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Biologically Active Compounds in Essential Oil of *Tagetes minuta* and their Effects on Arthropod Pests

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Abstract

Synthetic pesticides have been extensively and often indiscriminately used for the management of insect and mite pests. Their prolonged and excessive use has led to insecticide resistance, environmental contamination, and adverse effects on non-target organisms and human health. These concerns have intensified the search for safer and sustainable botanical alternatives. *Tagetes minuta* (wild marigold) is a promising candidate, as it produces essential oils rich in bioactive compounds such as (Z)-β-ocimene and tagetone, which possess strong insecticidal, acaricidal, and repellent properties. The efficacy of *T. minuta* essential oil has been demonstrated against a wide range of pests, including stored-grain insects, field crop pests, and livestock ectoparasites. This review summarises the chemical composition, bioactivity, and pest management potential of *T. minuta* essential oil, highlighting its prospects as an eco-friendly alternative to conventional synthetic pesticides.

Keywords: Acaricidal Activity, Botanical Pesticides, Essential Oil Bioactive Compounds, Integrated Pest Management, Insecticidal Activity, *Tagetes minuta* Essential Oil

Agricultural crops are constantly exposed and/or threatened by insect and mite pests which affect their growth and quality. Domestic livestock, including cattle, horses, sheep, pigs, and poultry, serve as hosts to a diverse range of arthropod parasites, primarily ticks, mites, and various insect species[1]. To curb the above menace, farmers usually rely on quick management options, mainly synthetic chemicals[2]. Although synthetic pesticides are effective, their continuous overuse and misuse have led to the development of resistant pest species, pose a risk to human health and the environment and harm non-target organisms, ultimately threatening biodiversity[3]. Moreover, excessive dependence on synthetic pesticides has resulted in pesticide residues in food commodities exceeding Maximum Residue Limits (MRLs), raising concerns regarding food safety and international trade[4]. Repeated pesticide exposure has also been linked to chronic health issues such as endocrine disruption, neurotoxicity, and carcinogenic effects in

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humans[5]. The negative impacts resulting from the use of synthetic insecticides have highlighted the need for alternative pest management strategies[6].

Plants rich in bioactive compounds have been successfully employed to manage a wide range of agricultural pests as well as arthropod pests of veterinary importance[7,8]. The significance of botanical pesticides lies in their effectiveness, biodegradability, diverse mode of action, low toxicity and widespread availability of source materials[9]. Botanical pesticides are sourced from plants across various families, such as Myrtaceae, Lauraceae, Rutaceae, Lamiaceae, Asteraceae, Apiaceae, Cupressaceae, Poaceae, Zingiberaceae, Piperaceae, Liliaceae, Apocynaceae, Solanaceae, Caesalpinaceae, and Sapotaceae, and are commonly used in the form of plant extracts, essential oils, or both.

Tagetes minuta (Family: Asteraceae) is an annual perennial herb widely recognised as wild marigold. The common English name "wild marigold" is derived from its historical association with "Mary's gold"[10]. The plant's leaves are slightly glossy, green, and pinnately dissected into 4-6 pairs of pinnae[11,12]. *T. minuta* has been naturalised in diverse climatic conditions worldwide[13], and has a rich history of human use across various cultures and geographical regions. It has been utilised as food, in perfumes, medicines, and ornamentals, and plays an important role in ritual and socio-cultural practices[14]. The plant produces a diverse array of secondary metabolites throughout its growth and development[15]. Essential oils, also known as ethereal or volatile oils, represent some of the most significant compounds in the secondary metabolism of aromatic plant families such as Myrtaceae, Lauraceae, Lamiaceae, including Asteraceae[16,17]. The term "essential" denotes that these oils capture the distinctive scent or essence of the plant. The essential oil derived from *T. minuta* has been extensively researched both in-*vivo* and *in-vitro* for various bioactive properties. It has been documented to possess antimicrobial, insecticidal, nematicidal, acaricidal, and repellent actions against a broad spectrum of pests and pathogens affecting humans, livestock, and plants[18]. Beyond its agricultural relevance, *T. minuta* has been traditionally used in ethnomedicine for the treatment of gastrointestinal disorders, respiratory ailments, and skin infections, indicating its broad-spectrum biological activity[19]. The extensive traditional knowledge associated with this plant further supports its potential as a source of eco-friendly bioactive compounds for pest management and veterinary applications.

