersion test	*Hyalomma* spp.	(Valcárcel *et al.*, 2021)
Tanacetum vulgare	Tansy	Asteraceae	α-pinene, α-terpinene β-pinene	40 µg/mg	Hydrodistillation	Larvae	Moderate	Immersion test	*Hyalomma* spp.	(Valcárcel *et al.*, 2021)
Thymus mastichina	Mastic thyme	Lamiaceae	p-cymene, γ-terpinene, thymol	40 µg/mg	Hydrodistillation	Larvae	Moderate	Immersion test	*Hyalomma* spp.	(Valcárcel *et al.*, 2021)
Thymus vulgaris	Thyme	Lamiaceae	p-cymene, thymol, γ-terpinene	40 µg/mg	Hydrodistillation	Larvae	Excellent	Immersion test	*Hyalomma* spp.	(Valcárcel *et al.*, 2021)
Thymus zygis	Spanish thyme	Lamiaceae	Thymol, p-cymene, γ-terpinene	40 µg/mg	Hydrodistillation	Larvae	Excellent	Immersion test	*Hyalomma* spp.	(Valcárcel *et al.*, 2021)
Juniperus thurifera	Thuringian juniper	Cupressaceae	Sabinene	20 mg/mL	Hydrodistillation	Eggs	Moderate	Egg hatchability assay	*H. agypticum*	(El-Mustapha *et al.*, 2021)
Citrullus Colocynthis	Bitter melon	Cucurbitaceae	Linoleic acid, stearic acid, palmitic acid	20 and 40%	Steam distillation	Eggs and larvae	Moderate	Egg hatchability test, packet Test	*H. anatolicum*	(Mahran *et al.*, 2020)
Citrus sinensis	Sweet orange	Rutaceae	β-Pinene limonene	0.0024-0.01473%	Hydrodistillation	Adults	Moderate	Immersion test	*H. dromedarri*	(Ashour *et al.*, 2023)
Citrus limon	Lemon	Rutaceae	α-Pinene, β-pinene, limonene	0.00235-0.14215%,	Hydrodistillation	Adults	Moderate	Immersion test	*H. dromedarri*	(Shour *et al.*, 2021)
Cymbopogon citratus	Lemon-grass	Poaceae or Gramineae	Citral α, citral β, nerol, geraniol	12.5-100%	Hydrodistillation	Larvae	Excellent	Packet test	*H. anatolicum*	(Shyma *et al.*, 2022)
Citrus aurantiifolia	Key lime	Rutaceae	Limonene, geraniol	12.5-100%	Hydrodistillation	Larvae	Excellent	Packet test	*H. anatolicum*	(Shyma *et al.*, 2022)
Carica papaya	Papaya	Caricaceae	α-tocopherol, squalene, phytol	12.5-100%	Hydrodistillation	Larvae	Excellent	Packet test	*H. anatolicum*	(Shyma *et al.*, 2022)
Catharanthus roseus	Vinkle	Apocynaceae	Vincristine, vinblastine, vinorelbine	12.5-100%	Hydrodistillation	Larvae	Excellent	Packet test	*H. anatolicum*	(Shyma *et al.*, 2022)
Eucalyptus cammadelulensis	River red gum	Myrtaceae	Aphellandren, α-pinene, c-terpinene	1%	Hydrodistillation	Eggs, larvae, nymph	Excellent	Immersion test	*H. anatolicum*	(Hatem *et al.*, 2020)
Salvia rosemarinus	Rosemary	Lamiaceae	Trans-anethole, estragole	20%	Hydrodistillation	Adult	Excellent	Oil immersion screening	*H. dromedarri*	(Abdel-Ghany *et al.*, 2023)
Azadaricta indica	Neem	Maliacaea	Azadirechtin, nimbin, salannin	20%	Hydrodistillation	Adult	Excellent	Oil immersion screening	*H. dromedarri*	(Abdel-Ghany *et al.*, 2023)
Allium sativum	Garlic	amaryllidaceae	Allicin, alliin, diallyl disulphide	20%	Hydrodistillation	Adults	Excellent	Oil immersion screening	*H. dromedarri*	(Abdel-Ghany *et al.*, 2023)
Cupressus genus	Cyprus	Cupressaceea	Monoterpenes, diterpenes	20%	Hydrodistillation	Adults	Excellent	Oil immersion screening	*H. dromedarri*	(Abdel-Ghany *et al.*, 2023)
Myristica fragrans	Nutmeg	Myristicaceae	Sabinene, myristicine	800 mg/mL	Hydrodistillation	Adults and eggs	Moderate	Antioxidant assay	*H. dromedarri*	(Wang *et al.*, 2024)
Syzygium aromaticum	Clove	Myrtaceae	Eugenol, β-caryphyllene, eugenyl acetate	10 mg/mL	Steam distilation	Adults, larvae	Excellent	Adult immersion test, larval immersion test	*H. scupense*	(Alimi *et al.*, 2023)

