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Review

Plant extracts to control ticks of veterinary and medical importance: A review

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ABSTRACT

Farmers in developing countries are faced with many diseases that limit the productivity of their animals, many of these are caused by tick infestations. Years of use and overuse of available chemical ectoparasiticides have resulted in the large scale development of resistance in these parasites as well as negative environmental impacts. To reduce these impacts, much focus has been placed on the search for alternative, environmentally friendly parasite control strategies with lower chance of the development of resistance. Many rural farmers have used plants to control ticks. In some cases the traditional use has been confirmed, in other cases, only the traditional use has been documented. A review of published scientific articles was conducted for medicinal plants with *in vitro* acaricidal or tick-repellent activities against immature and adult stages of ticks. Veterinary databases (All Databases, CAB Abstracts and Global Health, Medline, Pubmed, Web of Science, BIOSIS Citation Index, Science Direct, Current Content Connect and Google Scholar) were used. The search words included “acaricidal”, “tick-repellent”, “medicinal plants”, “phytomedicine” and “anti-tick assays”. More than 200 plant species from several countries globally have tick-repellent or acaricidal properties using *in vitro* assays. The different extractions and plant parts used as well as the efficacy where available is listed. Species including *Azadirachta indica*, *Gynandropsis gynandra*, *Lavendula augustifolia*, *Pelargonium roseum* and *Cymbopogon* spp. had good acaricidal and larvicidal effects with 90–100% efficacy, comparable to those of currently used acaricides. A number of active compounds such as azadirachtin, carvacrol, linalool, geraniol and citronellal have been isolated. Based on their wide use by rural livestock farmers, plant-based compounds may be a good source of effective acaricidal preparations either as an extract or as a source of new acaricidal compounds. The focus may have to be on acaricidal rather than on repellent activities to facilitate control of ticks.

Contents

1. Introduction

In the tropics and sub-tropics, small-scale and emerging farmers own approximately 40% of the national livestock herds/flocks (Keyyu

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et al., 2003). These farmers are faced with many constraints that limit the productivity of their animals. The prevalence of ticks and tick-borne diseases particularly in the wet seasons (Keyyu et al., 2003) is an important restraint. Ticks, which are haematophagous ectoparasites, have a wide range of hosts and geographic diversity. They transmit protozoan, bacterial, rickettsial and viral diseases and are among the most important vectors of diseases which can be severely debilitating or fatal to livestock, humans and companion animals (Walker et al., 2003; Jongejan and Uilenberg, 2004).

Ixodid ticks such as *Amblyomma variegatum* Fabriscius, *Rhipicephalus appendiculatus* Neumann and *Rhipicephalus* (*Boophilus*) *microplus* (Canestrini, 1888) in particular are among the most economically important parasites in the tropics and subtropics (Bram, 1983). Tick-borne protozoan diseases such as theilerioses and babesiosis and rickettsial diseases such as anaplasmoses and cowdriosis are the most common diseases of small and large ruminants affecting the livelihoods of farming communities in Africa, Asia and Latin America (Jongejan and Uilenberg, 2004). In addition to transmitting diseases, heavy infestations of ticks can cause a reduction in live weight, anaemia and losses in milk production in domestic animals, while tick bites themselves result in damage to hides (Rajput et al., 2006).

Due to severity of the diseases transmitted by ticks a substantial proportion of the annual input costs by many livestock keepers go into the management and control of ticks and tick-borne diseases (Kaaya and Hassan, 2000). While the true economic losses are not easily quantifiable, losses were estimated at US$720 million, US$100 million and US$1 billion per year for Africa, Australia and South America respectively (Horn, 1987; Cobon and Willadsen, 1990; Kaaya and Hassan, 2000; Minjauw and McLeod, 2003). When losses per disease are looked at, *Theileria* control in eastern, central and southern Africa was estimated at US$168 million annually, while the annual cost of tropical theileriosis management in India was estimated at US$384.3 million. The *Theileria* parasite has also been implicated as the cause of annual production losses in excess of US$200 million in small scale and traditional farming communities of Kenya and Tanzania (Mukhebi et al., 1992; Kivaria, 2006). While less substantial than *Theileria*, losses from heartwater were estimated at US$6 million *per annum* in Zimbabwe over a 10-year period from the cost of acaricides, milk losses and treatment costs (Coetzer et al., 1994). Based on this information, it is evident that ticks and the diseases they transmit are a major constraint to the improvement of the livestock industry, particularly in developing countries, where they contribute to food insecurity. Due to financial devastation caused by ticks and tick-borne diseases, animals infected are often treated by the farmer with either an allopathic or herbal remedy.

Current control programmes are largely based on the use of commercially available chemicals such as the arsenicals, chlorinated hydrocarbons, organophosphates, carbamates, formamidines, pyrethroids, macrocyclic lactones, and more recently the insect growth regulators (George et al., 2004). Arsenicals were effectively used globally to control ticks for 30 to 40 years prior to the development of resistance in *Boophilus* ticks (George et al., 2004). While these products were inexpensive, stable and water-soluble, they were characterized by short residual effects of less than one or two days and were also environmentally destructive (Drummond, 1960). The arsenicals were eventually replaced by the chlorinated hydrocarbons between 1945 and 1955. The chlorinated hydrocarbons were characterized by a long residual effect and were very effective. Unfortunately these molecules were very stable and persisted in the environment and tissues of treated livestock for fairly long periods (Connell et al., 1999). The product also had a major knock-on effect on predators higher in the food chain prompting their eventual withdrawal (Spickett, 1998). Organophosphates, an esteric compound of phosphoric acid synthesis, supplemented organochlorines in the 1955–70s. In contrast to the organochlorines, they were characterized by a shorter residual effect, lower environmental persistence but substantially higher acute toxicity in livestock and by 1963, resistance was reported (Wharton, 1967).

Formamidines, chlordimeform, clenpyrin and chloromethiuron, are members of a small group of chemicals that are effective against ticks (George et al., 2004). Chlordimeform was introduced in Australia as an additive to organophosphates in dipping vats to restore their efficacy on organophosphate-resistant tick strains (Nolan, 1981). It was later withdrawn from the market because of evidence of carcinogenicity (Ware, 2000). Results of successful tests of amitraz for the control of *R.* (*B.*) *microplus* on cattle in Australia with an experimental formulation (BTS 27 419) were reported in 1971 (Palmer et al., 1971). Subsequent trials with commercial amitraz formulations in Australia (Roy-Smith, 1975) and in the United States of America (George et al., 1998) proved the efficacy of the acaricide against *R.* (*B.*) *microplus*. A series of trials executed over a five-year period in South Africa proved the effectiveness of amitraz for the control of *B. decoloratus*, *R. appendiculatus*, *R. evertsi* and *A. hebraeum* (Stanford et al., 1981).