Although plant extracts, bioactive fractions, or isolated compounds are utilised for various applications, the general procedures for their production remain consistent, regardless of the intended biological assay[20]. Key steps in obtaining high-quality bioactive molecules include selecting an appropriate solvent, employing suitable extraction techniques, conducting phytochemical screening, applying fractionation methods, and utilising accurate identification techniques. Solvents frequently employed in the extraction of medicinal plants include polar solvents (such as water and alcohols), moderately polar solvents (such as acetone and dichloromethane), and non-polar solvents (such as n-hexane, ether, and chloroform).

ESSENTIAL OIL COMPOSITION OF *T. MINUTA*

A variety of secondary metabolites have been reported in *T. minuta* essential oil which include mainly acyclic monoterpenes, sesquiterne, flavonoids, and thiopenes. Major components of its essential oil are (Z)-β-ocimene, (Z)- and (E)-tagetone, dihydrotagetone and (Z)- and (E)-tagetenone[13,21,22] (Figure 1). Chemical composition of essential oils is influenced by various internal and external factors, such as plant species, geographic location, climate conditions, harvesting time, and extraction method[23-25]. Similarly, *T. minuta* essential oil also shows huge variation in chemical composition due to various anthropological and environmental factors such as method of harvesting, geographical location, harvesting stage, parts utilised and climatic conditions under which the plant develops[22,26,27]. The chemical composition of essential oil mostly varies with the geographical region with specific climatic conditions. Ramaroson-Raonizafinimanana *et al.*[28] reported significantly lower levels of (Z)-β-ocimene and dihydrotagetone *in T. minuta* essential oil in

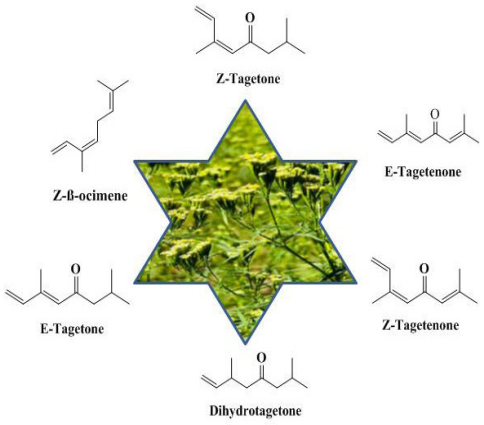


Figure 1. Major constituents of *T. minuta* essential oil.

Madagascar compared to the essential oils from Rwanda, Turkey, India, and France.

In addition to major constituents, minor components present in *T. minuta* essential oil may play a crucial role in enhancing overall biological activity through synergistic effects. Several studies have emphasised that even compounds present in trace amounts can significantly influence toxicity, repellency, and persistence against target pests[29,30]. Therefore, comprehensive chemical profiling rather than reliance on major constituents alone is essential for understanding its pesticidal potential.

ACTIVITY OF *TAGETES MINUTA* ESSENTIAL OIL AGAINST CROP ARTHROPOD PESTS

Owing to the above-mentioned composition of *T. minuta* essential oil, it is reported to have significant pharmacological properties[31]. More specifically, *T. minuta* essential oil containing acyclic monoterpenes, sesquiterpene generally called terpenoids, is reported to have significantly higher activity against agricultural pests like insects, mites, nematodes and weeds[27,31]. Among insect pest control, the stored product sector appears to be an ideal candidate for developing new EO-based alternative insect pest control strategies due to their characteristic of being volatile and susceptible to degradation. *T. minuta* is also reported to have significant activity against stored grain insect pests (Table 1). Krishna *et al.*[32] reported significant fumigation and contact activity of *T. minuta* essential oil against *Callosobruchus maculatus*, *Sitophilus oryzae* and *Tribolium castaneum*. The essential oil also has oviposition deterrent activity (81%) with significant reduction in egg hatchability (91%). Recently, Jayaram *et al.*[33] reported that *T. minuta* essential oil exhibited significant insecticidal activity, including fumigant, repellent, and oviposition-deterrent effects, against two pulse beetle species, namely *Callosobruchus maculatus* and *C. chinensis*. Keïta *et al.*[34] also reported insecticidal activity of *T. minuta* essential oil. Further, essential oil of *T. minuta* is also evaluated for its insecticidal action against other stored grain insect pests[35,36]. Moreover, *Plutella xylostella*, one of the most destructive field pests of the Brassicaceae family, is reported to be susceptible to *T. minuta* essential oil with antifeedant and repellent activity[37]. Shen *et al.*[38] reported that among three *Tagetes* species evaluated, intercropping with *Tagetes minuta* in apple orchards provided the most pronounced and consistent control of major lepidopteran insect pests. Like other essential oil, generally there is lack of studies evaluating the insecticidal activity of *T. minuta* against field insect pests. Other closely related species, *Tagetes patula,* have also been reported to have significant insecticidal properties[39-41].

