The Journal of Basic and Applied Zoology

RESEARCH Open Access

In vitro acaricidal efficacies of crude extract and fractions of *Croton hirtus* leaf against *Rhipicephalus annulatus*

Oluwatodimu Adekoya[1*], Genesis Adewuyi[1], Olubukola Adenubi[1], Foluke Akande[2] and Adeoye Oyewusi[1]

Abstract

Background Ticks and tick-borne diseases continues to be a global problem with direct and indirect impact on both humans and animals. The use of acaricides has been a common tick control method because of their ease of use and commercial availability; however, there are rising cases of resistance to synthetic acaricides, resulting in serious economic losses. This study aimed to evaluate the acaricidal activity of crude extracts and fractions from the leaves of *Croton hirtus* against the cattle tick *Rhipicephalus annulatus*. An adult immersion test method was adopted to assess the acaricidal potential of the *C. hirtus* extract and fractions at varied concentrations (1–20%), with 2% Tween-80 and 2% cypermethrin serving as negative and positive controls, respectively. Field ticks from cattle were collected, grouped (n = 10), and exposed to various test preparations. Tarsal reflexes, photosensitivity, reproductive indices, and oviposition inhibition were measured at 6 h post-immersion and daily for 14 days. Microsoft Excel® 2017 spreadsheet was used for data collation, and results were analysed with one-way ANOVA and Tukey HSD test on GraphPad (Prism 7), with $p \leq 0.05$ considered statistically significant.

Results Findings showed 100% tick mortality and a 95% inhibition of oviposition with the chloroform fraction (1%). The egg mass varied across the treatment groups, with the chloroform fraction being the least (< 10 mg), while the aqueous extract and other fractions were like the negative control. The mean adult mortality rate was not statistically different across the treatments.

Conclusion The chloroform fraction (1%) of *C. hirtus* leaves exhibited superior acaricidal activity against *R. annulatus* ticks compared with other fractions. Future research should explore and document the mechanisms of action of this essential oil as a natural tick control remedy.

Keywords Adult immersion test, *C. hirtus*, Essential oil, Oviposition, Fractions

*Correspondence:
Oluwatodimu Adekoya
adekoyaoa@funaab.edu.ng
[1]Department of Veterinary Pharmacology and Toxicology, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria
[2]Department of Veterinary Parasitology and Entomology, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria

© The Author(s) 2026. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

Background

Livestock production is an important aspect of agriculture in Nigeria, accounting for almost 31% of the nation's agriculture-sourced gross domestic product (Jimoh et al., 2023). Cattle farming, a major source of protein, is practiced within three major systems: intensive, semi-intensive and extensive, with over 15 million herds being raised extensively (FAO, 2018). Despite having the largest cattle population in Africa, Nigeria has not been able to meet the growing demand for animal-sourced protein. Multifactorial causes have been responsible; however, diseases are the leading cause of poor cattle productivity (Mamman et al., 2021).

Ticks are important ectoparasites of animals globally (Liyanaarachchi et al., 2015). These blood-sucking parasites are vectors of many pathogens that cause diseases in warm-blooded animals (Ramalho-Ortigao & Gubler, 2020). In addition to diseases, they cause direct harm to livestock, including anemia, irritation, immunosuppression, and poor hide quality, resulting in low market value. Annual global losses from ticks and tick-borne diseases are estimated to be nearly US$7 billion, underscoring the urgency of effective control strategies (Fouche et al., 2019).

Several tick control management approaches have been developed, including the use of biological control agents, anti-tick vaccines, breeding of tick-resistant livestock, and chemical acaricides (Rodriguez-Vivas et al., 2018). Among these options, synthetic acaricides remain the most widely used because of their accessibility, rapid onset of action, and ease of use (Schorderet-Weber et al., 2018). However, prolonged and indiscriminate use has led to the emergence of acaricide-resistant tick populations, with the accumulation of acaricide residues in meat and milk and environmental contamination (McNair, 2015). These limitations highlight the need for safer and environmentally friendly alternatives for tick control in modern livestock production.



Fig. 1 Picture of the *Croton hirtus* plant

Recently, the search for safer and more effective acaricides has involved the use of plants (Zhang et al., 2024). Plant species contain diverse bioactive constituents with pharmacological properties, including alkaloids, phenolics, terpenoids, flavonoids, and saponins (Adenubi et al., 2018). *Vernonia amygdalina*, *Calpurnia aurea*, *Ricinus communis*, and *Nicotiana tabacum* are examples of plants that have demonstrated acaricidal activity (Adenubi, 2017; Fouche et al., 2016; Kemal et al., 2020). Nonetheless, further research is needed to identify additional botanicals with potential efficacy against economically important tick species, such as *Rhipicephalus annulatus*.

Rhipicephalus annulatus, commonly known as the southern cattle tick, is predominantly found in tropical and subtropical regions, where it infests cattle, small ruminants, and horses (Tan et al., 2021). It is a major vector of bovine piroplasmosis, transmitting *Babesia bovis*, *Babesia bigemina,* and *Anaplasma marginale* (Hassan et al., 2025). Owing to its significant impact on cattle health, productivity, and survival, *R. annulatus* continues to impose a substantial economic burden on livestock producers (Adenubi et al., 2021).

