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Chemistry

Therapeutic potential of essential oils extracted from organic residues from the plant species *Citrus reticulata*

Potencialidades terapêuticas dos óleos essenciais extraídos de resíduos orgânicos oriundos da espécie vegetal *Citrus reticulata*

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ABSTRACT

The *Citrus* genus (Rutaceae) includes species with health benefits, such as *Citrus reticulata* (tangerine tree), originally from China and cultivated in tropical and subtropical regions, including Brazil. Its fruits contain bioactive compounds, including limonene, linalool, hesperidin, and α-terpinene, which are widely used in the pharmaceutical and food industries. The essential oil extracted from the peels exhibits antimicrobial, antioxidant, and anti-inflammatory properties, being effective against pathogens and in cellular protection. This study conducted a systematic review of 51 articles published between 2014 and 2025, highlighting the properties and biological activities of *C. reticulata* essential oil. Monoterpenes were the predominant compounds, with limonene as the main constituent, associated with therapeutic effects. The research demonstrated that the essential oil has activity against *Staphylococcus aureus*, *Escherichia coli*, and *Candida albicans*, as well as repellent, antitumor, and antimicrobial properties. The exploitation of tangerine residues for essential oil extraction provides economic and environmental benefits, reducing organic waste and promoting sustainable practices in the agro-food industry. These findings emphasize the potential of tangerine by-products in developing innovative solutions for health and the environment.

Keywords: Bioactivity; *Citrus*; Mandarine

RESUMO

O gênero *Citrus* (Rutaceae) inclui espécies com benefícios à saúde, como *Citrus reticulata* (tangerineira), originária da China e cultivada em regiões tropicais e subtropicais, como o Brasil. Seus frutos contêm compostos bioativos, incluindo limoneno, linalol, hisperidina e α-terpineno, amplamente utilizados nas indústrias farmacêutica e alimentícia. O óleo essencial extraído das cascas apresenta propriedades antimicrobianas, antioxidantes e anti-inflamatórias, sendo eficaz contra patógenos e na proteção celular. Este estudo realizou uma revisão sistemática de 51 artigos publicados entre 2014 e 2025, destacando as propriedades e atividades biológicas do óleo essencial de *C. reticulata.* Os monoterpenos foram os compostos predominantes, com o limoneno como principal constituinte, associado a efeitos terapêuticos. A pesquisa evidenciou que o óleo essencial possui ação contra *Staphylococcus aureus, Escherichia coli* e *Candida albicans,* além de propriedades repelente, antitumoral e antimicrobiana. A exploração dos resíduos da tangerina para extração do óleo essencial proporciona benefícios econômicos e ambientais, reduzindo o desperdício orgânico e promovendo práticas sustentáveis na indústria agroalimentar. Esses achados ressaltam o potencial dos subprodutos da tangerina no desenvolvimento de soluções inovadoras para a saúde e o meio ambiente.

Palavras-chave: Bioatividade; *Citrus*; Tangerina

1 INTRODUCTION

The genus *Citrus*, which belongs to the Rutaceae family, encompasses approximately 17 species found in various tropical and temperate regions around the world. Among them, *Citrus reticulata*, commonly known as mandarin, stands out due to its unique characteristics that attract researchers in search of essential oils. Originating from China, this fruit has adapted well to other locations, such as Brazil, where it has become quite popular (Welbert et al., 2024).

Mandarin trees typically have a small to medium stature, growing up to 10 meters in height. They are easily recognizable by their rounded shape and lush, glossy green leaves (Dezotti et al., 2017). The fruits are small, with a thin and easily peelable skin, exhibiting colors that range from orange to yellow. In addition to being juicy and sweet, they possess a slight tang, making them popular for fresh consumption as well as for juice production (Luna et al., 2022).