USE OF *T. MINUTA* ESSENTIAL OIL AGAINST VETERINARY ECTOPARASITES

The continued reliance on synthetic or chemical acaricides as a principal control strategy for managing pests of veterinary and medical significance has become problematic due to their indiscriminate use, causing resistance development and environmental concerns[50-52]. As a result, research on plant-derived products has gained attention as sustainable alternatives[53,54]. The essential oil from *T. minuta* has shown promising acaricidal and repellent properties against a variety of ectoparasites and endoparasites in livestock[52]. *R. (Boophilus) microplus* is a major ectoparasite affecting

Table 1. Activity of *T. minuta* essential oil against arthropod pests

S. No.	Type of activity	Target pest (Stage)	Country	References
1	Fumigation	*Callosobruchus maculatus* (eggs and adults)	Guinea	[34]
2	Fumigation, repellent and oviposition deterrent activity	*C. maculatus, C. chinensis*(adults)	India	[33]
3	Antifeedant and repellent activity	*Plutella xylostella* (caterpillar)	India	[37]
4	Fumigation activity	*Brevicoryne brassicae*	Iran	[42]
5	Reproductive effect/ developmental abnormalities	*Acyrthosiphon pisum (Harris) (pea aphid), Myzus persicae (Sulzer) (peach-potato aphid), and Aulacorthum solani (Kaltenbach) (glasshouse and potato aphid)*	UK	[43]
6	Fumigation and contact toxicity	*C. maculatus* (Fabricius), *Sitophilus oryzae* (Linnaeus)and *Tribolium castaneum*	India	[32]
7	Toxicity, olfactory, repellent activity	*Ceratitis capitata, Triatoma infestans*	Argentina	[44]
8	Contact toxicity	*Alphitobius diaperinus*	Argentina	[45]
9	Larvicidal activity	*Anopheles gambiae*	Uganda	[46]
10	Larvicidal	*Aedes aegypti*	Germany	[47]
11	Repellent activity	*A. aegypti* and *C. quinquefasciatus* and *Anopheles stephensi*	Germany	[47]
12	Acaricidal activity	*Rhipicephalus microplus*	Brazil	[48]
13	Repellent activity	Blow Flies	USA	[49]

livestock and is responsible for substantial economic losses through both direct parasitism and transmission of pathogens such as *Babesia bovis*, *B. bigemina*, and *Anaplasma marginale*[55,56]. The efficacy of essential oil from *T. minuta* has been assessed in several studies reporting significant acaricidal activity of essential oil with over 95% efficacy at 20% concentration against *R. microplus*, *R. sanguineus*, *Amblyomma cajennense*, and *Argas miniatus*[10,57]. Andreotti *et al.*[48] documented the efficacy of essential oil from *T. minuta* to be 99.98% in pen trials against *R. microplus*, underscoring its potential as a natural acaricide. It exhibited significant efficacy in suppressing tick population growth by reducing egg production and eliminating surviving ticks on infested cattle, indicating strong acaricidal activity of the essential oil against larval, nymphal, and adult stages. The essential oil has also been reported to exhibit contact toxicity against *Alphitobius diaperinus* (Panzer) (Coleoptera: Tenebrionidae), a common pest in poultry farms[45].

Apart from acaricidal activity, essential oil from *T. minuta* exhibits repellent activity against blowflies and is used in livestock wound dressings[49]. Its biodegradability, low toxicity, and broad-spectrum activity make it a strong candidate for integration into

environmentally friendly, sustainable livestock pest management strategies.