Croton hirtus is a woolly leafed herb of the family Euphorbiaceae that is widely used in African ethnomedicine because of its rich phytochemical profile, which includes glycosides, alkaloids, steroids, terpenoids, anthraquinones, and flavonoids (Ramalho-Ortigao & Gubler, 2020). Traditionally, this plant has been used to treat skin infections, epilepsy, diabetes, malaria, convulsions, inflammation, and pain (Isyaka et al., 2024). Studies from Vietnam and Brazil have shown that various *Croton* species exhibit antibacterial, mosquito larvicidal, and molluscicidal activities, likely attributed to their volatile compounds, such as β-caryophyllene and caryophyllene oxide (de Jesus Prado et al., 2022; Luu-dam et al., 2023). However, little is known about the acaricidal potential of *C. hirtus* leaves against *Rhipicephalus annulatus*, particularly in Nigeria.

Methodology

Study location

This study was conducted at the Department of Veterinary Pharmacology and Toxicology, Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State, Nigeria.

Collection of plant material

Fresh *C. hirtus* leaves (Fig. 1) were collected from their natural habitat within the University community of FUNAAB, situated at 7°13′47″N latitude and 3°26′21″E

longitude. The plant was identified and authenticated at the Department of Botany, Federal University of Agriculture, Abeokuta, where a voucher specimen (FHA-4279) was allocated. Following identification, the leaves were air-dried and ground into a fine powder.

Extraction and fractionation

The powdered leaves (5 kg) were soaked in distilled water at a 1:10 ratio for 48 h, separated using a muslin cloth, and filtered using Whatman number 1 (Aiyegoro & Okoh, 2010). Rotary evaporation at 60 °C was performed to concentrate the filtrate. The crude extract was further fractionated into chloroform and ethyl acetate fractions in a separating funnel (Awouafack et al., 2013). Following bioassay-guided isolation, the crude aqueous extract, chloroform and ethyl-acetate soluble fractions from each plant were tested for acaricidal efficacy against adult female *R. (B) annulatus ticks*.

Essential oil extraction

The essential oil (EO) was extracted from fresh leaf of *C. hirtus* using the hydrodistillation method in a Clevenger apparatus (Ogunwande et al., 2019). After being blended, the fresh plant material was weighed and put into an extraction flask filled with distilled water. The flask was set up on the heating mantle, and the temperature was raised to 100°C. At this temperature, hot steam with EO moves into the cooling chamber, where the vapor is condensed. The EO is collected over water and dried over crystals of sodium sulphate and kept in a vial bottle at 4°C.

Collection and housing of field ticks

Engorged female *R. (B.) annulatus* ticks were carefully hand-picked from cattle at the lairage of Lafenwa abattoir (Fig. 2). The ticks were then transported in perforated, labeled plastic jars to the Department of Veterinary Pharmacology and Toxicology laboratory, College of Veterinary Medicine (COLVET), FUNAAB. The ticks were then identified with a digital microscope using both taxonomic descriptions and morphological keys, as described by Dantas-Torres (2019). Ticks were housed in a tick rearing chamber with a temperature of 25 (± 3) °C, a relative humidity of 70–80%, and a light/dark cycle of 14:10 h (Thorsell et al., 2006).

Experimental procedure

Adult Immersion Test (AIT) was employed as outlined by Adenubi et al. (2021). Engorged adult female ticks were grouped (10 ticks per group) and each group was weighed. Test samples of varying concentrations (20, 10, 5, 2.5 and 1%) were prepared with Tween 80 (2%)and ticks were immersed in the two ml of test solution for two minutes while gently agitating them. Tween-80 (2%) was used as negative control while commercial grade Cypermethrin (2%) served as the positive control. All tests were performed in duplicate. After treatment, each tick was placed in transparent bowls lined with tissue non-tissue fabric for the post-immersion observation. All bowls containing the ticks were then placed in the tick-rearing chamber for a 14 day period (Fig. 3).

After treatment, each tick (in each bowl) was monitored at zero hour and at sixth hour to observe the tarsal reflex and photosensitivity, following the procedure described by Akande et al., (2020). Thereafter, they were checked every 24 h for tarsal reflexes, photosensitivity and oviposition. On day 14, the eggs were collected and weighed, for the estimation of reproductive indices (RI) and percentage inhibition of oviposition (IO %) for treatments and controls using the following formula:



Fig. 2 *Rhipicephalus annulatus* tick



Fig. 3 Ticks housed in the tick-rearing chamber at controlled temperature and relative humidity,

$$\text{RI} = \frac{weightofeggs(g)}{Initialweightofengorgedfemales(g)}$$

where RI = Reproductive index

$$\text{IO } (\%) = \frac{(RInegativecontrol - RIextract)}{(RInegativecontrol)} x100$$

where IO = Inhibition of oviposition.

Data analysis

Data obtained was recorded in Microsoft Excel® and statistically analyzed using GraphPad Prism (version 7.0). Descriptive statistics was used to express results of tick adult mortality, reproductive indices, and inhibition of oviposition expressed as mean and standard error of mean (SEM) of proportion while Larva hatch was expressed as either positive or negative.

Results

Yield of the crude extract, fractions and EO of *C. hirtus* leaves

Fractions from the crude extract had various colours and weights; the aqueous fraction had a dark-brown powder, weighing 4.2 g; the ethyl-acetate fraction had a green powder with a yield of 12.63 g; while the chloroform fraction was a dark-brown viscous semi-solid with a yield of 13.9 g. Essential oil from the plant had a straw colouration and yielded a total volume of two (2) mLs. Table 1).