Macrocyclic lactones are acaricides with potent insecticidal activity which were first described in 1978 (Burg et al., 1979). Two classes of macrocyclic lactones with acaricidal activity are the avermectins (ivermectin, eprinomectin), which are derivatives of the actinomycete *Streptomyces avermitilis* and the milbemycins, derived from fermentation products of *Streptomyces hygroscopicus aureolacrimosus* (Lasota and Dybas, 1991). Macrocyclic lactone acaricides are efficacious, but their high cost limits their use (Kemp et al., 1999). Fipronil, a phenylpyrazole compound; fluazuron, a benzoyl phenyl urea; spinosad represents new pesticides, but because of the persistence of residues in fat, it is necessary to withhold treated cattle from human consumption for up to six weeks after use (Bull et al., 1996).

The issues mentioned above have motivated the search for alternative parasite control strategies that are potentially environmentally friendly with fewer negative consequences to the animal being treated. Principal among these alternatives are the plant-based treatment protocols as the healing effect of plants has been explored for thousands of years (Chopra, 2003; Wang and Li, 2005). Other proposals for the full development of medicinal plants as tick repellents/acaricides has been advocated (Gassner et al., 1997) as plants inherently have a number of protective mechanisms to combat predator and pathogen attacks. These include repellency through production of hairs and volatile compounds such as cis-Jasmone (Birkett et al., 2000), 1, 8-cineole (Klocke et al., 1987); and production of chemicals with arthropocidal activities such as I-menthone from *Mentha piperita* L. (Croteau and Winters, 1982; Silva-Aguayo, 2006). These phytochemicals act in different ways, such as counteraction of growth regulatory hormones, inhibition of egg development, disruption of mating and sexual communication, and inhibition of chitin formation (Katoch et al., 2007; Chagas et al., 2012). A number of plant-derived novel antiparasitic drugs have already made significant contributions to human and animal health such as quinine, the oldest antimalarial drug, obtained from the South American plant, *Cinchona officinalis* L., and artemisinin from *Artemisia annua* L. (Ronald and Acton, 1987).

Pyrethrum derived from the dried flower heads of *Chrysanthemum cinerariifolium* (Trev.) Vis and *Chrysanthemum coccineum* has been used for centuries as an insecticide and lice remedy in the Middle East (Casida, 1980). More importantly, pyrethrum provided the backbone for the synthesis of more potent synthetic pyrethroids. The 1st generation pyrethroids (bioallethrin, tetramethrin, resmethrin and bioresmethrin) developed in the 1960s, following the elucidation of the structures of pyrethrin I and II, its main pesticidal components (Isman and Machial, 2006). The third generation of this class of chemicals, permethrin and fenvalerate, were the first of these products available for control of ticks on cattle (Davey and Ahrens, 1984; Ware, 2000). Cypermethrin and deltamethrin are examples of fourth generation cyano-substituted pyrethroids that are effective acaricides (Stubbs et al., 1982; Kunz and Kemp, 1994; Aguirre et al., 2000). Pyrethroids now constitute the majority of commercial household insecticides and their activity is often enhanced by addition of the synergist piperonyl butoxide, a known inhibitor of key microsomal cytochrome

P450 enzymes (Devine and Denholm, 1998). The insecticidal activity of pyrethrum has relatively low mammalian toxicity and an unusually fast biodegradation hence, it is one of the most commonly used, non-synthetic insecticide allowed in certified organic agriculture (Pottorff, 2010).

In 2007, a new repellent, BioUD, with the active ingredient 7.75% 2-undecanone, originally derived from wild tomato (*Lycopersicon hirsutum* Dunal *f. glabratum* C. H. Müll) plants, was registered by the U.S. Environmental Protection Agency (Gershenzon and Dudareva, 2007; Witting-Bissinger et al., 2008).

2. Methodology

This article reviews previous research on plants extracts and essential oils as acaricides/repellents. The keywords used to collect literature for this review were "tick-repellent", "acaricidal", "medicinal plants", "phytomedicine" and "anti-tick assays". Veterinary databases (All Databases, CAB Abstracts and Global Health, Medline, Pubmed, Web of Science, BIOSIS Citation Index, Science Direct, Current Content Connect and Google Scholar) were searched between January and December, 2014. Specifically, *in vitro* anti-tick assays employed in the last 100 years (1914–2014) were given priority consideration. Plant species tested, the country in which the experiments was/were performed, type of assays used, stage of ticks targeted and method of administration were considered in the filtration. The Medline was filtered down using MeSH Qualifier (Parasitology) and MeSH Headings (Ticks)-in view of the very large returns of titles >15,000- and other filters were applied to other databases as necessary. All documents considered were in English or translated into English.

3. Results and discussion

Acaricidal and insecticidal properties of many plant species have been widely investigated against phytophagous pests and mosquitoes (Calmasur et al., 2006; Mukandiwa et al., 2014), blowflies (Mukandiwa et al., 2012, 2013), mites (Kim et al., 2004; Nong et al., 2013a) and ticks (Lori et al., 2005) with differing results. Many of the earlier studies on acaricidal activities focussed on the *in vitro* and *in vivo* effects and toxicity of chemical acaricides on various insects and acarines (Wilson, 1948; Guilhon, 1950; Arthur, 1951; Hadani et al., 1969).

In the 1970s, more intensive evaluation of plants for their acaricidal activities was started by Khaidarov (1971), who evaluated 84 plant species. Of these, 21 had *in vitro* acaricidal activity against larvae and adults of *Rhipicephalus bursa* C. & F., *Hyalomma anatolicum* Koch and *Hyalomma marginatum* Koch. More recently, various plant products, crude extracts and essential oils have been evaluated for their repellent and acaricidal properties against all the stages (adult, nymph, larva and egg) of economically important tick species with encouraging results (Chungsamarnyart et al., 1988, 1990, 1991a; Mehlhorn et al., 2005; Coskun et al., 2008; Daemon et al., 2009; Magadum et al., 2009; Monteiro et al., 2009; Clemente et al., 2010; Kamaraj et al., 2010; Zorloni et al., 2010; Ghosh et al., 2011; Koc et al., 2012; Monteiro et al., 2012; Singh et al., 2014). This has also included numerous review publications of tick-repellent and acaricidal properties periodically (Kaaya, 2000; Copping and Menn, 2000; Flamini, 2003; Nerio et al., 2010; gar Ebadollahi, 2011; Zoubiri and Baaliouamer, 2011; Maia and Moore, 2011; Borges et al., 2011; Andreotti et al., 2014; George et al., 2014; Ghosh and Ravindran, 2014).

3.1. Taxonomic distribution of activity and countries where the work was done

For this review, a total of 30 families of plant species with acaricidal activity were identified. Sixteen families had only one species represented and five families had only two representative. The Lamiaceae and Asteraceae were the most used with 12 and 8 representatives (Table 2).

As could be expected a large proportion of the published work was done in tropical countries where ticks play an important role (Table 3). Most of the references were from Brazil (15), India (12) and South Africa (4). The plant species used originated from countries where the eco-climatic conditions are suitable for tick survival. If plants in these tropical environments have compounds that protect them against arachnids, insects and other pests it is possible that these compounds may also be active against ticks. Because ticks cause major problems in these areas, rural farmers are more likely to use plants for tick control.