MECHANISMS OF ACTION OF *TAGETES MINUTA* ESSENTIAL OIL

As the essential oil of *Tagetes minuta* is rich in monoterpenes and sesquiterpenes, it is expected to exert neurotoxic effects against arthropod pests. Such effects are commonly associated with inhibition of acetylcholinesterase (AChE), disruption of octopaminergic signalling, and modulation of γ-aminobutyric acid (GABA) gated chloride channels, ultimately resulting in paralysis and mortality in insects and mites[58,59]. In addition, lipophilic constituents such as tagetones and ocimenes are likely to penetrate the insect cuticle and interfere with cellular respiration and membrane integrity, leading to physiological dysfunction[60,61]. Owing to these multiple and overlapping modes of action, *T. minuta* essential oil is expected to reduce the risk of rapid resistance development when compared with single-site synthetic insecticides.

ROLE OF *T. MINUTA* ESSENTIAL OIL IN RESISTANCE MANAGEMENT

Resistance to conventional insecticides and acaricides has become a major constraint in pest management programs worldwide. Botanical pesticides, including essential oils, are increasingly recognised for their potential role in resistance management due to their complex chemical composition and synergistic interactions among constituents[62]. Studies have shown that essential oils can inhibit detoxification enzymes such as cytochrome P450 monooxygenases, esterases, and glutathione S-transferases, thereby enhancing susceptibility of resistant pest populations[63,64]. According to Arena *et al.*[45], co-application of cypermethrin with *Tagetes minuta* essential oil resulted in a significant increase in cypermethrin toxicity. In this context, *Tagetes minuta* essential oil may serve as a resistance-breaking or resistance-delaying agent when incorporated into Integrated Pest Management (IPM) strategies.

FORMULATION CHALLENGES AND TECHNOLOGICAL ADVANCEMENTS

Despite promising laboratory results, the practical application of *Tagetes minuta* essential oil, like other essential oils, is often limited by high volatility, susceptibility to oxidation, poor water solubility, and short residual activity under field conditions[62]. Recent advances in formulation technologies, including nanoemulsions, microencapsulation, liposomes, and polymer- based delivery systems, have shown considerable potential in overcoming these limitations by enhancing stability, enabling controlled release, and improving bioavailability of essential oils[59]. Such formulation strategies not only improve field efficacy but also allow dose reduction and minimise phytotoxic risks.

REGULATORY ASPECTS AND COMMERCIALISATION PROSPECTS

Although botanical pesticides are generally perceived as safer alternatives, their regulatory approval remains complex and varies across countries. In many regions, essential oil-based formulations face fewer regulatory barriers than synthetic pesticides; however, issues related to standardisation, shelf life, and large-scale production still limit commercialisation[65]. Strengthening regulatory frameworks, providing incentives for biopesticide development, and promoting public-private partnerships could accelerate the adoption of *T. minuta* essential oil-based products in both agricultural and veterinary sectors.

CONCLUSION

The growing limitations of synthetic pesticides such as resistance development, environmental contamination, and risks to human and animal health underscore the need for safer and sustainable pest

management alternatives. *T. minuta* (wild marigold) essential oil, rich in bioactive constituents including (Z)-β-ocimene and tagetone, has demonstrated broad-spectrum insecticidal, acaricidal, and repellent activity against stored-grain pests, field crop insects, and livestock ectoparasites. To enhance its effectiveness and promote large-scale adoption, future strategies should focus on the development of stable and standardised formulations (*e.g.*, nanoemulsions, microencapsulation, and controlled-release systems) to improve persistence and field efficacy. Optimisation of extraction methods, chemotype selection, and dose standardisation is essential to ensure consistent bioactivity. In addition, integration of *T. minuta* essential oil into Integrated Pest Management (IPM) programs either alone or in combination with other biopesticides and reduced-risk synthetic pesticides could enhance control efficiency while minimising resistance development. Comprehensive field validation, toxicological assessments, cost-benefit analyses, and regulatory support will further facilitate its commercialisation and acceptance among farmers and livestock producers.

CONFLICT OF INTEREST

Authors declare no competing interest.

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AUTHORS CONTRIBUTION

NP, PK, and NG: conceived and designed the study. NP, SS, and NG: performed the literature review and wrote the first draft. All authors read, edited and approved the final manuscript.