Table 1 Yield of the crude extract, fractions and EO of *C. hirtus* leaves

Extract and essential oil	Yield	Colour
Aqueous Extract	4.2 g	Dark brown powder
Ethyl-acetate	12.63 g	Green powder
Chloroform	13.9 g	Dark brown with a viscous consistency
Essential Oil (EO)	2 mls	Straw-coloured liquid

Acaricidal activities of crude extract, fractions and essential oil of *C. hirtus* leaves at different concentrations

In this study, 2.5% test concentration of the crude extract caused 80% mortality with 1% concentration causing only 40% tick mortality (Fig. 4). Essential oil of *C. hirtus* leaves at 1% and 2.5% concentrations caused 70% mortality but the other concentrations, like 5%, 10% and 20%, caused an average of 60% tick death (Fig. 5). For the ethyl-acetate fraction, concentrations of 1%, 2.5%, 5% and 10% caused tick mortality that ranged between 50 and 80%. However, 20% concentration of ethyl-acetate fraction demonstrated the highest (90%) acaricidal activity (Fig. 6). Unlike other fractions, all the test concentration of the chloroform fraction caused 100% tick mortality and comparable to the positive control (Fig. 7) (Table 2).

Tarsal reflex score and photosensitivity of treated ticks with aqueous crude extract of *C. hirtus* leaves

In the first 24 h, no death was reported for all the test treatments with ticks having normal tarsal reflexes and photosensitive reaction (Table 2). For crude extract, tarsal reflex score decreased after the first 24 h with ticks appearing weak and paralysed as cypermethrin control had 100% mortality. Similarly, in the essential oil group, tick activity declines after 24 h to 40% on day 14. While ethyl acetate and chloroform test concentrations cause 66% and 100% death respectively.

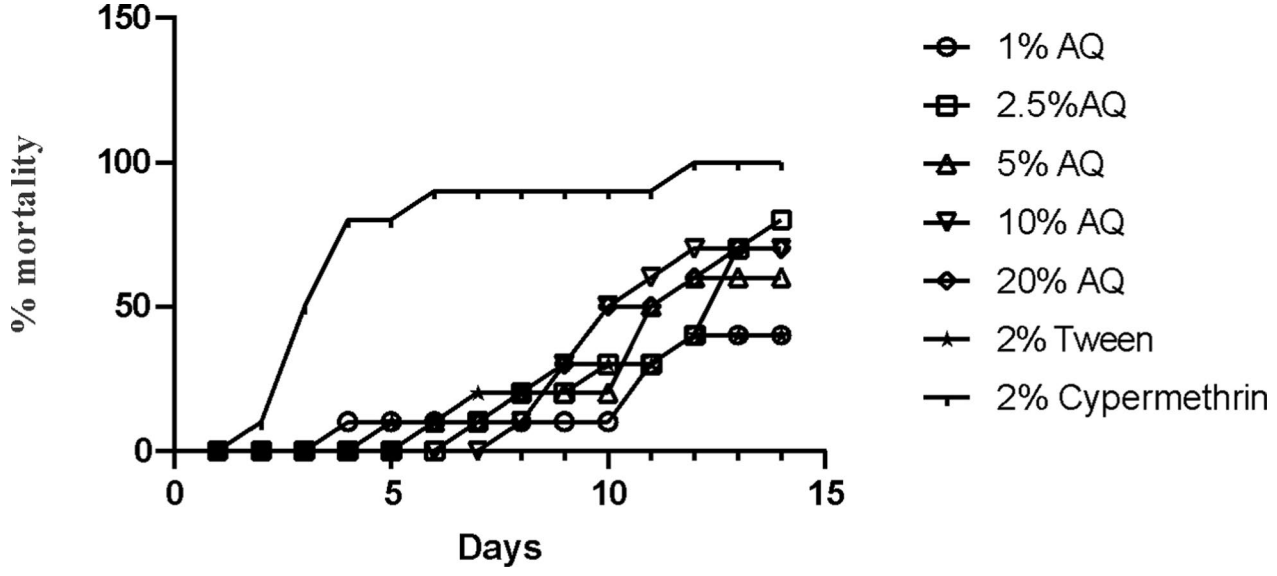


Fig. 4 Acaricidal activities of *C. hirtus* aqueous crude extract (at various concentrations) against *R. annulatus* tick

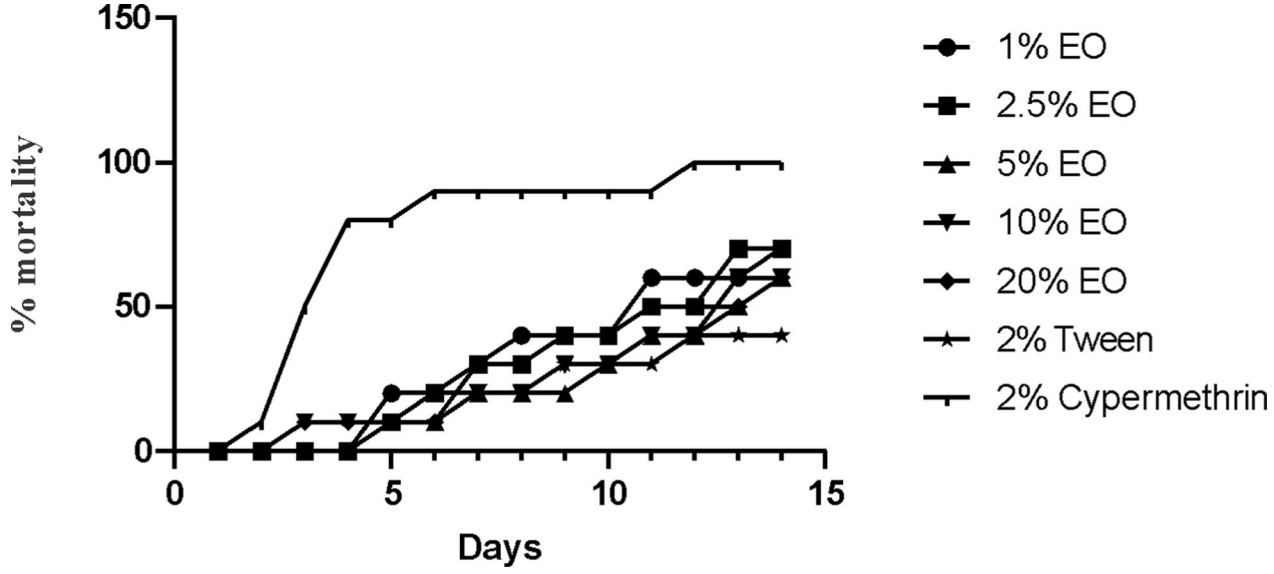


Fig. 5 Graph showing the acaricidal activities of *C. hirtus* EO against *R. annulatus* tick

