Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Bioactivity of essential oils of Dizygostemon riparius (Plantaginaceae) on Tetranychus neocaledonicus (Acari: Tetranychidae)

Mirla Cristina Ferreira
Ellen Cristine Nogueira Nojosa
Izaías Santos Marques
Clenilma Marques Brandão
Djanira Rubim dos Santos
Georgiana Eurides de Carvalho Marques
Kiany Sirley Brandão Cavalcante
Rogério de Mesquita Teles
Douglas Rafael e Silva Barbosa
douglas.barbosa@ifma.edu.br

Instituto Federal de Educação Ciência e Tecnologia do Maranhão: Instituto Federal de Educacao Ciencia e Tecnologia do Maranhao https://orcid.org/0000-0003-0234-773X

Research Article

Keywords: acaricidal effect, aromatic plant, Cerrado, jack beans, phytosanitary, terpene chemical profile

Posted Date: June 24th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-4396767/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Abstract

The red mite, *Tetranychus neocaledonicus* (Acari: Tetranychidae) is one of the most important agricultural pests that cause significant damage to crop productivity from family farmers to large rural producers, and chemical control, via pesticides, is widely employed. However, their continuous and exacerbated use presents numerous health and environmental risks. In this context, the secondary metabolites present in the essential oils of aromatic plant species have been gaining prominence as eco-efficient alternatives. For example, the terpene profile of the essential oil (EO) of the recently described species *Dizygostemon riparius* (Plantaginaceae) has gained attention. Initially, *D. riparius* was collected from the banks of the Rio Preto in São Benedito do Rio Preto, Maranhão, Brazil. The EOs were extracted using the hydrodistillation method and contained terpene classes, which, according to the literature, have shown significant biological activity. The EOs were then tested against *T. neocaledonicus* mites (Acari: Tetranychidae), demonstrating their toxic potential, with lethal concentrations (LC_{50}) of 2.52 µL/mL and 4.17 µL/mL for the white and lilac floral morphotypes, respectively. The white morphotype showed 62% repellency at the two sublethal concentrations tested, whereas the lilac morphotype showed percentages of 76% and 66% for the LC_{20} and LC_{30}, respectively. The present study is the first to report the acaricidal potential of the EO chemical constituents of the white and lilac morphotypes of *D. riparius* against *T. neocaledonicus*.

1. INTRODUCTION

Currently, insecticides and fungicides with synthetic origins are the most commonly used control methods for the elimination of insect pests and fungal pathogens, respectively, as they can increase crop productivity at a reduced cost to satisfy the market (Jepson et al. 2020). However, the continuous use and inappropriate application of these pesticides can lead to insect pest resistance and adverse effects on non-target beneficial arthropods, disturbing the ecological balance in addition to the bioaccumulation of toxic residues and contamination of food products (Lasserre-Zuber et al. 2018; Sabbahi et al. 2022).

In the context of agricultural pests, mites of the family Tetranychidae are considered among the most concerning. They are popularly known as spider mites or web mites, as they produce silk lines that cover their hosts, providing protection against attack by possible predators (Basha et al. 2021; Pavela et al. 2016). *Tetranychus neocaledonicus* André, known as the red mite due to its reddish color, has been highlighted for the damage it causes to about 1,200 plant species, which is attributed to its considerable adaptability to dry and hot environments (Briozo et al., 2023; Nere et al., 2021).

Tetranychus neocaledonicus is considered a pest in several crops, including fruits, vegetables, and ornamental plants. Particularly, this mite also has potential as an agricultural pest of beans, may cause significant damage, leading to reduced production, and control measures are needed to minimize these effects (Gomes Neto et al. 2017, 2019).

Investigating the availability of active substances present in native plant species with the potential for inclusion in integrated pest management (IPM) programs in agroecosystems, as well as the effectiveness of natural products from different botanical species, is necessary for the development of more ecologically friendly and cheaper products. Ideally, such products should be accessible to subsistence farmers, as they can be produced on the property (Kumar et al. 2021).

The use of phytosanitary products is an eco-efficient alternative for consideration, because only a small quantity is required for their application, which leads to less environmental contamination in addition to having an inhibitory action on the growth of insect pests/pathogens, whether in attractive or repellent forms (Jamiołkowska 2020). Among the eco-efficient phytosanitary products with a biomolecule-rich matrix, essential oils (EOs) are responsible for numerous activities, such as bioactivity against mites (Ni et al. 2021). EOs are rich in bioactive substances that are produced as protective mechanisms against damage caused by external agents, such as in the management of plant diseases in agriculture (Catani et al. 2022).

Dizygostemon riparius Scatigna & Colletta (Lamiales: Plantaginaceae) is a recently described Brazilian plant species, with its first record of occurrence on the banks of Rio Preto, in the municipality of São Benedito do Rio Preto, eastern Maranhão, Brazil (Scatigna et al. 2019). The taxonomy presents two morphotypes according to the color of its flowers, lilac or white, which stand out for exhaling a characteristic aroma in their petals that are characterized by having a glandular ovary of the villi, densely tomentose stems, and a corolla tube slightly longer than (Scatigna et al. 2019). *Dizygostemon* currently contains two species *D. floribundum* (Benth.) Radlk. also described from northeastern Brazil.

Studies carried out on *D. riparius* have indicated the presence of active substances with potential applications in integrated pest management. The first study on the chemical composition of the EO of the leaves of lilac and white floral morphotypes revealed a matrix rich in terpenes, in addition to larvicidal potential against Aedes albopictus (Skuse) (Diptera: Culicidae) larvae (Brandão et al. 2020). An evaluation of the phytochemical and larvicidal profiles of extracts of the lilac morphotype against A. aegypti (L.) larvae revealed that polymethoxyflavones are one of the main groups of compounds, with significant activity against these mosquito larvae (Martins et al. 2023).