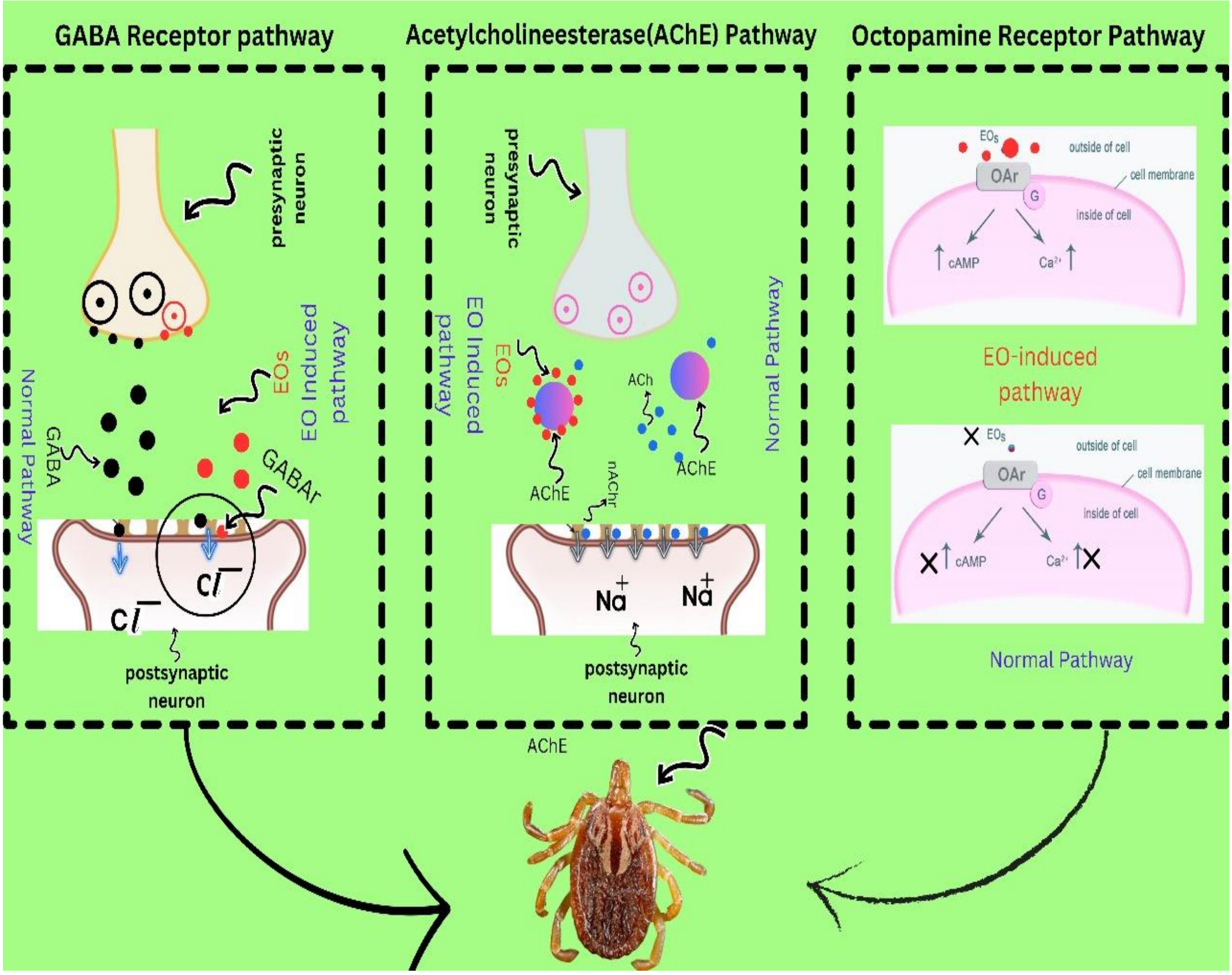


Fig. 3: Mode of action of essential oils against *Hyalomma* ticks (www.canva.com).

overharvesting of some useful plants ultimately harms biodiversity (Kurth *et al*., 2021; Semenzato and Fani, 2024).

Besides all these factors, the use of EOs against *Hyalomma* ticks presents a promising environmentally friendly alternative to synthetic acaricides. The complex chemical composition of plant-based EOs reduces the likelihood of resistant development in ticks, and their versatility offers repellent and ovicidal properties. With the advancement in technology, their effectiveness and stability also increase their potential. Future research should focus on bioactive compounds like terpenoids and phenylpropanoids, which exhibit strong acaricidal properties. Furthermore, standardization is difficult due to the variation in efficacy depending on tick species, environmental conditions, and oil sources. Strategic developments and interventions are required in many areas to improve the use of EOs against ticks in the future. Advanced extraction methods such as supercritical fluid extraction and ultrasound-assisted extraction, can enhance yield and bioactivity. Formulating EOs as emulsions or nano-capsulated forms can improve their stability, increase effectiveness, reduce evaporation, and extend their lasting effect in different environments. By combining certain EOs with other synthetic or natural acaricides, one can take advantage of synergistic effects that increase their effectiveness. There is a dire need to find and separate active ingredients for their specific uses. Enhancing extraction techniques and encouraging the sustainable growth of EO-rich plants would reduce production costs and increase the accessibility of EOs for farmers and veterinarians. By improving the controlled release of EOs over prolonged periods, novel delivery systems and encased microbeads can lower the frequency of applications. Our knowledge will grow, and their application will be optimized with more investigation into the mechanisms of action of EOs and their impacts on non-target species.