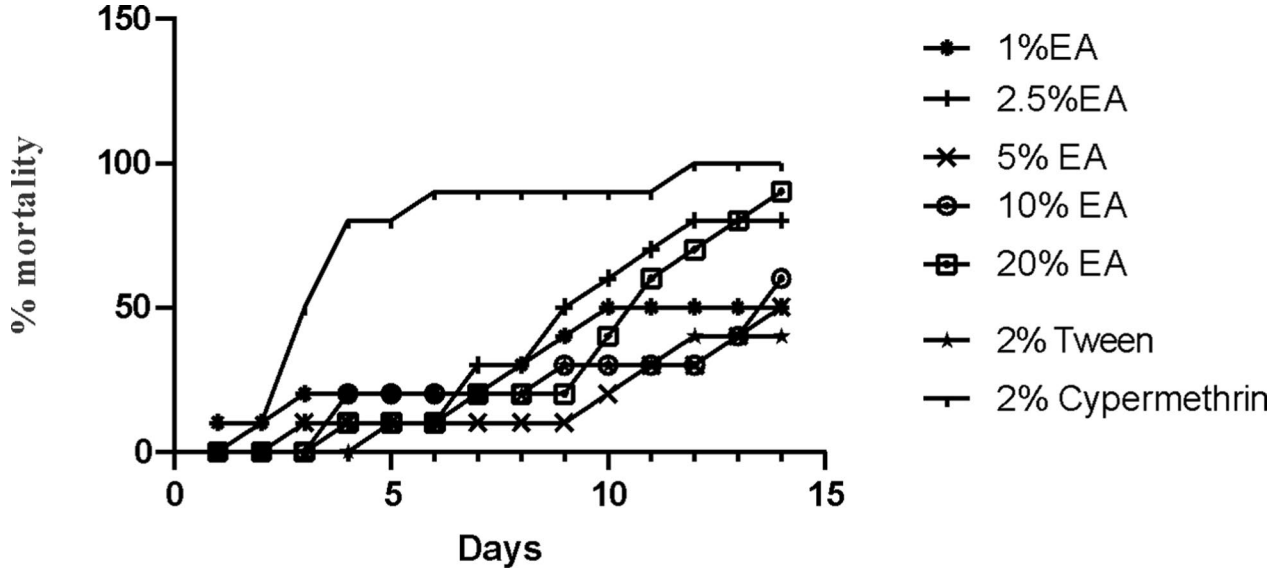


Fig. 6 Graph showing the acaricidal activities of *C. hirtus* ethyl-acetate fraction (at various concentrations) against *R. annulatus* tick

Percentage mortality, reproductive indices and inhibition of oviposition of engorged female *R. (B.) annulatus* ticks treated with different concentrations of crude (aqueous) extract, EO and fractions of *C. hirtus* leaves

Crude (aqueous) extract, EO, Ethyl acetate and Chloroform fractions of *C. hirtus* exhibited varying acaricidal activity, with the Choroform exhibiting higher tick killing activity at 1% concentration which is comparable to the positive control cypermethrin. In addition, ticks across each treatment oviposited eggs that weighed between 300 and 600 mg unlike what was observed with Chloroform treatment, where there was a reduction in oviposited eggs. The reproductive indices and inhibition of oviposition in the Chloroform test treatments between 10 mg/ml–100 mg/ml ranged from 93.4 to 95%. After 21 days of observation, only the eggs from ticks treated with Chloroform fraction of *C. hirtus* failed to hatch (Table 3).

Discussion

The colour of crude extract of *C. hirtus* leaves and its fractions ranged from dark brown to green and varied consistency, while the EO had a distinct straw-colour and a citrus scent. The essential oil color and smell is majorly a result of terpenes like β-caryophyllene and α-cadinol, and their abundance vary for geographical and seasonal factors (Luu-dam et al., 2023). The yield for the crude, fractions and essential oil of *C. hirtus* obtained in this study was low; this compares with reports from other studies