Thus, the present study investigated the acaricidal and repellent potential of EOs extracted from both floral morphotypes of *D. riparius*, which is native to the Cerrado in the state of Maranhão, Brazil, on *T. neocaledonicus* mites.

2. MATERIAL AND METHODS

The bioassays were carried out at the Laboratory Interdisciplinary, Department of Education, Research and Extension, Instituto Federal do Maranhão Campus Codó. The temperature and relative humidity data were monitored daily with the aid of a thermohygrometer.

2.1. Plant material and essential oil extraction

Dizygostemon riparius was collected from the banks of the Preto River in São Benedito do Rio Preto-Maranhão (3°19'27.9"S and 43°31'02.6"W). For EO extraction, the hydrodistillation method was used with the Clevenger extractor modified using glass (Farmacopeia 2010), coupled to a 2 L flask and a heating blanket at 100 ºC, connected to an ultra-thermostatic bath (model LS Logen Scientific, Diadema, Brazil) maintained at a temperature of 10°C.

2.2. Acaricidal activity of essential oils on adult females of T. neocaledonicus

2.2.1. Tetranychus neocaledonicus rearing

Tetranychus neocaledonicus was reared on jack bean plants (*Canavalia ensiformes* L.) (Fabales: Fabaceae) that were not exposed to oils. To maintain rearing conditions, 25-day-old plants were infested with mite eggs, larvae, nymphs, or adults. Then, experimental arenas were constructed in plastic Petri dishes (140 x 15 mm) lined with water-saturated foam and covered with filter paper to support the rearing of the mites in the laboratory. The stock rearing was kept at a temperature of 25 ± 1 ºC, relative humidity of 70 ± 10%, and a 12-hour photophase (de Santana et al. 2020).

2.2.2. Toxicity

The toxicity of *D. riparius* EOs on *T. neocaledonicus* was evaluated using the residual method, which is recommended as a standard for laboratory tests. The arenas were prepared in plastic Petri dishes (90 x 15 mm) containing foam 10 mm thick that was moistened and covered with filter paper. Then, jack bean leaf disks (Ø 50 mm) were immersed in EO concentrations (0.40/0.81/1.30/1.62/3.25/6.5 µl/mL) or distilled water/DMSO (the control) under light agitation for five seconds, and after 30 minutes of drying, they were infested with five 4–5 day-old adult female *T. neocaledonicus*. The disks were arranged on the filter paper inside the plastic Petri dishes and kept in an incubator at a temperature of 25 ± 1 ºC and 70 ± 10% relative humidity. Mortality was evaluated 48 h after infestation, and the mites that did not move were considered dead after light contact with a fine hairbrush (de Santana et al. 2020).

2.2.3 Repellent effect of the essential oils

For the repellency tests, the lethal concentrations LC_{30} and LC_{20} predetermined in the toxicity tests for adult females were used. Arenas were made in plastic Petri dishes (90 × 15 mm) containing moistened foam (10 mm thick) and covered with filter paper. Half of the jack bean leaf disks were treated with sublethal concentrations, and the other half did not receive treatment. Ten 4–5 day old adult female *T. neocaledonicus* were released, and 48 h after infestation, the number of females attracted to each treatment was evaluated (Breda et al., 2016). The repellency index (RI) was calculated using the formula: RI = 2G / (G + P), where G = % of mites attracted in the treatment and P = % of mites attracted in the control. The RI values vary on the scale between zero and two, where RI = 1 indicates similar repellency between the treatment and the control, RI > 1 indicates less repellence of the treatment compared to the control and RI < 1 indicates the greater repellency of the treatment compared to the control. the witness. The security interval used to consider whether or not the treatment is repellent was obtained using the

average of the RI and the respective standard deviation (SD). Thus, if the average RI is less than 1 - SD, the oil is repellent; if it is greater than 1 + DP, the oil is attractive and if it is between 1 - DP and 1 + DP, the oil is considered neutral (Matos et al., 2020). This index is an adaptation of the formula for consumption index cited by Lin et al. (1990).

2.2.4 Instantaneous rate of population growth

The instantaneous population growth rate (ri) was calculated for the sublethal LC_{30} and LC_{20} concentrations determined in the toxicity tests for adult females, following the same methodology. For this, the equation proposed by Walthall and Stark (1997) was used:

$r_i = [\ln(N_f/N_0)]/\Delta t$

Where Nf = final number of mites; N0 = initial number of mites; and Δt = number of days the test was run. The total evaluation time was 10 days after the initiation of the experiments, and the total number of mites (eggs, mobile immature forms, and adults) was recorded.

2.2.5 Statistical analysis and experimental design

Toxicity tests for adult females, repellency, and the instantaneous rate of population growth were conducted in a completely randomized design with five replicates. The lethal (LC_{50}) and sub-lethal concentrations (LC_{30} and LC_{20}) of the essential oils for the toxicity tests were determined using PROC PROBIT in SAS version 8.02 (SAS Institute 2001). For the instantaneous rate of population growth, the results were subjected to analysis of variance, and the means were compared by Tukey's post-hoc test at a 5% probability using the SAS program (SAS Institute, 2001). For repellency tests, the number of mites attracted was compared by using the chi-square test with PROC FREQ in SAS (SAS Institute 2001).

3. RESULTS

3.1. Chemical composition of the essential oils

The essential oils of the lilac (EODrl) and white (EODrw) D. riparius morphotypes have chemical profiles consisting of monoterpenes, oxygenated monoterpenes, sesquiterpenes, and oxygenated sesquiterpenes (Brandão et al. 2020). Table 1 presents the main constituents of the EOs in the respective floral morphotypes, with the biomass subjected to natural drying.

Table 1
Chemical constituents of EO*Dr*w and EO*Dr*l.