3.2. Compounds used

Many of the plants reviewed in this study contained terpenes and terpenoids (Table 1). These phytochemicals derived from units of isoprene (hemi-, mono-, sesqui-, di- etc.) (Moore et al., 2007; Laudato and Capasso, 2013) are structurally a diverse assemblage of compounds that make up the largest group of secondary plant chemicals (Langenheim, 1994), and are involved in defence against herbivorous animals and pathogens (Kappers et al., 2005).

3.3. Extractants used

A number of solvents including hexane, acetone, ethanol and distilled water were used as extractants in the papers reviewed with ethanol being the solvent most commonly used (Table 1). It has been reported previously that many natural products have low water solubility and need to be dissolved in organic solvents or surfactant agents before being used in experimental systems (Domingues et al., 2013). In a study by Gonçalves et al. (2007), the effects of solvents and surfactant agents on adult female and larvae of the cattle tick *R.* (*B.*) *microplus* was evaluated. Acetone and methanol were the most toxic solvents while ethanol had moderate toxicity. Ravindran et al. (2011a, 2011b) however noted that methanol can be safely used for dissolving herbal extracts for testing acaricidal properties. While it is recognized that aqueous solvents are widely used in ethnoveterinary medicine, organic solvents may work better in acaricidal bioassays as the cuticle of ticks is formed externally mainly by waxes and internally by proteins (Balashov, 1972) hence the more non polar a chemical compound is, the greater will be its ability to penetrate the cuticle (Chagas et al., 2002).

Different bioassay methods including petri-dish method, larvae packet test, tick climbing repellency bioassays using vertical rods or strips of fabric, immersion tests have been used by researchers with immersion tests and larvae packet tests more commonly used (Table 1). All species and stages of life cycle of Ixodid ticks have been studied by different researchers and *R.* (*B.*) *microplus* was the tick most commonly studied (Table 1). *R.* (*B.*) *microplus*, a one-host tick, parasitic mainly on cattle is one of the most widely distributed tick species and is a major threat to the cattle industry in tropical and subtropical areas (Dominguez-García et al., 2010). The tick is also the most important economically as it is responsible for severe losses caused by tick worry, blood loss, damage to hides, injection of toxins and disease transmission. Around the world, extracts from approximately 55 plant species belonging to 26 families have already been evaluated against *R.* (*B.*) *microplus* (Borges et al., 2011).

Though much work had been done on evaluating plants with tick-repellent and acaricidal properties, certain limitations have been identified. These range from:

1) Lack of standardized testing methods or extractants making comparisons among studies very difficult to relate to day to day use of repellents/acaricides for the control of ticks on animals.

Table 1
Medicinal plants with tick-repellent and acaricidal properties and their phytochemical constituents.

Plant	Family	Plant part	Extractant	Major phytochemical constituent(s)	Tick species	Age (ticks)	Bioassay	Summary of results	Country	References
Aegle marmelos (Linn.) Correa ex Roxb	Rutaceae	L	HX CH EA AC MeOH	Aeglemarmelosine, alkaloids, coumarins	*H. bispinosa* *R.*(*B.*) *microplus*	A LV	APT LPT	3 mg/ml and 2 mg/ml MeOH extract caused 100% acaricidal MR for *H. bispinosa* and 100% larvicidal MR for *R.* (*B.*) *microplus* at 24 h PT respectively.	India[a]	Elango and Rahuman (2011)[a] Laphookhieo et al. (2011)[b]
Allium sativum L.	Alliaceae	Cl	MeOH	Allicin, terpenoids, steroids	*R.* (*B.*) *microplus*	A LV	AIT LPT	100 mg/ml caused 69% larvicidal MR, 85.83% IO, 100% failure of eclosion of eggs and 80% acaricidal MR within 15 days.	India[a]	Aboelhadid et al. (2013) Shyma et al. (2014)[a] Reuter and Sendi (1994)[b]
Ananas comosus L. Merr.	Bromeliaceae	Sk	DW	Ananasate, 1-*O*-caffeoylglycerol, caffeic acid, *p*-coumaric acid, β-sitosterol, daucosterol	*R.* (*B.*) *microplus*	EF LV	AIT LPT	500 mg/ml caused 39.1% IO, 33.3% EHI, efficacy percentage of 59.4% and 0% larvicidal MR at 24 h PT.	Brazil[a]	Domingues et al. (2013)[a] Ma et al. (2007)[b]
Andrographis paniculata (Burm.f.) Wall. ex Nees.	Acanthaceae	L	HX CH EA AC MeOH	Tannins, flavonoids, carbohydrates and proteins	*H. bispinosa* *R.*(*B.*) *microplus*	A LV	LPT	3 mg/ml MeOH extract caused 100% acaricidal MR for *H. bispinosa* and 2 mg/ml EA extract caused 100% larvicidal MR for *R.* (*B.*) *microplus* at 24 h PT.	India[a,b]	Tanwer and Vijaguergia (2010)[b] Elango and Rahuman (2011)[a]
Anisomeles malabarica (L) R. Br.	Lamiaceae	L	HX CH EA AC MeOH	Alkaloids, saponins, protein, gum, mucilage	*H. bispinosa*	A	APT	3 mg/ml AC and MeOH extract caused 100% acaricidal MR at 24 h PT.	India[a,b]	Zahir et al. (2010)[a] Nisha and Packialakshmi (2014)[b]
Artemisia absinthium L.	Asteraceae	AP	EtOH CH	Cis-epoxyocimene, sesquiterpenes	*Hyalomma anatolicum* *R. sanguineus*	A E LV	AIT EHT LPT	200 mg/ml caused 100% larvicidal MR, 100% EHI, 59.1% OR and 86.7% acaricidal MR for *H. anatolicum* at 24 h PT. For *R. sanguineus*, there was 100% larvicidal MR, 100% EHI, 85.1% OR and 93.3% acaricidal MR.	India[a,b]	Bailen et al. (2013)[b] Godara et al. (2014a, 2014b)[a]
Azadirachta indica A. Juss	Meliaceae	L B S	EtOH	Azadirachtin	*R.*(*B.*) *microplus*	EF	AIT	8 mg/ml caused 80% acaricidal MR and 34.0 mg egg mass reduction at 5 h PT.	India[a]	Williams (1993) Williams and Mansingh (1996) Akhila and Rani (1999)[b] Gupta et al. (2000) Choudhury (2001) Benavides et al. (2001) Abdel-Shafy and Zayed (2002) Al-Rajhy et al. (2003) Abdel-Shafy et al. (2006) Alwin et al. (2007) Shyma et al. (2012) Srivastava et al. (2008)[a]
Baccharis trimera (Less.) DC	Asteraceae	L	DW	Diterpenes	*R.*(*B.*) *microplus*	EF	AIT	150 mg/ml caused 100% EHI 15 days PT.	Brazil[a]	Lago et al. (2008)[b] Lázaro et al. (2013)[a]
Calea serrata Less	Asteraceae	AP	HX	Eupatorio-chromene, precocene II	*R.* (*B.*) *microplus* *R. sanguineus*	EF LV	AIT LIT	6.25 mg/ml caused 100% larvicidal MR of both tick species at 48 h PT. 50 mg/ml caused 100% EHI and	Brazil[a]	Steinback et al. (1997)[b] Ribeiro et al. (2008)[a]