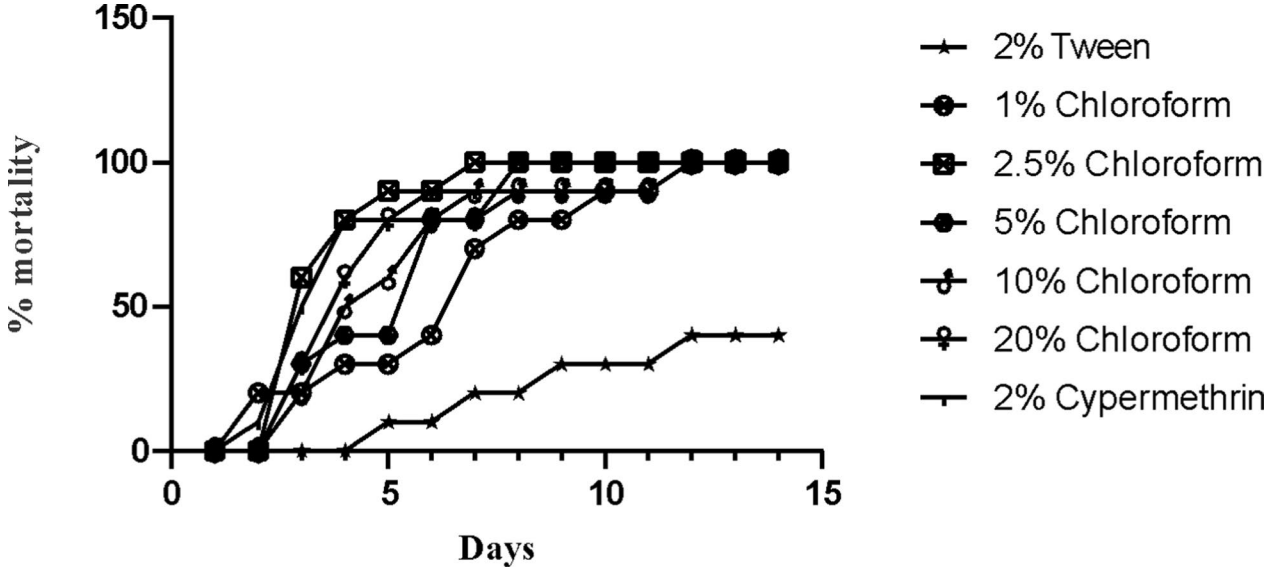


Fig. 7 Graph showing the acaricidal activities of *C. hirtus* chloroform fraction (at various concentrations) against *R. annulatus* tick

(do Vale et al., 2021; Luu-dam et al., 2023). Variations in the extract yield are influenced by extraction solvent and method, geographical location of the study, and environmental factors such as rainfall and temperature (Daouda et al., 2014; De Lima et al., 2012; Mittal & Nanda, 2017). Ultimately, the type and amount of secondary bioactive metabolites present in the extract would vary and influence their biological activity.

Following adult immersion tick test, this study documents the chloroform fraction of *C. hirtus* leaves as having the best tickicidal activity against *R. (B.) annulatus* at the concentration of 10 mg/mL. However, varying acaricidal activity was observed with other fractions in this study (50%–80%) with aqueous crude extract having the poorest activity (< 50%) even at the highest test concentration of 20%. Comparative studies of Chloroform fractions and essential oil extraction have shown that the latter contains broader range of bioactive components including fatty acids, esters, and monocyclic (Akande et al., 2020) compounds, which in this study may appear to improve the acaricidal activity, suggesting synergistic interactions between volatile and non-volatile compounds (Aly et al., 2024; Martos et al., 2013).

Tarsal reflexes and photosensitivity scoring are usually adopted as measures of the effect of the test acaricide on tick activity during in vitro studies (Adenubi et al., 2023). In this study, all test treatments caused changes in the tarsal reflex score like what was observed in the cypermethrin treatment. Cypermethrin, a more commonly used synthetic pyrethroid insecticide, caused paralysis and death of ticks post immersion. This is because it disrupts voltage-sensitive sodium channels in the nervous system of ticks, leading to paralysis and death (Akande et al., 2020).

Chloroform fraction of *C. hirtus* leaves caused a 95% inhibition of oviposition, reduction in the mass of eggs, thus impacting the reproductive indices of treated *R.* (*B.*) *annulatus*. Also, eggs oviposited failed to hatch after a 21-day period. Thus suggesting that the treatment impacted the hatchability of tick larva. This finding aligns with Adenubi et al. (2021), in a study that also documents a botanical (*Eucalyptus globulus*) essential oil as possessing both adulticidal and larvicidal effects against ticks. Other plants have been recorded to cause death to ticks via other mechanistic pathways, two examples include *Ligusticum striatum*, which causes distruption of the oxidative glycolytic pathway in dust mites, and *Zanthoxylum bungeanum* causes inhibition of acetylcholinesterases in ticks (Tang et al., 2025).

Plants with prospects as acaricides are of significance because of the growing concerns of acaricide resistance. Also, many of the commercially available acaricides persists in food and even the environment resulting in food poisoning and death of many non-target insect species (Flamini, 2006; Mužinić & Želježić, 2018). Adopting the use of botanicals would help address many of these challenges and improve animal health and productivity.

Conclusion and recommendation

This study showed the acaricidal potential of chloroform fraction of *C. hirtus* leaves against engorged adult female *R. (B.) annulatus* ticks. In addition, it caused a reduction in tick oviposition and inhibited larva hatch from tick eggs. Further research needs to isolate compounds and validate which is responsible for the acaricidal action and identify whether this compound is present in all part of the *C. hirtus* plant.