Compounds	Morphotypes	
	EO*Dr*w (%)	EO*Dr*l (%)
Fenchil acetate	45.8	48.0
Fenchol	35.0	33.5
Caryophyllene	4.2	4.3
Caryophyllene Oxide	2.3	2.6
Source: Brandão et al. (2020).		

It is noteworthy that the constituents fenchil acetate, fenchol, caryophyllene, and caryophyllene oxide were reported in the study as the primary constituents of the analyzed EO matrix, representing more than 80% of the analyzed EO matrix.

3.2 Acaricidal activity of the essential oils on adult females of T. neocaledonicus

The toxicity of the EOs tested after 48 h of treatment on *T. neocaledonicus*, in terms of lethal and sublethal concentrations (Table 2), demonstrated a subtle variation in the concentration-mortality curves, despite the fact that they were oils from the same plant species, distinguishing only the floral morphotype. EOs showed no difference in toxicity between floral phenotypes considering LC_{20}, LC_{30}, and LC_{50} values due to overlapping confidence intervals. The estimated lethal and sublethal concentrations were generated from a straight concentration-response line; in this case, mite mortality was the response. The slopes of the lines were also very similar between the two floral morphotypes, indicating no difference in toxicity. Higher slope values indicate that small variations in oil concentration promote large variations in mortality. The Probit model was adequate for analyzing concentration-mortality data, with low χ 2 values and P values ranging from 0.14 to 0.16.

Table 2. Toxicity of EO*Dr*l and EODrw on *Tetranychus neocaledonicus*.

EO	Parameters										
	DF	N	Slope ± SE	LC_{20} (CI95%)	LC_{30} (CI95%)	LC_{50} (CI95%)	TR_{30}	TR_{30}	TR_{50}	χ^2	*P*
EODrw	3	200	1.66± 0.17	0.78 (0.53–1.06)	1.22 (0.89–1.58)	2.52 (1.96–3.28)	1.49	1.54	1.65	5.06	0.16
EO*Dr*l	2	250	1.51±0.21	1.16 (0.67–1.67)	1.88 (1.24–2.55)	4.17 (3.11–5.74)	-	-	-	3.81	0.14

N= number of insects used in the test; DF = degrees of freedom; SE = standard error; CI = confidence interval; TR = toxicity ratio; χ^2 = Chi-square; *P* = probability.

3.3. Repellent effect of the essential oils

Dizygostemon riparius EOs also showed promising results in terms of their repellent activity, based on the repellency index (RI). Both sublethal concentrations of the morphotypes were classified as repellents (Table 3). In both EOs, the sublethal concentrations of LC_{20} and LC_{30} resulted in a significantly lower number of attracted mites than the control treatment, corroborating the repellency classification results (Fig. 1).

Table 3
Repellency classification of EO*Dr*w and EO*Dr*l on *Tetranychus neocaledonicus.*

EOs	LC (µL/mL)	RI (M ± SD)*	Classification
EO*Dr*w	0.78	0.48 ± 0.30	Repellent
	1.22	0.61 ± 0.16	Repellent
EO*Dr*l	1.16	0.76 ± 0.26	Repellent
	1.88	0.76 ± 0.17	Repellent
* (Repellence index. M = mean; SD = standard deviation.			

For EODrw, the two sublethal concentrations tested showed an average of 3.8 attracted mites for both LC_{20} and LC_{30}, thus presenting 62% repellency. OEDrl attracted an average of 2.4 and 2.8 mites to LC_{20}

and LC_{30}, respectively, which represents 76% and 66% repellency for these two sublethal concentrations.

3.4 Instantaneous rate of population growth

The instantaneous rate of population growth, when applied to the LC_{20} of the EO of *D. riparius*, showed no significant difference between the white (0.0819) and lilac (0.0852) floral morphotypes compared with the control treatment (0.1009). Therefore, this sublethal concentration does not affect population growth of the mite *T. neocaledonicus* (Fig. 2A).

When the LC_{30} of *D. riparius* EO (Fig. 2B) was applied to the mites, there was a significant difference in the population growth between the white (0.0547) and lilac (0.0748) floral morphotypes compared to the control treatment (0.1009). The white floral morphotype resulted in lower population growth than mites in the control and lilac morphotype treatments. Therefore, the sublethal concentration LC_{30} of this EO morphotype significantly affects the population growth of *T. neocaledonicus*.

4. DISCUSSION

The use of EO-based bioinsecticides against mites of the genus *Tetranychus* has been studied for a wide variety of plants, such as cinnamon (Melia azedarach L.), lemongrass (*Cymbopogon flexuosus* [Nees ex Steudel] J.F. Watson), and clove (*Eugenia caryophyllus* [Spreng.] Bullock & S.G. Harrison). In this regard, EOs that largely contain oxygenated monoterpenes in their composition have shown acute and ovicidal toxicity in adults of *Tetranychus urticae* Koch and *T. neocaledonicus* species. Thus, they have been selected as active substances for the development of botanical acaricides applied by fumigation (Briozo et al. 2022; Heidarinejad Tehrani et al. 2022).

The application of *D. riparius* EOs to mites was carried out using the residual method, and their toxicity was confirmed based on their 95% confidence limits and low values of LC_{50}. The LC_{50} of 2.52 µL/mL for EODrw and 4.17 µL/mL for OEDrl, proved to be very favorable for the control of *T. neocaledonicus* females, in addition to showing no difference in toxicity, due to overlapping intervals of confidence (Table 2). The values found are consistent with the values of the study carried out by Briozo et al. (2022), in which the LC_{50} for the EOs of *C. flexuosus* and *E. caryophyllus* were equal to 3.24 µL/mL and 2.01 µL/mL, respectively against the mites *T. neocaledonicus*. In addition to its toxic effect against mites, the EO of D. riparius also has a similar action on other pests, as reported in the study by Brandão et al. (2020), where the effective larvicidal activity of the EO was observed against 4 th instar larvae of the mosquito *A. albopictus*.