The mandarin is extensively studied due to its exceptional chemical composition and the potential therapeutic benefits of its bioactive compounds, making it a valuable resource for the pharmaceutical and food industries (Dezotti et al., 2017). Its aromatic properties and health benefits also contribute to its status as a highly appreciated fruit. Understanding its physical, chemical, and biological characteristics is crucial for exploring the therapeutic potential of organic waste in the extraction of essential oils (Ramos et al., 2024).

In addition to its nutritional value, mandarin plays an important role in the food economy, with its cultivation and trade driving job creation and income in various producing regions. For many families, it is a significant source of livelihood (Ningrum et al., 2024). Citrus fruits, particularly mandarins, hold cultural significance in various culinary traditions and festivities and can be consumed fresh or transformed into juices, sweets, and other delicacies, in addition to providing organic waste with bioactive potential (Moraes et al., 2019).

In terms of consumption, mandarins are favored in countries such as China, Brazil, India, Spain, and the United States, which lead global production. In Brazil, the states of São Paulo and Minas Gerais are the primary producers. The export of the fruit, both fresh and processed, caters to internal and external markets, underscoring its economic relevance (D'Angelis et al., 2024; Ningrum et al., 2024).

The main chemical compounds found in mandarins include limonene, which imparts its characteristic citrus aroma, and citral, renowned for its anti-inflammatory and antioxidant properties. Other compounds such as bergamotene, potentially therapeutic in dermatology, and linalool, which possesses antimicrobial and relaxation properties, are also present. These compounds are essential for the sensory and therapeutic properties of *C. reticulata*, being subjects of research and applications across various fields, from the food industry to integrative medicine (Ramos et al., 2024).

The essential oil extracted from mandarin waste exhibits antimicrobial, antioxidant, and anti-inflammatory properties, demonstrating efficacy in combating pathogens and protecting cells against damage caused by free radicals (Fong et al., 2020; Wedamulla et al., 2022). Furthermore, it is effective in pest control, helping to protect agricultural crops by repelling harmful insects (Ningrum et al., 2024).

For all these reasons, the essential oil of *C. reticulata* presents a promising alternative for aiding in the treatment of various health conditions. The objective of this study is to conduct a systematic review of the biological activities already described in the literature concerning the essential oil extracted from organic waste of mandarins, seeking to explore innovative applications in alternative medicine, preventive health, and therapeutic treatments.

2 METHODOLOGY

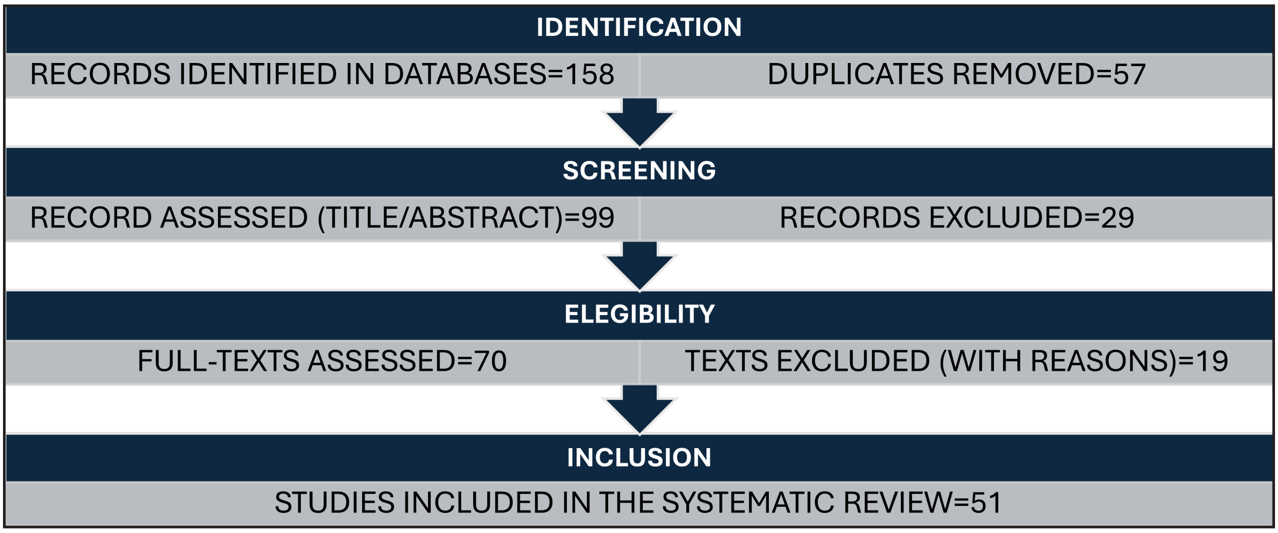
A systematic review was conducted to evaluate and synthesize studies published between 2014 and 2025, utilizing the following descriptors: "*Citrus reticulata*," "organic residues," "monoterpenes," "tangerine," and "bioactive compounds." All descriptors are available on the "Health Sciences Descriptors" platform by BIREME (DECs). The guiding question was: What are the properties and biological applications associated with the oil of *Citrus reticulata* and its bioactive compounds, considering the utilization of organic residues?