(continued on next page)

Table 1 (*continued*)

Plant	Family	Plant part	Extractant	Major phytochemical constituent(s)	Tick species	Age (ticks)	Bioassay	Summary of results	Country	References
								14.6% ELI in *R.* (*B.*) *microplus* after 14 days.		
Calotropis procera (*Ait*) *R.Br*	Asclepiadaceae	LX	AC	Stigmasterol, β-sitosterol, digitoxin, calotoxin	*Hyalomma dromedarii*	EF LV	Contact LIT AIT	The contact LC_{50} value against adults and larvae was 9.63 $\mu g/cm^2$ and 6.16 $\mu g/cm^2$ respectively whereas the dipping LC_{50} values were 1096 mg/l and >20.3 $\mu g/cm^2$ respectively.	Saudi Arabia[a]	Al-Rajhy et al. (2003)[a] Shyma et al. (2012) Kakar et al. (2012)[b]
Calpurnia aurea ssp. aurea (Aiton) Benth.	Fabaceae	L	DW HX AC	Calpurmenin, 13a-(2′-pyrrolecarboxylic acid) ester, virgiline, lupanine	*R. pulchellus*	Unfed adult	TCR Contact	Tick attraction was observed. 200 mg/ml AC extract caused 100% acaricidal MR.	Ethiopia[a,b]	Zorloni et al. (2010)[a,b] Nana et al. (2010)
Capsicum frutescens L.	Solanaceae	F	EtOH	Capsaicin	*R.*(*B.*) *microplus*	EF	AIT	75 mg/ml caused 85% MR at 48 h PT; 25 mg/ml caused 86.8%. There was 99.9% acaricide efficacy.	Brazil[a]	Nazari et al. (2007)[b] Vasconcelos et al. (2014)[a]
Carapa guianensis Aubl.	Meliaceae	Se	EO	Hexacosanoic acid-2,3-dihydroxy-glyceride, ursolic acid, naringenin, scopoletin	*R. sanguineus*	EF	AIT	200 mg/ml showed 80.17% reproductive efficiency index.	Brazil[a]	Qi et al. (2004)[b] Vendramini et al. (2012)[a] Roma et al. (2013)
Carica papaya L.	Caricaceae	Se	MeOH	Alkaloids, glycosides, phenols and tannins	*R.* (*B.*) *microplus*	EF LV	Contact LIT AIT	100 mg/ml, caused 82.2% larvicidal MR, 100% IO and eclosion of eggs, 93.33% acaricidal MR within 15 days.	India[a]	Ocloo et al. (2012)[b] Shyma et al. (2014)[a]
Cassia didymobotrya (Fresen) Irwin & Barneby	Leguminosae	AP	MeOH DCM HX	Stilbenes, flavones, 7-acetylchrysophanol,bianthrones, tetrahydroanthracenes	*R. appendiculatus*	LV	FR	0.25 mg/ml MeOH. extract showed 87.67% repellency.	Uganda[a]	Delle Monache et al. (1991)[b] Opiro et al. (2012)[a]
Chamaecyparis nootkatensis (D. Don) Spach	Cupressaceae	AP	AC	Carvacrol, nookatene, nookatone	*I. scapularis*	N	Vertical bioassay	Nootkatone and valencene-13-ol had repellent conc. $(RC)_{50}$ values of 0.0458 and 0.0712% respectively at 4 h PT.	USA[a]	Panella et al. (2005)[b] Dietrich et al. (2006)[a]
Citrus maxima Burm.	Rutaceae	F	EtOH	Phenol, saponins, alkaloids, tannins, terpenoids	*R.* (*B.*) *microplus*	EF LV	AIT LIT	100 mg/ml caused 62.61% larvicidal MR 1–2 h post dipping and 100% acaricidal MR 24 h PT.	Thailand[a]	Chungsamarnyart and Jansawan (1996)[a] Chanthaphon et al. (2008)[b] Pandey et al. (2010)[b]
Citrus reticulata Blanco	Rutaceae	F	EtOH	L-limonene, γ-terpene, β-phellandrene	*R.* (*B.*) *microplus*	EF LV	AIT LIT	100 mg/ml. caused 90.77% larvicidal MR 1–2 h PT and 100% acaricidal MR 24 h PT.	Thailand[a]	Chungsamarnyart and Jansawan (1996)[a] Sultana et al. (2012)[b]
Citrus sinensis L.	Rutaceae	F	EtOH	Flavonoids, tannins, saponins, phytate, oxalate, limonene	*R.* (*B.*) *microplus*	EF LV	AIT LIT	100 mg/ml caused 98.59% larvicidal 1–2 h PTand 99% acaricidal MR 24 h PT.	Thailand[a]	Chungsamarnyart and Jansawan (1996)[a] Oluremi et al. (2007)[b]
Citrus hystrix DC (Swangi)	Rutaceae	F	EtOH	Glycerolglycolipids, tannins, tocopherols, furanocoumarins, flavonoids, alkaloids	*R.* (*B.*) *microplus*	EF LV	AIT LIT	100 mg/ml caused 90.29% larvicidal MR 1–2 h PT and 98% acaricidal MR 48 h PT.	Thailand[a]	Chungsamarnyart and Jansawan (1996)[a] Arumugam et al. (2014)[b]