According to Isman (2020), the toxicity of EOs to mites is due to interactions between low molecular weight terpenoids present in EOs and their nervous system, such as the attack of these terpenoids on the neuromodulator octopamine, acid-controlled chloride channels, gamma-aminobutyric acid (GABA), and/or nicotinic acetylcholine receptors, although there is still the possibility of several sites and mechanisms of action being affected simultaneously when there is a synergism between the

constituents (Verdeguer et al., 2020). Thus, the toxicity of essential oils in the present study could also be related to their neurotoxic mechanisms of action.

The profile of the chemical structures of *D. riparius* EOs is in line with the literature, which relates the majority of terpene constituents in the EO matrix to their activity against insects (Rocha et al. 2022) and mites (Araújo et al. 2020). The major constituents of *D. riparius* EOs, fenchil acetate (45.8 and 48.0%) and endo-fenchol (35.0 and 33.5%), in the matrix of EODrw and EODrl, respectively (Table 1), are classified as oxygenated monoterpenes, probably being responsible for a large part of the toxic activity of these oils, as they have an inhibitory effect on acetylcholinesterase, causing mite mortality. Although it is a constituent in a lower percentage in the EO matrix under study, caryophyllene oxide (2.3 and 2.6%, respectively) is known to have several biological properties, including serving as a very efficient acaricide (Fu et al., 2021). Thus, further studies with these isolated compounds are needed to verify their toxicity and confirm whether they have an isolated toxic effect or whether this effect is synergistic against *T. neocaledonicus* mites.

EOs have a lipophilic nature and high volatilization, making them capable of being inhaled and absorbed by mite cuticles. Depending on the degree of resistance and the target population, they can inhibit growth, causing neurotoxic effects, in addition to interfering with breathing and consequently leading to death (Lucia and Guzmán 2021; Ni et al. 2021). In this context, considering the neurotoxic effect and cuticular absorption, EODrw and EODrl demonstrate potential for the management of *T. neocaledonicus* owing to their high contact toxicity.

Some studies corroborate the results of the present work, highlighting the biological potential of the species that can be observed in cases that used other EOs similar in composition to the EO of *D. riparius*, such as the EO of *Tarchonanthus camphoratus* L. (Asteraceae), which has a high percentage of oxygenated monoterpenes, in addition to having biological activities attributed to the major compound fenchol, including anticancer (Nasr et al. 2020), antimicrobial (Matasyoh et al. 2007), antioxidant, and cytotoxic properties (Ali et al. 2013).

Yildirim et al. (2013) conducted a study to analyze the toxicity of monoterpene compounds present in the matrix of most EOs when applied in contact with adults of *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) under laborator conditions. They reported that the oxygenated monoterpene fenchol, classified as one of the major compounds in the present study, is toxic when applied by fumigation. In addition, analysis of variance showed that the effects of different monoterpenes on the mortality rate of *S. zeamais* were highly significant based on the dosage rate and exposure time and are considered promising alternatives to control insects in stored products.

Repellency is an important sublethal effect that depends on the concentration used and must be considered when selecting a product for the general management of agricultural pests, as this characteristic makes it possible to significantly reduce the permanence of pests in the field, reflecting parameters such as oviposition time and, consequently, productivity loss (Basaid et al. 2021). The number of adult females attracted was significantly lower (P<0.05) in leaf discs treated with *D. riparius*

EOs. When applied to *T. neocaledonicus* at the two sublethal concentrations tested, EODrw presented a repellency of 62% for both. EODrl showed 76% and 66% repellency at the two sublethal concentrations, LC_{20} and LC_{30}, respectively. Repellency varies according to the method used, which includes the concentrations of EOs, species of mites used, and plant species used to rear the mites (Briozo et al. 2022). The mode of action of both natural and synthetic repellents is directly related to the formation of a vapor layer on the skin with an odor that becomes unbearable for insects and mites and consequently induces them to redirect their path and prevent contact with the host (da Silva; Ricci-Júnior 2020).

Therefore, the EOs tested in the present study showed good repellent potential against *T. neocaledonicus*, with a repellency percentage above 50%. These results indicated that the repellent effect of essential oils could be an interesting alternative for controlling this mite in crops. Other studies have shown that EOs from plants such as *Citrus sinensis* Osbeck var. pears, *Citrus aurantium* L., *Salvia officinalis* L., *Rosmarinus officinalis* L., *Hyssopus officinalis* L., and *Ferula gummosa* Boiss. exhibit repellent activity against tetranychid mites, significantly reducing plant infestation (da Camara et al. 2015; Fatemikia et al. 2017; Salman et al. 2015). Therefore, the repellent effect of EOs is an important tool for preventing *T. neocaledonicus* infestations, further reducing the need to apply acaricides, which can negatively affect the environment and human health. In addition, the use of EOs as repellents could be a more economical and sustainable control option for farmers. Therefore, the repellent effects of EODrw and EODrl make them promising alternatives for the control of *T. neocaledonicus*.

The components of EOs can act in several ways in the pest system, be they insects or mites. In addition to the deaths, they can cause changes in reproductive parameters, such as oviposition and egg viability, directly influencing the instantaneous rate of population growth. The use of EOs can significantly reduce the population growth of mites, in which *Artemisia annua* L., *Rosmarinus officinalis* L. *Varronia curassavica* Jacq., *Cymbopogon flexuosus*, *Eugenia caryophyllus*, and *Illicium verum* Hook f. stand out, reducing the population growth of Tetranychus mites, including *T. neocaledonicus*, resulting in lower infestations on plants (Andrade et al. 2021; Briozo et al. 2022; Esmaeily et al. 2017). In the present study, it was found that EODrw resulted in slower population growth than the control treatment. Therefore, the sublethal LC_{30} concentration of this EO significantly affected the population growth of *T. neocaledonicus* and can prevent the rapid multiplication and dissemination of this pest when applied at this concentration on plants, thereby preventing severe damage to crops.