Inclusion criteria consisted of empirical studies and periodicals published from 2014 to 2025, while exclusion criteria involved the elimination of reviews, theses, dissertations, final course projects, duplicate studies and studies focused exclusively on extracts of *C. reticulata*. The flowchart follows PRISMA guidelines to report the study selection process in systematic reviews.

Figure 1 outlines the stages of this systematic review, organized into four main phases: Identification, Screening, Eligibility, and Inclusion. In the identification phase, 158 records were located in the databases and 57 duplicates were removed, leaving 99 unique records for analysis.

During the screening process, these records were assessed based on their titles and abstracts, resulting in the exclusion of 29 records that did not meet the predefined criteria. At the eligibility stage, the full texts of 70 records were thoroughly analyzed, leading to the exclusion of 19 of them for justified reasons. Ultimately, 51 studies met all inclusion criteria and were incorporated into the systematic review.

Figure 1 – Flowchart of the systematic review of the biological potentials of essential oil extracted from parts of the plant species *Citrus reticulata*

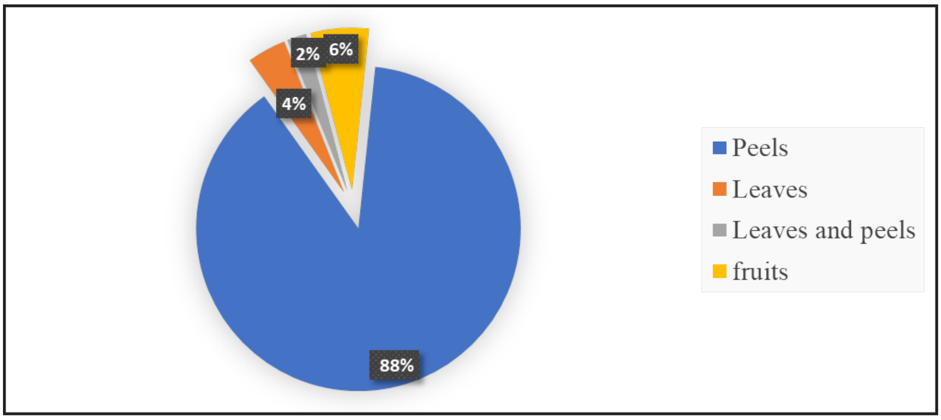


Source: Authorship (2025)

3 RESULTS AND DISCUSSION

Out of the 51 articles selected for the systematic review, the majority investigated the extraction of essential oil from the fruit peels, totaling 46 studies. Other research explored different parts of the plant or in combination, such as leaves (2 studies) and the whole fruit (3 studies), as shown in Figure 2. These data highlight the predominance of using peels as the primary source for extraction, reflecting their significance as a raw material rich in bioactive compounds, with fewer studies focused on other parts of the plant.