Table 2 Tarsal reflex of engorged female *R. annulatus* ticks treated with different concentrations of crude (aqueous) extract, fractions and EO of *C. hirtus* leaves

RESPONSE	SCORE	Aqueous extract					Essential Oil					Ethyl acetate					Chloroform					Cypermethrin	Tween-80
		1%	2.50%	5%	10%	20%	1%	2.50%	5%	10%	20%	1%	2.50%	5%	10%	20%	1%	2.50%	5%	10%	20%	2%	2%
No response	0	4	8	6	7	7	7	7	6	6	6	5	8	5	6	9	10	10	10	10	10	10	5
Moving 1–2 limbs slowly	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moving 1–2 limbs at a fast rate	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moving more than 2 limbs but slowly	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moving > 2 but < 8 limbs but slowly	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moving all limbs	5	6	2	4	3	3	5	3	3	4	4	5	2	5	4	1	0	0	0	0	0	0	5

EO: Essential oil

Table 3 Table showing the cross tabulations between the test concentrations, mean adult mortality, mass of eggs, reproductive indices, inhibition oviposition and larva hatch

Test Sample	Conc. (%)	MAM ± SEM (%)	Mass of eggs (mg)	RI	IO (%)	LH
Crude (aqueous) extract	1	70.00 ± 30.00	400	0.4	20	+
	2.5	90.00 ± 10.00	400	0.5	0	+
	5	80.00 ± 20.00	600	0.5	0	+
	10	85.00 ± 15.00	300	0.38	25	+
	20	85.00 ± 15.00	600	0.43	14	+
Essential Oil	1	75.00 ± 5.00	300	0.38	25	+
	2.5	70.00 ± 0.00	400	0.44	11	+
	5	60.00 ± 0.00	400	0.33	33	+
	10	60.00 ± 0.00	300	0.25	50	+
	20	60.00 ± 0.00	400	0.33	33	+
Ethyl acetate	1	75.00 ± 25.00	300		40	+
				0.3		
	2.5	90.00 ± 10.00	300	0.6	20	+
	5	75.00 ± 25.00	600	0.46	8	+
	10	65.00 ± 5.00	300	0.27	45	+
	20	85.00 ± 5.00	300	0.38	25	+
Chloroform	1	90.00 ± 10.00	10	0.03	95	
	2.5	90.00 ± 10.00	< 10	0.03	93.4	–
	5	75.00 ± 25.00	< 10	0.03	95	–
	10	95.00 ± 5.00	10	0.03	93.4	–
	20	90.00 ± 10.00	200	0.4	20	+
2% Cypermethrin	2	95.00 ± 5.00	0	0	100	–
2% Tween-80	2	50.00 ± 0.00	400	0.9	10	+

MAM: Mean adult mortality; SEM: Standard error of mean; RI: Reproductive index; IO: Inhibition of oviposition; LH: Larva hatch; +: Positive; -: Negative

Limitations

Seasonal changes influenced the availability of the ticks for the study.

Abbreviations

EO Essential oil
PT Post treatment
MAM Mean adult mortality
RI Reproductive index
IO Inhibition of oviposition
LH Larva hatch
SEM Standard error of mean

Acknowledgements

Not applicable

Author contributions

OA: Conceptualization and Experimental design; GA: Conducted the study; OA and GA: Wrote first draft; OA: Data analysis; OTA, AO and FA: Critical review for publication. All authors reviewed the manuscript.

Funding

Personal funds were used for this study.

Data availability

All data supporting the findings of this study are available within the paper and raw data can be provided upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors carefully reviewed and approved the manuscript for peer review and publication.

Competing interests

The authors declare no competing interests.

Received: 21 January 2026 / Accepted: 16 March 2026
Published online: 30 March 2026

References

Adenubi, O. T. (2017). Acaricidal Efficacy of Crude Extracts and Isolated Flavonoids from *Calpurnia aurea* Subsp. Aurea Against *Rhipicephalus turanicus* [Ph.D., University of Pretoria (South Africa)]. In *PQDT-Global* (2890698219). ProQuest One Academic. https://lib-e2.lib.ttu.edu/login?url=https://www.proquest.com/dissertations-theses/acaricidal-efficacy-crude-extracts-isolated/docview/2890698219/se-2?accountid=7098

Adenubi, O. T., Abolaji, A. O., Salihu, T., Akande, F. A., & Lawal, H. (2021). Chemical composition and acaricidal activity of *Eucalyptus globulus* essential oil against the vector of tropical bovine piroplasmosis, *Rhipicephalus (Boophilus) annulatus*. *Experimental and Applied Acarology, 83*(2), 301–312. https://doi.org/10.1007/s10493-020-00578-z

Adenubi, O. T., McGaw, L. J., Eloff, J. N., & Naidoo, V. (2018). *In vitro* bioassays used in evaluating plant extracts for tick repellent and acaricidal properties: A critical review. *Veterinary Parasitology, 254*, 160–171. https://doi.org/10.1016/j.vetpar.2018.03.008

Adenubi, O. T., Olatunbosun, O. G., Adekoya, O. A., Akande, F. A., Attama, S. C., & Oyewusi, J. A. (2023). *In vitro* evaluation of the acaricidal efficacy of aqueous extract and essential oil of *Momordica charantia* L. against *Rhipicephalus (Boophilus) annulatus* ticks. *Nigerian Veterinary Journal, 43*(4), 24–35. https://doi.org/10.4314/nvj.v43i4.3

Aiyegoro, O. A., & Okoh, A. I. (2010). Preliminary phytochemical screening and in vitro antioxidant activities of the aqueous extract of *Helichrysum longifolium*

DC. *BMC Complementary and Alternative Medicine, 10*(1), Article 21. https://doi.org/10.1186/1472-6882-10-21

Akande, F. A., Adenubi, O. T., & Garba, A. O. (2020). In vitro analysis of the efficacy of selected commercial acaricides on the cattle tick *Rhipicephalus (Boophilus) annulatus* (Acari: Ixodidae). *Egyptian Journal of Veterinary Sciences, 51*(2), 153–161. https://doi.org/10.21608/ejvs.2020.21560.1144

Aly, S. H., Elissawy, A. M., El Hassab, M. A., Majrashi, T. A., Hassan, F. E., Elkaeed, E. B., Eldehna, W. M., & Singab, A. N. B. (2024). Comparative metabolic study of the chloroform fraction of three *Cystoseira* species based on UPLC/ESI/MS analysis and biological activities. *Journal of Enzyme Inhibition and Medicinal Chemistry, 39*(1), Article 2292482. https://doi.org/10.1080/14756366.2023.2292482