In general, this study is the first to report the acaricidal potential of the chemical constituents of the white and lilac floral morphotype EOs of *D. riparius* against *T. neocaledonicus* mites. The *D. riparius* EOs were demonstrated to have a toxic effect on *T. neocaledonicus* mites at low concentrations as well as a repellent effect. The white floral morphotype, present at the two sublethal concentrations tested, showed 62% repellency, whereas the lilac morphotype showed 76% and 66% repellency at the two sublethal concentrations tested. The white floral morphotype showed slower population growth than that of the control treatment, so it can be concluded that the sublethal concentration LC_{30} of his EO significantly affected the population growth of *T. neocaledonicus*. This study expands the investigations on the bioactivity of EOs from botanical species in Maranhão State, specifically a recently described plant

species native to Cerrado Maranhense, Brazil, in addition to strengthening the eco-efficient use of these safe and efficient natural defensives in agricultural cultivars, such as jack beans. Besides, the safety and efficacy of essential oils need to be established to prevent adverse effects on human health and the environment. Studying essential oils' effects can help identify their potential toxicity, allergenicity, and other harmful effects that may pose a threat to public health and the ecosystem. Furthermore, understanding their mode of action on non-target organisms can help minimize their impact on beneficial insects, pollinators, and other non-target species. This knowledge is essential for developing effective and sustainable ways to harness their benefits while mitigating their negative impacts.

Declarations

All authors of this manuscript declare that have no conflicts of interest.

CONFLICT OF INTEREST

All authors of this manuscript declare that have no conflict of interest.

FUNDING

Instituto Federal de Educação, Ciência e Tecnologia do Maranhão – R$ 2858,86. EDITAL

AUTHOR CONTRIBUTIONS

M.C.F., E.C.N.N., I.S.M., C.M.B. and D.R.S.B. participated in all stages of manuscript production; D.R.S., G.E.C.M., K.S.B.C., and R.M.T. contributed to writing the manuscript, statistical analysis.

ACKNOWLEDGEMENTS

The IFMA São Luís-Monte Castelo campus and Codó campus (PRPGI notice No. 14/2022 – NATIONAL EXCHANGE 2022), Research Groups BIOMASSA, NEA, and ENTOMOL, and Development Agencies CAPES, CNPQ and FAPEMA are thanked for supporting and funding this study.

AVAILABILITY OF DATA AND MATERIAL

No applicable

CODE AVAILABILITY

No applicable

References

1. Ali NAA, Al-Fatimi MA, Crouch RA, Denkert A, Setzer WN, Wessjohann L (2013) Antimicrobial, antioxidant, and cytotoxic activities of the essential oil of Tarchonanthus camphoratus. Nat Prod Commun 8(5):1934578X1300800534. https://doi.org/10.1177/1934578X1300800534
2. Andrade FP, Venzon M, Dôres das, Franzin RGR, Martins ML, de Araújo EF, G. J., Fonseca MCM (2021) Toxicity of Varronia curassavica Jacq. essential oil to two arthropod pests and their natural enemy. Neotrop Entomol 50(5):835–845. https://doi.org/10.1007/s13744-021-00906-x
3. Araújo MJC, Moraes MM, Born FS, Camara CAG (2020) Acaracidal Property and Repellent Action Against Tetranychus Urticae Koch of Essential Oils from ThreeSpecies of Piper That Occur in Fragments of the Atlantic Forest in the State of Pernambuco, Brazil. Revista Virtual Química 12:629–638. https://doi.org/10.21577/1984-6835.20200050
4. Arena JS, Merlo C, Defagó MT, Zygadlo JA (2020) Insecticidal an antibacterial effects of some essential oils against the poultry pest Alphitobius diaperinus and its associated microorganisms. J Pest Sci 93:403–414. https://doi.org/10.1007/s10340-019-01141-5
5. Basaid K, Chebli B, Mayad EH, Furze JN, Bouharroud R, Krier F, Barakate M, Paulitz T (2021) Biological activities of essential oils and lipopeptides applied to control plant pests and diseases: A review. Int J Pest Manage 67(2):155–177. https://doi.org/10.1080/09670874.2019.1707327
6. Basha HA, Mostafa EM, Eldeeb AM (2021) Mite pests and their predators on seven vegetable crops (Arachnida: Acari). Saudi J Biol Sci 28(6):3414–3417. https://doi.org/10.1016/j.sjbs.2021.03.004
7. Benmoussa H, Béchohra I, He S, Elfalleh W, Chawech R (2023) Optimizatio of sonohydrodistillation and microwave assisted hydrodistillation by response surface methodology for extraction of essential oils from Cinnamomum cassia barks. Ind Crops Prod 192:115995. https://doi.org/10.1016/j.indcrop.2022.115995
8. Brandão CM, Cavalcante KSB, Teles deM, de Marques R, Monteiro GE, Andrade OS, E. H. A., Maia JGS (2020) Composition and larvicidal activit of the oil of Dizygostemon riparius (Plantaginaceae), a new aromatic specie occurring in Maranhão. Brazil Chem Biodivers 17(11):e2000462. 10.1002/cbdv.202000462
9. Breda MO, de Oliveira JV, Esteves Filho AB, Barbosa DRS, de Santana MF (2016) Host preference, population growth and injuries assessment of Polyphagotarsonemus latus (banks)(ACARI: Tarsonemidae) on Capsicum annuum L. Genotypes Bull Entomol Res 106(5):672–678. https://doi.org/10.1017/S0007485316000420
10. Briozo, M. E. O., De Franca, S. M., de Andrade Dutra, K., Navarro, D. M. D. A. F.,& Silva, P. R. R. (2022). Lethal and sublethal effects of essential oils on Tetranychusneocaledonicus (Acari:Tetranychidae). Systematic and Applied Acarology, 27(12), 2597–2617. https://doi.org/10.11158/saa.27.12.11
11. Briozo MEO, Silva JF, Ferraz JCB, Silva PRR, Melo JWDS, França D, S. M (2023) Biology and life table of Tetranychus neocaledonicus André (1933)(Acari: Tetranychidae) in different hosts. Syst Appl