Conclusions: The utilization of EOs against ticks is a novel design to resolve the reported drug opponent and increase the shelf life of anti-tick medicine. Our calculation revealed that EOs have a boosting interest for scientists in recently moving towards the investigation and their efficacy towards ticks. Many types of EOs have shown their efficacy against different species of *Hyalomma* ticks and are utilized as a commercial product. Furthermore, a limited marketplace for botanicals that have a short residual life, loss of uniformity, and calibration of EOs alongside the field test, changes in scarcity data that is a significant hindrance to the development of new commercial-based highly accurate EOs. Further boosting research analysis needed some novel standardized methods to calculate the above problem.

Table 3: Repellant activity of EOs against *Hyalomma* ticks

EOs	Common names	Family	Major components	Concentration used	Repellency	Test type	Efficacy	Tick's species	Reference
Lavandula angustifolia	Lavender	Lamiaceae	Linalool, linalyl acetate, limonene	1.0%	89.1%	Choice chamber test	Excellent	*Hyalomma (H) marginatum rufipes*	(Mkolo and Magano, 2007)
Lippia javanica	Yellow brush	Verbenaceae	Bicycle heptanes-2-one, 2-butanone	10.7 and 5.3%	100 and 69.2%	Y-tube olfactometer	Excellent	*H. marginatum*	(Magano *et al*., 2011)
Cupressus sempervirens	Italian cypress	Cupressaceae	α- pinene, δ-3-carene	20 mg/mL	100%	Petri dish repellency assay	Excellent	*H. scupense*	(Alimi *et al*., 2022)
Mentha pulegium	Pennyroyal	Lamiaceae	Cis-menthone, pulegone	20 mg/mL	95%	Petri dish repellency assay	Excellent	*H. scupense*	(Alimi *et al*., 2022)
Cupressus sempervirens and Mentha pulegium combination	-	Cupressaceae and Lamiaceae	α- pinene, Cis-menthone δ-3-carene	20 mg/mL	100%	Y-tube olfactometer	Excellent	*H. scupense*	(Alimi *et al*., 2022)
Tagetes minuta	Marigold	Asteraceae	β-ocimene, cis-ocimene and 3-methyl-2-(2-methyl-2-butenyl)-furan	0.072- 0.086 mL/mL	60%	Petri dish repellency assay	Moderate	*H. rufipes*	(Nchu *et al*., 2012)
Allium sativum	Garlic	Liliaceae	Diallyl disulfide, diallyl trisulfide (30.38%)	1.4%	87%	Petri dish repellency assay	Excellent	*H. rufipes*	(Nchu *et al*., 2020)
Eucalyptus spp.	Eucalyptus	Myrtaceae	1,8 cineol	unknown	78%	Petri dish repellency assay and ear bag method	Moderate	*H. marginatum*	(Inceboz *et al*., 2015)
Cymbopogon nardus	Citronella grass	Poaceae	Geraniol	1%	94.5%.	Ear bag method	Excellent	*Hyalomma* genus	(Khallaayoune *et al*., 2009)
Nicotiana tabacum	Tobacco	Solanaceae	α-ionene, β-damascenone, cis-5-butyl-4-methyldihydrofuran-2(3H)-one	20, 30 and 40%	100%	Petri dish repellency assay	Excellent	*H. marginatum rufipes*	(Magano *et al*., 2011)
Eucalyptus globoidea	Blue gum	Myrtaceae	1,8-cineol, α-pinene, pinocarveol-trans	20, 30 and 40%	More than synthetic acaricide	Petri dish repellency assay	Excellent	*H. marginatum rufipes*	(Magano *et al*., 2011)
Elletaria cardamomum	Cardamom	Zingbiracaeae	1,8-cineol, α-pinene	10, 20 and 40%	100%	Adult immersion and larval immersion	Excellent	*H. anatolicum*	(Alanazi *et al*., 2022)
Cinnamom cassia	Chines Cinnamon	Laurels	Cinnamaldehyde	1.5-3%	67-93%	Y-tube olfactometer	Excellent	*H. asiaticum*	(Zhou *et al*., 2023)
Melaluca alternifolia	Tea tree	Myrtaceae	Terpinene-4-ol, γ-terpinene	1 mg/mL	100%	Preference zone method	Excellent	*H. scupense*	(Alimi *et al*., 2024)
Chamaemelum nobile	Chamomile	Asteraceae	Bisabolene, famesene	4 mg/mL	95%	Prefereance zone method	Excellent	*H. scupese*	(Alimi *et al*., 2024)
Syzygium aromaticum	Clove	Myrtaceae	Eugenol, β-caryophyllene, eugenol acetate	5 mg/mL	100%	Filter paper method	Excellent	*H. scupense*	(Alimi *et al*., 2023)

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