Copaifera reticulata Ducke	Leguminosae	LX	DMSO DW	Oleoresin	*R.* (*B.*) *microplus*	LV	LPT	3.5 mg/ml caused 99% larvicidal MR at 24 h PT.	Brazil[a]	Prates et al. (1993) Chagas et al. (2002) Fernandes et al. (2005, 2007, 2008) de Freitas Fernandes and Freitas (2007)[a]
Corymbia citriodora (Hook.) K.D. Hill and L.A.S. Johnson	Myrtaceae	AP	EO	Citronellal	*R.* (*B.*) *microplus*	LV A	LPT AIT	100 mg/ml caused 100% OR, 100% hatching reduction 100% acaricidal and larvicidal MR at 24 h PT.	Brazil[a]	Lee and Chang (2000)[b] Clemente et al. (2010) Chagas et al. (2002) Chagas et al. (2014)[a]
Cymbopogon citratus (DC) Stapf	Poaceae	L S R	EtOH/EO	Myrcene, α-citral (geranial), β-citral (neral)	*R.* (*B.*) *microplus*	EF LV	AIT LIT	125 mg/ml caused 98.78% larvicidal MR 1–2 h PT and 100% acaricidal MR 5 days PT.	Thailand[a]	Chungsamarnyart and Jiwajinda (1992)[a] Onawunmi et al. (1984)[b]
Cymbopogon nardus (Linn) Rendle	Poaceae	L S R	EtOH/EO	Geraniol, trans-citral, cis-citral, geranyl acetate, citronellal, citronellol	*R.* (*B.*) *microplus*	EF LV	AIT LIT	125 mg/ml caused 95.78% larvicidal MR 1–2 h PT and 100% acaricidal MR 24 h PT.	Thailand[a]	Chungsamarnyart and Jiwajinda (1992)[a] Nakahara et al. (2003)[b] Clemente et al. (2010)
Cymbopogon winterianus Jowitt ex Bor	Poaceae	L	DW EtOH	Geraniol, citronellal, citronellol	*R.* (*B.*) *microplus*	EF LV	AIT LPT	50 mg/ml caused 58.01% IO and 10% EHI at 15 days PT.	India[a]	Martins (2006) Quintans-Júnior et al. (2008)[b] Singh et al. (2014)[a]
Datura stramonium L.	Solanaceae	L	MeOH	Alkaloids, atropine, scopolamine, tannin, proteins	*R. B. microplus*	EF LV	Contact LIT AIT	100 mg/ml caused 73.33% acaricidal MR at 15 day PT, 71.8% larvicidal MR, 77.17% IO and eclosion of eggs.	India[a]	Shyma et al. (2014)[a] Sayyed and Shah (2014)[b]
Digitalis purpurea L.	Scrophulariaceae	LX	AC	Digitoxin	*Hyalomma dromedarii*	EF LV	Contact LIT AIT	Contact and dipping LC_{50} values against larvae were 6.16 μg/cm^2 and 587.7 mg/l.	Saudi Arabia[a]	Al-Rajhy et al. (2003)[a]
Eupatorium adenophorum Spreng	Asteraceae	L	EtOH	Sabinene, 1,8-cineole, p-cymene, camphene	*H. longicornis*	LV N	LIT NIT	At a conc. of 1.5 g/ml (w/v), there was 100% MR for both larval and nymphal ticks 6 h PT.	China[a]	Nong et al. (2013b)[a] Padalia et al. (2010)[b]
Guiera senegalensis J.F. Gmel.	Combretaceae	L	EtOH PE	Guieranone A, alkaloids	*Hyalomma anatolicum*	All stages	Immersion test	150 mg/ml EtOH extract induced 100% larvicidal MR, 100% feeding inhibition and 100% ELI 48 h PT.	Sudan[a]	Osman et al. (2014)[a] Fiot et al. (2006)[b]
Gynandropsis gynandra (L.) Briq	Capparidaceae	AP	EO	Carvacrol, trans-phytol, linalool, trans-2-methylcyclopentanol,β-caryophyllene	*R. appendiculatus*	A	TCR	At 0.1 μl conc. there was 98.9% repellency.	Kenya[a]	Dipeolu et al. (1992) Malonza et al. (1992) Ndungu et al. (1995) Lwande et al. (1999)[a,b]
Hypericum polyanthemum Klotzsch ex H. Reichardt	Guttiferae	AP	HX MeOH	Xanthones, flavonoids, benzopyrans	*R.* (*B.*) *microplus*	EF L	AIT LIT	50 mg/ml HX extract caused 19.2% ELI and 6.25 mg/ml caused 100% larvicidal MR at 48 h PT.	Brazil[a]	Booth et al. (1986) Rocha et al. (1994)[b] Ferraz et al. (2001)[b] Borges et al. (2003) Ribeiro et al. (2007)[a]
Jatropha curcas L.	Euphorbiaceae	L	EtOH	Stigmasterol, β-sitosterol, campesterol	*R. annulatus*	EF	AIT	50 mg/ml caused 90% EHI at 30 days PT.	India[a]	Neuwinger (1994)[b] Gübitz et al. (1999)[b] Juliet et al. (2012)[a]
Lavendula augustifolia Mill	Lamiaceae	AP	DW	1,8-cineole, camphor, borneol	*Hyalomma marginatum rufipes*	A	TCR	200 mg/ml caused 100% repellency up to 2 h PT.	South Africa[a]	Jaenson et al. (2006) Mkolo and Magano (2007)[a]

(continued on next page)

Table 1 (*continued*)

Plant	Family	Plant part	Extractant	Major phytochemical constituent(s)	Tick species	Age (ticks)	Bioassay	Summary of results	Country	References
										Pirali-Kheirabadi and Teixeira da Silva (2010)[b] Azar et al. (2011)
Leucaena leucocephala (Lam) De Wit	Fabaceae	AP	DW	Quercetin, mimosine, ficaprenol-11	*R.* (*B.*) *microplus*	A LV	AIT LIT	4.8 mg/ml caused 66.79% larval MR at 48 h PT, 33.14% EHI and 1.8% ELI at 21 days PT.	Mexico[a]	Fernandez-Salas et al. (2011)[a] Salem et al. (2011)[b]
Leucas aspera (Willd)	Lamiaceae	AP	EtOH	Nicotine, diterpenes, lignans, flavanoids	*R. annulatus*	EF	AIT	100 mg/ml conc. Caused 54.16% acaricidal MR and 100% EHI at 15 days PT.	India[a]	Mangathayaru et al. (2006)[b] Ravindran et al. (2011a, 2011b)[a]
Leucas indica Spreng	Lamiaceae	L	EtOH	Flavones, diterpenes	*R. annulatus*	EF	AIT	50 mg/ml alkaloid fraction caused 66% adult MR, 55% inhibition of fecundity and 100% hatching within 15 days PT.	India[a]	Mostafa et al. (2007)[b] Divya et al. (2014)[a]
Licania tomentosa Benth	Chrysobalanaceae	L	HX EtOH	Betulinic acid, licanolide, a new triterpene lactone, oleanolic acid, lupeol, palmitoleic acid, hexadecanoic acid	*R.* (*B.*) *microplus*	LV	LPT	600 mg/ml EtOH extract caused larvicidal MR of 40.26% 24 h PT.	Brazil[a,b]	Castilho et al. (2008)[b] Valente et al. (2014)[a]
Lindera melissifolia (Walt.) Blume	Lauraceae	D	EO	β-caryophyllene, α-humulene, germacrene D, β-elemene	*A. americanum* *I. scapularis*	N A	VFP	0.827 mg/cm^2 extract repelled 74% of the *A. americanum* nymphs at 15 min PT and 97.5% of *I. scapularis* adults.	USA[a]	Oh et al. (2012)[a,b]
Lippia javanica (Burm. F.) Spreng	Verbernaceae	AP	EO	Myrcene, 1,8-cineole, dihydrotagetone, ipsenone, 2-butanone	*Hyalomma marginatum rufipes*	A	TCR	107 mg/ml caused a repellency index of 100% at 1 h 30 min PT.	South Africa[a]	Magano et al. (2011)[a,b]
Lippia sidoides Cham	Verbernaceae	L	EO	Lippsidoquinone, quercetin, tecomaquinone	*R. sanguineus* *A. cajannense*	LV N	LPT	18.80 mg/ml caused 99% larvicidal MR and 96% nymphal MR (*R. sanguineus*); 100% larvicidal MR and 94% nymphal MR (*A. cajannense*).	Brazil[a]	Costa et al. (2001))[b] Gomes et al. (2014)[a]
Lysiloma latisiliquum (Tzalam)	Fabaceae	L	AC:DW	Tannins, crude protein, phenols	*R.* (*B.*) *microplus*	LV A	LIT AIT	19.2 mg/ml. caused 56% larval MR at 48 h PT, 69.34% EHI and 36.4% ELI at 21 days PT.	Mexico[a]	Alonzo-Diaz et al. (2006)[b] Fernandez-Salas et al. (2011)[a]
Matricaria chamomilla L.	Asteraceae	Fl	EtOH	Herniarin, oleanolic acid, stigmasterol	*R.* (*B.*) *annulatus*	EF	AIT	80 mg/ml caused 26.67% acaricidal MR at 24 h PT and 46.67% ELI at 5 days PT.	Iran[a]	Ahmad and Mishra (1997) Pirali-Kheirabadi and Razzaghi-Abyaneh (2007)[a]
Melaleuca alternifolia (Maiden & Betche) Cheel	Myrtaceae	AP	EO	1,8-cineole, α-pinene, β-pinene	*R.* (*B.*) *microplus*	EF	AIT	50 mg/ml and 100 mg/ml showed 100% reproductive inhibition.	Brazil[a]	Russell and Southwell (2002)[b] Pazinato et al. (2014)[a]
Ocimum basilicum L.	Lamiaceae	L	HX CH EA	Linalool, (Z)-cinnamic acid methyl ester, cyclohexene	*R.* (*B.*) *microplus*	A	AIT	60 mg/ml,80 mg/ml and 100 mg/mlcrude CH extracts produced 70%, 80% and 100% acaricidal MR respectively.	India[a]	Zhang et al. (2009)[b] Veeramani et al. (2014)[a]
Ocimum urticaefolium Roth	Lamiaceae	Fl	EO	Eugenol, 1,8-cineole, elemicin, β-Bisabolene, thymol	*R.* (*B.*) *microplus*	LV	LPT	50 mg/ml caused 100% larvicidal MR.	New Caledonia[a]	Hüe et al. (2014)[a]
Origanum minutiflorum	Lamiaceae	AP	EO	Carvacrol, camphene, myrcene	*R. turanicus*	Unfed	Vapour phase	200 mg/ml caused 100% acaricidal	Turkey[a,b]	Cetin et al. (2009)[a,b]