Acarology 28(3):497–507. https://doi.org/10.11158/saa.28.3.7

12. Catani L, Grassi E, di Montanara AC, Guidi L, Sandulli R, Manachini B, Semprucci F (2022) Essential oils and their applications in agriculture and agricultural products: A literature analysis through VOSviewer. Biocatal Agric Biotechnol 102502. https://doi.org/10.1016/j.bcab.2022.102502
13. da Camara CA, Akhtar Y, Isman MB, Seffrin RC, Born FS (2015) Repellent activity of essential oils from two species of Citrus against Tetranychus urticae in the laboratory and greenhouse. Crop Prot 74:110–115. https://doi.org/10.1016/j.cropro.2015.04.014
14. da Silva MRM, Ricci-Júnior E (2020) An approach to natural insect repellent formulations: from basic research to technological development. Acta Trop 212:105419. https://doi.org/10.1016/j.actatropica.2020.105419
15. de França SM, Breda MO, Barbosa DR, Araujo AM, Guedes CA (2017) The sublethal effects of insecticides in insects. Biol control pest vector insects 23–39. https://doi.org/10.5772/66461
16. de Santana MF, de Oliveira JV, Breda MO, Silva Barbosa e, Filho DR, A. B. E., de Oliveira CM (2021) Host preference, acaricides effects and population growth of Polyphagotarsonemus latus (Banks) (Acari: Tarsonemidae) on white and colored cotton cultivars. Pest Manag Sci 77(1):217–223. https://doi.org/10.1002/ps.6010
17. Gyrdymova YV, Rubtsova SA (2021) Caryophyllene and caryophyllene oxide: A variety of chemical transformations and biological activities. Chem Pap 1–39. https://doi.org/10.1007/s11696-021-01865-8
18. Esmaeily M, Bandani A, Zibaee I, Sharifian I (2017) Sublethal effects o Artemisia annua L. and Rosmarinus officinalis L. essential oils on life table parameters of Tetranychus urticae (Acari: Tetranychidae). Persian J Acarology 6(1). https://doi.org/10.22073/pja.v6i1.23974
19. Farmacopéia Brasileira IV, – parte 1. 5.São Paulo: Editora Atheneu, 1.320p. Fatemikia, Abbasipour S, H., Saeedizadeh A (2010) (2017). Phytochemical and acaricidal study of the Galbanum, Ferula gumosa Boiss.(Apiaceae) essential oil against Tetranychus urticae Koch (Tetranychidae). Journal of Essential Oil Bearing Plants, 20(1), 185–195. https://doi.org/10.1080/0972060X.2016.1257957
20. Fu QM, Zeng B, Qing-yue X, Bin-sheng H, Chun-xia H, Mei-hua B (2021) Essential oils for the treatment of dust mites. In E3S Web of Conferences (Vol. 271). EDP Sciences. https://doi.org/10.1051/e3sconf/2027104032
21. Gomes Neto AV, Silva PRR, Melo JW, Júnior M, L. C. D., França SMD (2017) Biology and life table of Tetranychus neocaledonicus on lima bean. Int J Acarol 43(8):622–626. https://doi.org/10.1080/01647954.2017.1377288
22. Heidarinejad Tehrani AH, Abbasipour H, Rezazadeh A (2022) Acaricida activity of the chinaberry, Melia azedarach L.(Lamiaceae) essential oil against Tetranychus urticae Koch. Int J Acarol 48(8):679–685. https://doi.org/10.1080/01647954.2023.2169350
23. Isman MB (2020) Commercial development of plant essential oils and their constituents as active ingredients in bioinsecticides. Phytochem Rev 19:235–241. https://doi.org/10.1007/s11101-019-09653-9

24. Jamiołkowska A (2020) Natural compounds as elicitors of plant resistance against diseases and new biocontrol strategies. Agronomy 10:173. https://doi.org/10.3390/agronomy10020173
25. Jampílek J, Kráľová K (2022) Biopesticides for management of arthropod pest and weeds. In Biopesticides (pp. 133–158). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-823355-9.00005-5
26. Jepson PC, Murray K, Bach O, Bonilla MA, Neumeister L (2020) Selectio of pesticides to reduce human and environmental health risks: a global guideline and minimum pesticides list. Lancet Planet Health 4(2):e56–e63. https://doi.org/10.1016/S2542-5196(19)30266-9
27. Kumar J, Ramlal A, Mallick D, Mishra V (2021) An overview of some biopesticides and their importance in plant protection for commercial acceptance. Plants 10(6):1185. https://doi.org/10.3390/plants10061185
28. Lasserre-Zuber P, Caffier V, Stievenard R, Lemarquand A, Le Cam B, Durel CE (2018) Pyramiding quantitative resistance with a major resistance gene in apple: from ephemeral to enduring effectiveness in controlling scab. Plant Dis 102(11):2220–2223. https://doi.org/10.1094/PDIS-11-17-1759-RE
29. Lin H, Kogan M, Fischer D (1990) Induced resistance in soybean to the Mexican bean beetle (Coleoptera: Coccinellidae): comparisons of inducing factors. Environ Entomol 19(6):1852–1857. https://doi.org/10.1093/ee/19.6.1852
30. Lucia A, Guzmán E (2021) Emulsions containing essential oils, their components or volatile semiochemicals as promising tools for insect pest and pathoge management. Adv Colloid Interface Sci 287:102330. https://doi.org/10.1016/j.cis.2020.102330
31. Martins SMA, Cavalcante KSB, de Mesquita Teles R, Brandão CM, Godinho AS, Silva LK, Holanda AC, da Rocha CQ (2023) Chemical profiling of Dizygostemon riparius (Plantaginaceae) plant extracts and its application against larvae of Aedes aegypti L.(diptera: culicidae). Acta Trop 237:106706. https://doi.org/10.1016/j.actatropica.2022.106706
32. Matasyoh JC, Kiplimo JJ, Karubiu NM, Hailstorks TP (2007) Chemical composition and antimicrobial activity of essential oil of Tarchonanthus camphoratus. Food Chem 101(3):1183–1187. https://doi.org/10.1016/j).foodchem.2006.03.021
33. Matos LF, da Cruz Lima E, de Andrade Dutra K, Navarro DMDAF, Alves JLR, Silva GN (2020) Chemical composition and insecticidal effect of essential oils from Illicium verum and Eugenia caryophyllus on Callosobruchus maculatus in cowpea. Ind Crops Prod 145:112088. https://doi.org/10.1016/j.indcrop.2020.112088
34. Nasr FA, Noman OM, Alqahtani AS, Qamar W, Ahamad SR, Al-Mishari AA, Alyhya N, Farooq M (2020) Phytochemical constituents and anticancer activities of Tarchonanthus camphoratus essential oils grown in Saudi Arabia. Saudi Pharm J 28(11):1474–1480. https://doi.org/10.1016/j.jsps.2020.09.013
35. Nere DR, Melo JWDS, De Lima DB, Bleicher E (2021) Identification o Tetranychus neocaledonicus (Acari: Tetranychidae)-resistant genotypes in Phaseolus lunatus. Syst Appl Acarology 26(12):2417–