Awouafack, M. D., McGaw, L. J., Gottfried, S., Mbouangouere, R., Tane, P., Spiteller, M., & Eloff, J. N. (2013). Antimicrobial activity and cytotoxicity of the ethanol extract, fractions and eight compounds isolated from *Eriosema robustum* (Fabaceae). *BMC Complementary and Alternative Medicine 13*(1), 289. https://doi.org/10.1186/1472-6882-13-289

Dantas-Torres, F., Fernandes Martins, T., Muñoz-Leal, S., Onofrio, V. C., & Barros-Battesti, D. M. (2019). Ticks (Ixodida: Argasidae, Ixodidae) of Brazil: Updated species checklist and taxonomic keys. *Ticks and Tick-Borne Diseases, 10*(6), Article 101252. https://doi.org/10.1016/j.ttbdis.2019.06.012

Daouda, T., Prevost, K., Gustave, B., Joseph, D. A., Nathalie, G., Raphaël, O., Rubens, D., Claude, C. J., Mireille, D., & Felix, T. (2014). Terpenes, antibacterial and modulatory antibiotic activity of essential oils from *Croton hirtus* L'Hér. (Euphorbiaceae) from Ivory Coast. *Journal of Essential Oil Bearing Plants, 17*(4), 607–616. https://doi.org/10.1080/0972060X.2014.958550

de Jesus Prado, V. M., de Jesus, R. A., Oliveira, J. M. A., Blank, A. F., Bezerra, D. P., Soares, M. B. P., Silva, V. R., de Souza Santos, L., Cardoso, C. L., Vilela, A. F. L., de Lima Nogueira, P. C., & de Souza Moraes, V. R. (2022). Biological studies and chromatograms aided by chemometric analysis in evaluation of seasonality and extraction method of *Croton grewioides* extracts. *Brazilian Journal of Botany, 45*(2), 607–618. https://doi.org/10.1007/s40415-022-00806-3

De Lima, S. G., Medeiros, L. B. P., Cunha, C. N. L. C., Da Silva, D., De Andrade, N. C., Neto, J. M. M., Neto., Lopes, J. A. D., Steffen, R. A., Araújo, B. Q., & Reis, F. D. A. M. (2012). Chemical composition of essential oils of *Croton hirtus* L'Her from Piauí (Brazil). *Journal of Essential Oil Research, 24*(4), 371–376. https://doi.org/10.1080/10412905.2012.692908

do Vale, J. P. C., Vasconcelos, M. A., Arruda, F. V. S., Firmino, N. C. S., Pereira, A. L., Andrade, A. L., Saker-Sampaio, S., Sampaio, A. H., Marinho, E. S., Teixeira, A. M. R., Marinho, M. M., Rodrigues, T. H. S., Teixeira, E. H., & dos Santos, H. S. (2021). Evaluation of antimicrobial and antioxidant potential of essential oil from *Croton piauhiensis* Müll. Arg. *Current Microbiology, 78*(5), 1926–1938. https://doi.org/10.1007/s00284-021-02449-1

Flamini, G. (2006). Acaricides of natural origin. Part 2. Review of the literature (2002–2006)¶. *Natural Product Communications, 1*(12), Article 1934578X0600101216. https://doi.org/10.1177/1934578X0600101216

Food and Agriculture Organization of United Nations (2018). Africa Sustainable Livestock 2050: Livestock production systems in Nigeria with spotlight on Dairy cattle and poultry (chicken) sectors. https://openknowledge.fao.org/server/api/core/bitstreams/e422f46b-f34e-4a26-8dcb-79f2551538ae/content

Fouche, G., Adenubi, O. T., Leboho, T., McGaw, L. J., Naidoo, V., Wellington, K. W., & Eloff, J. N. (2019). Acaricidal activity of the aqueous and hydroethanolic extracts of 15 South African plants against *Rhipicephalus turanicus* and their toxicity on human liver and kidney cells. *Onderstepoort Journal of Veterinary Research*. https://doi.org/10.4102/ojvr.v86i1.1665

Fouche, G., Ramafuthula, M., Maselela, V., Mokoena, M., Senabe, J., Leboho, T., Sakong, B. M., Adenubi, O. T., Eloff, J. N., & Wellington, K. W. (2016). Acaricidal activity of the organic extracts of thirteen South African plants against *Rhipicephalus (Boophilus) decoloratus* (Acari: Ixodidae). *Veterinary Parasitology, 224*, 39–43. https://doi.org/10.1016/j.vetpar.2016.05.011

Hassan, M. R., Abdullah, H. H. A. M., El-Maadawy, R. S., Abdel-Shafy, S., Khater, H., & Abd Elgawad, S. M. (2025). Molecular detection and distribution of piroplasms and *Anaplasma* species and their co-infections in cattle from three Egyptian governorates. *Veterinary Parasitology: Regional Studies and Reports, 65*, Article 101350. https://doi.org/10.1016/j.vprsr.2025.101350

Isyaka, S. M., Akintayo, A. H., & Abdullahi, A. M. (2024). A review of ethnomedicinal uses, phytochemistry and pharmacology of Nigerian crotons. *Archives of Current Research International, 24*(12), 250–274. https://doi.org/10.9734/acri/2024/v24i121016

Jimoh, S. O., Baruwa, O. I., & Kolapo, A. (2023). Analysis of profit efficiency of smallholder beef cattle farms in South-West Nigeria. *Cogent Economics & Finance, 11*(1), Article 2181786. https://doi.org/10.1080/23322039.2023.2181786