O. Schwarz and P.H. Davis						adult	toxicity bioassays	MR at 120 min.		
Origanum onites L.	Lamiaceae	AP	EO	Cymene, thymol, carvacrol, γ-terpinene	*R. turanicus*	A	APT	250 mg/ml and higher caused 100% MR at 24 h PT.	Turkey[a]	Coskun et al. (2008)[a] Skoula et al. (1999)[b]
Pelargonium graveolens L'Her	Geraniaceae	AP	EO	Linallol, citronellol, geraniol	*A.americanum*	N	VFP	0.103 mg/cm^2 repelled >90% of the nymphs.	USA[a]	Hsouna and Hamdi (2012)[b] Tabanca et al. (2013)[a]
Pelargonium roseum R. Br.	Geraniaceae	EO	EtOH	β-citronellol, citronellyl formate, geraniol, iso-menthone, linalool	*R. (B.) annulatus*	EF	AIT	50 mg/ml. caused 98.3% acaricidal MR at 6 days PT.	Iran[a]	Jalali-Heravi et al. (2006)[b] Pirali-Kheirabadi et al. (2009)[a]
Piper tuberculatum Jacq.	Piperaceae	F	HX EA EtOH MeOH	Piplartine, dihydro-piplartine, 3,4,5-trimethoxydihydrocinnamic acid	*R. (B.) microplus*	EF LV	AIT LPT	0.12 mg/ml HX extract showed 100% larvicidal MR at 24 h PT, 100% OR and 100% acaricidal efficiency.	Brazil[a]	Rodrigues et al. (2009)[b] da Silva Lima et al. (2014)[a]
Piscidia piscipula (L.) Sarg.	Fabaceae	L	AC/DW	Alkaloids, glycosides, isoflavones, retonoids	*R. (B.) microplus*	LV A	LIT AIT	19.2 mg/ml caused 88.14% larvicidal MR, no acaricidal effect on adult stages, 15.7% ELI and 39.2% EHI.	Mexico[a]	Fernandez-Salas et al. (2011)[a]
Ptaeroxylon obliquum (Thunb.) Radik	Ptaeroxylaceae	B	DW	Saptaeroxylon, pyrogall, resins, alkaloids	*R. sanguineus*	A N	AIT FP	400 mg/ml repelled ticks (100%) for 40 min PT.	South Africa[a]	Mulholland et al. (2000)[b] Moyo and Masika (2013)[a]
Rhododendron tomentosum (Stokes) H. Harmaja	Ericaceae	L	EO	Myrcene, limonene, paklustrol	*I. ricinus*	N	FV	100 mg/ml diluted in AC caused a repellency of 95.1% 5 min PT.	Sweden[a]	Belousova et al. (1991)[b] Jaenson et al. (2003)[b] Jaenson et al. (2005)[a]
Ricinus communis L.	Euphorbiaceae	L	EtOH	Quercetin, gallic acid, flavone, kaempferol	*R. (B.) microplus*	EF	AIT	100 mg/ml caused 95% acaricidal MR within 14 days PT.	India[a]	Ghosh et al. (2013)[a]
Satureja thymbra L.	Lamiaceae	AP	EO	Carvacrol, Γ-terpinene	*Hyalomma marginatum*	Unfed adult	VP	40 μl/l resulted in 100% acaricidal MR 3 h PT. Conc. between 5 to 20 μl/l resulted in 100% acaricidal MR 24 h PT.	Turkey[a]	Cetin et al. (2009)[a,b]
Simarouba versicolor St. Hil.	Simaroubaceae	SB	DCM	Quassinoids, triterpenoids, steroids,the flavonoid kaempferol	*R. (B.) microplus*	EF LV	LPT AIT	100 mg/ml caused larvicidal MR of 30.1% at 24 h PT.	Brazil[a,b]	Arriaga et al. (2002)[b] Valente et al. (2014)[a]
Solanum trilobatum L.	Solanaceae	L	DW	Carbohydrates, saponins, phytosterols, tannins	*Hyalomma anatolicum (a.) anatolicum* Koch	LV	LIT	10 mg/l caused 100% larvicidal MR.	India[a,b]	Sahu et al. (2013)[b] Rajakumar et al. (2014)[a]
Stemona collinsae Craib	Stemonaceae	R	MeOH	Stemofoline alkaloids	*R. (B.) microplus*	EF	AIT	250 mg/ml caused 38% acaricidal MR with 24 h PT.	Thailand[a]	Sastraruji et al. (2005)[b] Kongkiatpaiboon et al. (2014)[a]
Tagetes erecta L.	Asteraceae	L	HX CH EA AC	Thiophenes, flavonoids, carotenoids, triterpenoids	*R. (B.) microplus* *H. bispinosa*	LV A	LPT AIT	3 mg/ml and 2 mg/ml MeOH extract caused 70% acaricidal MR for *H. bispinosa*and 77% larvicidal MR for *R. (B.) microplus* 24 h PT.	India[a,b]	Elango and Rahuman (2011)[a] Vijay et al. (2013)[b]