2425. https://doi.org/10.11158/saa.26.12.16

36. Neto AVG, Silva PRR, Silva JDC, dos Santos MF, da Silva Melo JW, de França SM (2019) First record of mites associated with lima bean (Phaseolus lunatus L). J Plant Prot Res 59(3). https://doi.org/10.24425/jppr.2019.129752
37. Ni ZJ, Wang X, Shen Y, Thakur K, Han J, Zhang JG, Hu F, Wei Z (2021) Recent updates on the chemistry, bioactivities, mode of action, and industrial applications of plant essential oils. Trends Food Sci Technol 110:78–89. https://doi.org/10.1016/j.tifs.2021.01.070
38. Pavela R, Stepanycheva E, Shchenikova A, Chermenskaya T, Petrova M (2016) Essential oils as prospective fumigants against Tetranychus urticae Koch. Ind Crops Prod 94:755–761. https://doi.org/10.1016/j.indcrop.2016.09.050
39. Raman J, Kim JS, Choi KR, Eun H, Yang D, Ko YJ, Kim SJ (2022) Application of lactic acid bacteria (LAB) in sustainable agriculture: Advantages and limitations. Int J Mol Sci 23(14):7784. https://doi.org/10.3390/ijms23147784
40. Rocha MM, Rodrigues RDS, Guimarães PHV, da Gonsalves C, J. K. M (2022) Larvicide potential of essential oils from Brazilian plants against Aedes aegypti. Res Soc Dev 11(2):e53211226140–e53211226140. https://doi.org/10.33448/rsd-v11i2.26140
41. Sabbahi R, Hock V, Azzaoui K, Saoiabi S, Hammouti B (2022) A global perspective of entomopathogens as microbial biocontrol agents of insect pests. J Agric Food Res 10:100376. https://doi.org/10.1016/j.jafr.2022.100376
42. Salman SY, Saritas S, Kara N, Aydinli F, Ay R (2015) Contact, repellency and ovicidal effects of four Lamiaceae plant essential oils against Tetranychus urticae Koch (Acari: Tetranychidae). J Essent Oil Bearing Plants 18(4):857–872. https://doi.org/10.1080/0972060X.2014.914856
43. SAS Institute (2001) User'sguide, version 8.02, TS level 2MO. SAS Institute Inc. Cary, North Carolina
44. Scatigna AV, Brandão CM, Colletta D, Teles G, Cavalcante RDM, Souza KSB, V. C., Simões AO (2019) Dizygostemon riparius (Plantaginaceae, Gratioleae), a new species from Maranhão, northeastern Brazil. Willdenowia 49(2):177–186. https://doi.org/10.3372/wi.49.49206
45. Seifi R, Moharramipour S, Ayyari M (2018) Acaricidal activity of differen fractions of Moringa peregrina on two spotted spider mite Tetranychus urticae (Acari: Tetranychidae). Ind Crops Prod 125:616–621. https://doi.org/10.1016/j.indcrop.2018.09.031
46. Verdeguer M, Sánchez-Moreiras AM, Araniti F (2020) Phytotoxic effects and mechanism of action of essential oils and terpenoids. Plants 9(11):1571. https://doi.org/10.3390/plants9111571
47. Walthall WK, Stark JD (1997) Comparison of two population-level ecotoxicological endpoints: The intrinsic (rm) and instantaneous (ri) rates of increase. Environ Toxicol Chemistry: Int J 16(5):1068–1073. https://doi.org/10.1002/etc.5620160529
48. Yıldırım E, Emsen B, Kordalı S (2013) Insecticidal effects of monoterpenes on Sitophilus zeamais Motschulsky (Coleoptera: Curculionidae). https://doi.org/10.5073/JABFQ.2013.086.027