Kemal, J., Zerihun, T., Alemu, S., Sali, K., Nasir, M., Abraha, A., & Feyera, T. (2020). In vitro acaricidal activity of selected medicinal plants traditionally used against ticks in Eastern Ethiopia. *Journal of Parasitology Research, 2020*(1), Article 7834026. https://doi.org/10.1155/2020/7834026

Liyanaarachchi, D. R., Rajakaruna, R. S., Dikkumbura, A. W., & Rajapakse, R. P. V. J. (2015). Ticks infesting wild and domestic animals and humans of Sri Lanka with new host records. *Acta Tropica, 142*, 64–70. https://doi.org/10.1016/j.actatropica.2014.11.001

Luu-dam, N. A., Le, C. V. C., Satyal, P., Le, T. M. H., Bui, V. H., Vo, V. H., Ngo, G. H., Bui, T. C., Nguyen, H. H., & Setzer, W. N. (2023). Chemistry and bioactivity of croton essential oils: Literature survey and *Croton hirtus* from Vietnam. *Molecules*. https://doi.org/10.3390/molecules28052361

Mamman, A. H., Lorusso, V., Adam, B. M., Dogo, G. A., Bown, K. J., & Birtles, R. J. (2021). First report of *Theileria annulata* in Nigeria: Findings from cattle ticks in Zamfara and Sokoto States. *Parasites & Vectors, 14*(1), Article 242. https://doi.org/10.1186/s13071-021-04731-4

Martos, J., Luque, C. M. F., González-Rodríguez, M. P., Arias-Moliz, M. T., & Baca, P. (2013). Antimicrobial activity of essential oils and chloroform alone and combinated with cetrimide against *Enterococcus faecalis* biofilm. *European Journal of Microbiology and Immunology, 3*(1), 44–48. https://doi.org/10.1556/eujmi.3.2013.1.6

McNair, C. M. (2015). Ectoparasites of medical and veterinary importance: Drug resistance and the need for alternative control methods. *Journal of Pharmacy and Pharmacology, 67*(3), 351–363. https://doi.org/10.1111/jphp.12368

Mittal, V., & Nanda, A. (2017). Intensification of marrubiin concentration by optimization of microwave-assisted (low CO2 yielding) extraction process for *Marrubium vulgare* using central composite design and antioxidant evaluation. *Pharmaceutical Biology, 55*(1), 1337–1347. https://doi.org/10.1080/13880209.2017.1297837

Mužinić, V., & Želježić, D. (2018). Non-target toxicity of novel insecticides. *Arhiv Za Higijenu Rada I Toksikologiju, 69*(2), 86–102. https://doi.org/10.2478/aiht-2018-69-3111

Ogunwande, I. A., Avoseh, O. N., Olasunkanmi, K. N., Lawal, O. A., Ascrizzi, R., & Flamini, G. (2019). Chemical composition, anti-nociceptive and anti-inflammatory activities of essential oil of *Bougainvillea glabra*. *Journal of Ethnopharmacology, 232*, 188–192. https://doi.org/10.1016/j.jep.2018.12.017

Ramalho-Ortigao, M., & Gubler, D. J. (2020). 147—Human Diseases Associated With Vectors (Arthropods in Disease Transmission). In E. T. Ryan, D. R. Hill, T. Solomon, N. E. Aronson, & T. P. Endy (Eds.), *Hunter's Tropical Medicine and Emerging Infectious Diseases (Tenth Edition)* (pp. 1063–1069). Elsevier. https://doi.org/10.1016/B978-0-323-55512-8.00147-2

Rodriguez-Vivas, R. I., Jonsson, N. N., & Bhushan, C. (2018). Strategies for the control of *Rhipicephalus microplus* ticks in a world of conventional acaricide and macrocyclic lactone resistance. *Parasitology Research, 117*(1), 3–29. https://doi.org/10.1007/s00436-017-5677-6

Schorderet-Weber, S., Noack, S., Selzer, P. M., & Kaminsky, R. (2018). Blocking transmission of vector-borne diseases. In *Ectoparasites* (pp. 43–94). https://doi.org/10.1002/9783527802883.ch3

Tang, F., Wang, L., Han, R., Liu, S., Jiang, F., Zhan, X., & Wang, X. (2025). Acaricidal mechanism and active compounds of *Ligusticum* striatum methanol extract against *Dermatophagoides farinae*. *Natural Product Research*. https://doi.org/10.1080/14786419.2024.2448852

Tan, L. P., Hamdan, R. H., Hassan, B. N. H., Reduan, M. F. H., Okene, I. A. A., Loong, S. K., Khoo, J. J., Samsuddin, A. S., & Lee, S. H. (2021). *Rhipicephalus* tick: A contextual review for Southeast Asia. *Pathogens*. https://doi.org/10.3390/pathogens10070821

Thorsell, W., Mikiver, A., & Tunón, H. (2006). Repelling properties of some plant materials on the tick *Ixodes ricinus* L. *Phytomedicine : International Journal of Phytotherapy and Phytopharmacology, 13*(1–2), 132–134. https://doi.org/10.1016/j.phymed.2004.04.008

Zhang, L., Teng, Q., Guo, J., Zou, M., Xue, Q., Zhao, J., & Li, Y. (2024). Efficacy and underlying mechanisms of the essential oil derived from *Rosmarinus officinalis* against *Aleuroglyphus ovatus* (Acari: Acaridae). *International Journal of Acarology, 50*(3), 209–221. https://doi.org/10.1080/01647954.2024.2311668

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.