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Table 1 (*continued*)

Plant	Family	Plant part	Extractant	Major phytochemical constituent(s)	Tick species	Age (ticks)	Bioassay	Summary of results	Country	References
Tagetes minuta L.	Asteraceae	AP	MeOH EO	Tagetone, dihydrotagetone, ocimenones, piperitone	*Hyalomma rufipes*	A EN	TCR GI	Sig. dose repellent response. Delayed moulting in 60% of nymphs after 25 days.	South Africa[a]	Jacobson (1983)[b] Nchu et al. (2012)[a,b]
Tagetes patula L.	Asteraceae	AP	EtOH	Kaempferol, patuletin, quercetin-3-O-pentoside	*R. sanguineus*	EF LV	AIT LIT	50 mg/ml showed 21.50% ELI, 10% acaricidal MR and 99.78% larvicidal MR in 5 min PT.	Brazil[a,b]	Politi et al. (2012)[a,b]
Tamarindus indica L	Leguminoceae	F	EtOH DW	Crude protein, carbohydrate, fatty acids	*R.* (*B.*) *microplus*	EF	AIT	500 mg/ml caused 99% acaricidal MR 7 days PT.	Thailand[a]	Chungsamarnyart and Jansawan (2001)[a] Khanzada et al. (2008)[b] De Caluwé et al. (2010)[b]
Tetradenia riparia (Hochst) Codd	Lamiaceae	L	EO	Diterpenes, α-pyrones, phytosterols	*R.* (*B.*) *microplus*	EF LV	AIT LPT	250 mg/ml caused 100% larvicidal MR at 24 h PT.	Brazil[a]	Codd (1985)[b] Gazim et al. (2011)[a,b]
Thymus vulgaris L.	Lamiaceae	L	EtOH	Thymol, camphor	*R. sanguineus* *D. nitens*	LV	LPT	20 mg/ml conc. caused 98.1% larvicidal MR for *R. sanguineus* and 99.5% larvicidal MR for *D. nitens* 24 h PT.	Brazil[a]	Rota et al. (2008)[b] Daemon et al. (2009)[a] Monteiro et al. (2009)
Vitex negundo L.	Lamiaceae	L R	DW EtOH	Flavonoids, flavones, glycosides, triterpenes, tannins	*R.* (*B.*) *microplus*	EF	AIT	50 mg/ml EtOH extract caused 53.77% IO and DW extract caused 50% EHI 15 days PT.	India[a,b]	Ladda and Magdum (2012)[b] Singh et al. (2014)[a]
Withania somnifera Dunal	Solanaceae	L	DW EtOH	Steroids, alkaloids, salts, flavonoids	*R.* (*B.*) *microplus*	EF	AIT	50 mg/ml EtOH extract caused 40.22% IO and 50% EHI 15 days PT.	India[a,b]	Singh et al. (2014)[a] Monika (2014)[b]

Plant parts: L — Leaves; S — Stem; SB — Stem Bark; B — Bark; R — Root; AP — Aerial parts; D — Drupes; EO — Essential Oil; CV — Cloves; Fl — Flowers; Sk — Skin; Se — Seed.
Extract and extractant used: PE — Petroleum ether; MeOH — Methanol; EtOH — Ethanol; CH — Chloroform; AC — Acetone; HX — Hexane; DW — Distilled Water; EA — Ethyl Acetate.
Test type: AIT — Adult Immersion Test; LPT — Larvae Packet Test; APT — Adult Packet Test; LIT — Larvae Immersion Test; EHT — Egg Hatchability Test; TCR — Tick Climbing Repellency; FR — Fingertip Repellency; VP — Vapour Phase; VFP — Vertical Filter Paper; FP — Filter Paper; FV — Falcon Vial.
Tick Species: R — *Rhipicephalus*; B — *Boophilus*; A — *Amblyomma*; H — *Haemaphysalis*; I — *Ixodes*; D — *Dermacentor*.
Others: MR — Mortality Rate; Conc. — Concentration; A — Adult; LV — Larvae; N — Nymph; E — Egg, EF — Engorged adult female; PT — Post Treatment; ELI — Egg Laying Inhibition; EHI — Egg Hatching Inhibition; IO — Inhibition of oviposition; OR — Oviposition Reduction; Ppm — Parts per million.

[a] The main contribution.

[b] The reference for the phytochemical constituents.

Table 2
Different plant families and the number of species.

S/No	Lamiaceae	Asteraceae	Rutaceae	Fabaceae	Solanaceae	Leguminosae	Meliaceae
1	*Anisomeles malabarica*	*Artemisia absinthium*	*Aegle marmelos*	*Calpurnia aurea*	*Capsicum frutescens*	*Cassia didymobotrya*	*Azadirachta indica*
2	*Lavendula augustifolia*	*Baccharis trimera*	*Citrus reticulata*	*Leucaena leucocephala*	*Datura stramonium*	*Copaifera reticulata*	*Carapa guianensis*
3	*Leucas aspera*	*Calea serrata*	*Citrus maxima*	*Lysiloma latisiliquum*	*Solanum trilobatum*	*Tamarindus indica*	
4	*Leucas indica*	*Eupatorium adenophorum*	*Citrus sinensis*	*Piscidia piscipula*	*Withania somnifera*		
5	*Ocimum urticaefolium*	*Matricaria chamomilla*	*Citrus hystrix*				
6	*Origanum minutiflorum*	*Tagetes erecta*					
7	*Origanum onites*	*Tagetes minuta*					
8	*Satureja thymbra*	*Tagetes patula*					
9	*Tetradenia riparia*						
10	*Thymus vulgaris*						
11	*Vitex negundo*						
S/No	Poaceae	Myrtaceae	Euphorbiaceae	Geraniaceae	Verbanaceae	Asclepiadaceae	Bromeliaceae
1	*Cymbopogon citratus*	*Corymbia citriodora*	*Jatropha curcas*	*Pelargonium graveolens*	*Lippia javanica*	*Calotropis procera*	*Ananas comosus*
2	*Cymbopogon nardus*	*Melaleuca alternifolia*	*Ricinus communis*	*Pelargonium roseum*	*Lippia sidoides*		
3	*Cymbopogon winterianus*						
S/No	Acanthaceae	Caricaceae	Cupressaceae	Combretaceae	Scrophulariaceae	Capparidaceae	Guttiferae
1	*Andrographis paniculata*	*Carica papaya*	*Chamaecyparis nootkatensis*	*Guiera senegalensis*	*Digitalis purpurea*	*Gynandropsis gynandra*	*Hypericum polyanthemum*
S/No	Ptaeroxylaceae	Ericaceae	Chrysobalanaceae	Lauraceae	Alliaceae	Piperaceae	Simaroubaceae
1	*Pteroxylon obliquum*	*Rhododendron tomentosum*	*Licania tomentosa*	*Lindera melissifolia*	*Allium sativum*	*Piper tuberculatum*	*Simarouba versicolor*
S/No	Stemonaceae						
1	*Stemona collinsae*						