Figures

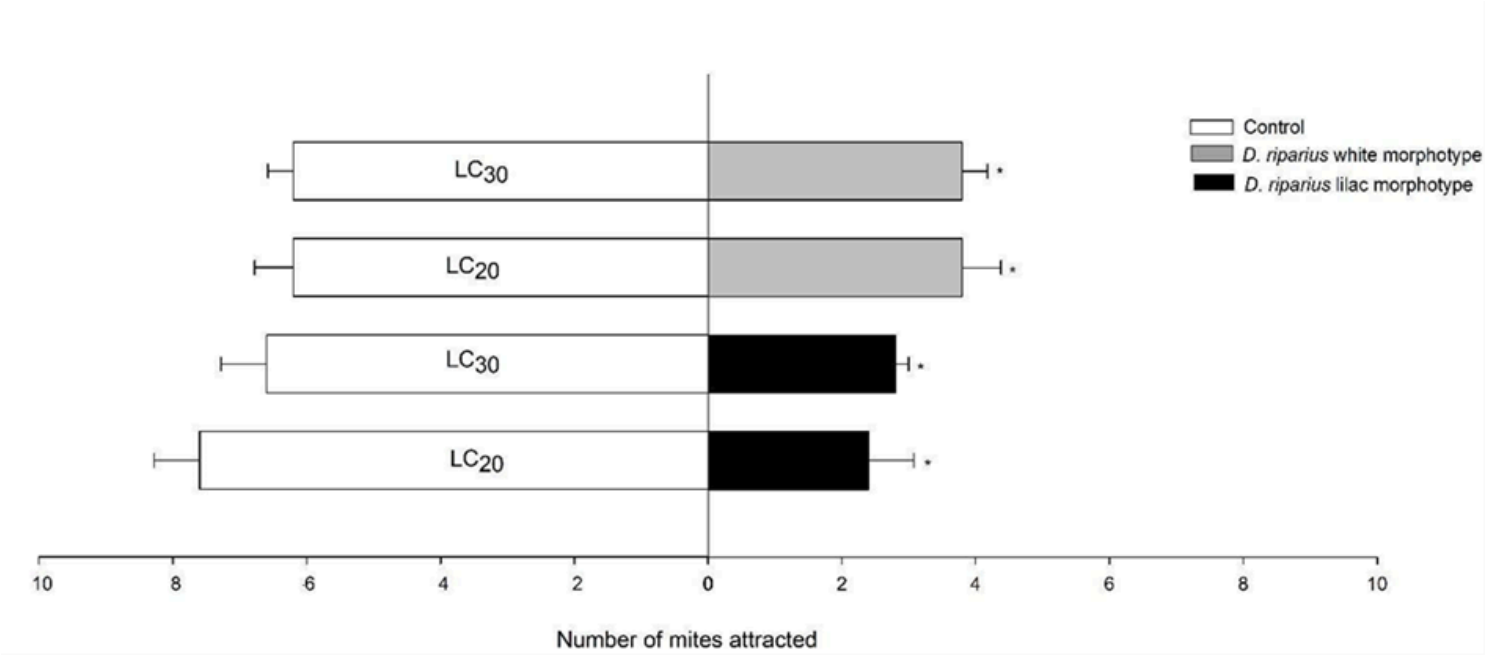


Figure 1

Repellent effect of EO*Dr*l and EODrw on *Tetranychus neocaledonicus*. *Significant by Chi-square test (P<0.05).

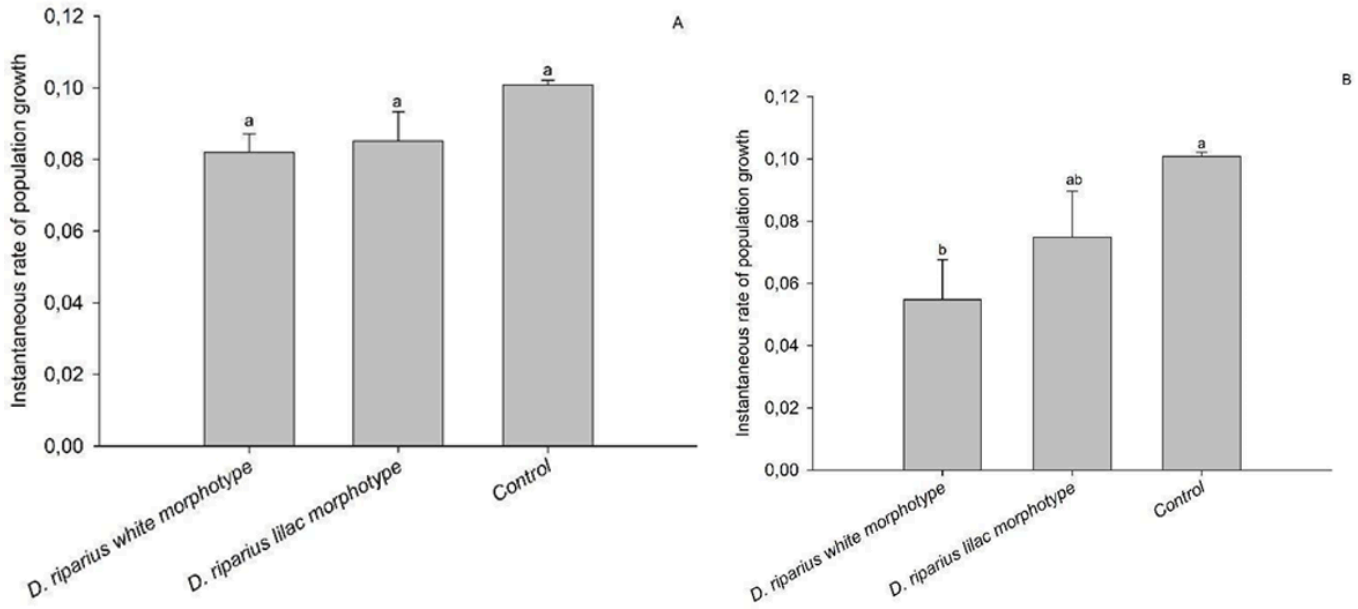


Figure 2

Instantaneous rate of population growth of *Tetranychus neocaledonicus* when exposed to EO*Dr*l and OEDrw. A) LC_{20}; B) LC_{30}. *Means followed by the same letter do not differ statistically by Tukey's test (P<0.05).