2) Reduced efficacy of plant extracts when tested in field trials is undoubtedly a hindrance to development of alternative acaricides. Most assays rely on the use of laboratory-reared non-resistant tick species. Also, many natural products do not persist in the environment, due to degradation caused by photo-oxidation, temperature, pH and microbial action (Mulla and Su, 1999).
3) Differences in climatic conditions, the cultivation and collection of plant materials for extract production may cause differences in results (Heimerdinger et al., 2006). The acaricidal activity of *Melia azedarach* fruits stored for five months at room temperature decreased (de Sousa et al., 2008). There was a 5% reduction in azadirachtin content after one month and 35% reduction after four months of storage of *Azadirachta indica* seeds (Yakkundi et al., 1995). Though the synthesis of chemical compounds is determined by the genetic characteristics of a plant, edaphoclimatic factors may also play a role (Lapa et al., 2002). Thus, the chemical composition of plant extracts may vary depending on the climate and soil type where plants were grown. Such indications were observed by Hüe et al. (2014) where the essential oil of *Ocimum gratissimum* from New Caledonia contained high amounts of eugenol and (Z)-β-ocimene as the main components whereas *O. gratissimum* from Cameroun was mainly constituted by thymol and γ-terpinene. This may be more valid for compounds such as essential oils released based on external stimuli than for stable metabolites. Water stress conditions did not materially influence the antimicrobial activity under natural and laboratory conditions (Netshiluvhi and Eloff, 2016a, 2016b).
4) Lack of pharmacokinetic studies on the time course of drug absorption, distribution, metabolism and excretion.

4. Conclusion

Research on plant extracts for use in tick control has grown in recent years in an attempt to find compounds with tick-repellent and acaricidal properties that can be used in association with or as replacements for synthetic compounds. One advantage from the use of these natural products is that resistance may develop slowly as there is usually a mixture of different active agents with different mechanisms of action (Baladrin et al., 1985; Chagas et al., 2002; Olivo et al., 2009). However, most research in the development of natural products for pest control have usually ended in the laboratory. Some of the limitations mentioned above may be the reason hence efforts should be made by researchers towards providing standard methods.

The success attained with pyrethrum, the molecule isolated from *Chrysanthenum* spp. and its derivatives, shows that there is also another approach that may yield good results. In-depth investigation of the large number of plants with good activity may be a worthwhile exercise. The major difficulties in commercializing an active compound are safety to humans, possibility of synthesizing at a reasonable cost, stability, development of resistance and environmental safety. The use of plant extracts to control ticks, especially *R.* (*B.*) *microplus*, seems to be a viable alternative, given the number of plants with compounds with activity against this tick that have already been found (Borges et al., 2011). However, difficulty in transposing the efficacy obtained from the laboratory to the field is one of the main obstacles. To promote an holistic approach to the knowledge of ticks and tick-borne diseases, collaborations of entomologists, epidemiologists, virologists, parasitologists, bacteriologists, toxicologists, zoologists, molecular biologists and veterinarians will be necessary (Estrada-Peña and de la Fuente, 2014). Formulations to protect the active compounds from environmental degradation and enable fast penetration into ticks are needed. There is also the need to conduct pharmacokinetic investigations to ensure that standardized extracts are used. Most importantly, toxicological studies to identify risks to human and animal health cannot be neglected.

It needs to be borne in mind that the market for plant-based acaricidal products is extremely promising, especially if the high levels of synthetic acaricide consumption are considered. These alternative products for controlling cattle ticks would not only be useful for organic livestock production but could also be an

Table 3
Number of references in different continents.

	ASIA				
S/No	India	Thailand	Iran	Saudi Arabia	China
1	Elango and Rahuman (2011)	Chungsamarnyart and Jansawan (1996)	Pirali-Kheirabadi and Razzaghi-Abyaneh (2007)	Al-Rajhy et al. (2003)	Nong et al. (2013a, 2013b)
2	Shyma et al. (2014)	Chungsamarnyart and Jiwajinda (1992)	Pirali-Kheirabadi et al. (2009)		
3	Zahir et al. (2010)	Kongkiatpaiboon et al. (2014)			
4	Godara et al. (2014a, 2014b)				
5	Srivastava et al. (2008)				
6	Singh et al. (2014)				
7	Ravindran et al. (2011a, 2011b)				
8	Divya et al. (2014)				
9	Juliet et al. (2012)				
10	Veeramani et al. (2014)				
11	Ghosh et al. (2013)				
12	Rajakumar et al. (2014)				

	AMERICA		
S/No	Brazil	USA	Mexico
1	Domingues et al. (2013)	Dietrich et al. (2006)	Fernandez-Salas et al. (2011)
2	Lázaro et al. (2013)	Oh et al. (2012)	
3	Ribeiro et al. (2008)	Tabanca et al. (2013)	
4	Vasconcelos et al. (2014)		
5	de Freitas Fernandes and Frietas (2007)		
6	Chagas et al. (2014)		
7	Ribeiro et al. (2007)		
8	Valente et al. (2014)		
9	Gomes et al. (2014)		
10	Pazinato et al. (2014)		
11	da Silva Lima et al. (2014)		
12	Politi et al. (2012)		
14	Gazim et al. (2011)		
15	Daemon et al. (2009)		

	AFRICA				
S/No	South Africa	Ethiopia	Uganda	Sudan	Kenya
1	Mkolo and Magano (2007)	Zorloni et al. (2010)	Opiro et al. (2012)	Osman et al. (2014)	Lwande et al. (1999)
2	Magano et al. (2011)				
3	Moyo and Masika (2013)				
4	Nchu et al. (2012)				

	OCEANIA	EUROPE	
S/No	New Caledonia	Turkey	Sweden
1	Hüe et al. (2014)	Cetin et al. (2009)	Jaenson et al. (2005)

alternative for controlling resistant strains. As prevention of contamination of food and the environment is a worldwide desire, it is essential to invest in developing a pharmaceutical phytotherapy industry, with interdisciplinary approaches towards finding solutions to the menace caused by ticks and tick-borne diseases (one-health concept). Apart from the products developed from the neem tree, the pyrethrins and the use of limonene, there is little published data on natural products effective in the field. It becomes imperative to explore the bioactive principles of these phytochemicals or their derivatives to diversify the base of effective acaricides in the field of human and veterinary medicine.

Conflict of interest

The authors declare no conflict of interest.

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