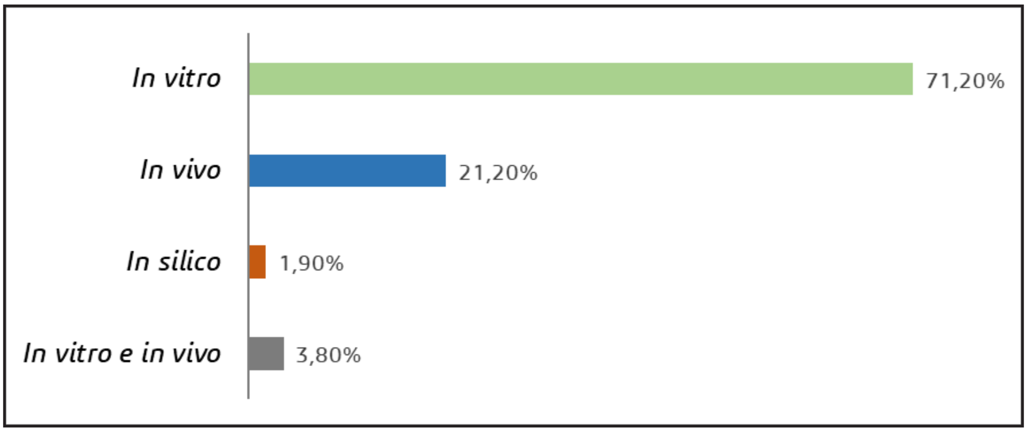
Figure 2 – Parts of the plant species *Citrus reticulata* for essential oil extraction



Source: Authorship (2025)

All analyzed articles were experimental studies classified according to the type of methodology used, namely “*in vivo*,” “*in vitro*,” and “*in silico*,” as depicted in Figure 3.

Figure 3 – Recording of the types of experimental studies analyzed with the species *Citrus reticulata* (%)



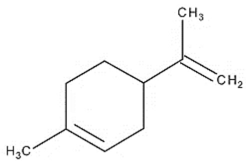
Source: Authorship (2025)

The peels of the fruit of C. reticulata are considered byproducts that are commonly discarded after fruit processing; however, they represent a valuable source of bioactive compounds that can be repurposed and serve as raw material for the development of other products, thereby promoting sustainability and fostering a circular economy (Lucarini et al., 2021).

Peels are regarded as the plant part most extensively explored for essential oil extraction compared to other parts such as leaves, seeds, and even the pulp of the fruit, as observed in the current research illustrated in Figure 2. This is attributed to their high concentration of volatile compounds, such as monoterpenes, which confer a high yield and a rich, desirable chemical composition for various industrial and therapeutic applications (Tao et al., 2009; Li et al., 2022; Welbert et al., 2024). Additionally, the reutilization of these residues can contribute to reducing the environmental impact caused by the disposal of organic waste, which can create breeding grounds for pathogens (Kipper et al., 2023).

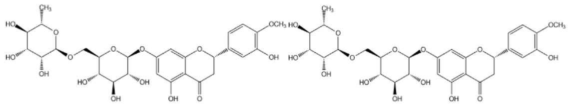
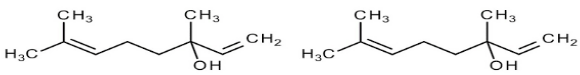
Among the 51 articles analyzed regarding the chemical composition of essential oils, it was found that in 50 of them, the predominant compound was limonene, as represented in Table 1, while other compounds are reported in Table 2. This predominance highlights the significance of this compound as a key constituent, especially in oils extracted from citrus fruits, reinforcing its role as a high-value compound for biological applications (Lin et al., 2015).

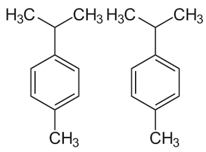
Table 1 – Compound limonene with its respective PubChem code, chemical structure, and studies indicating its major composition in citrus fruits

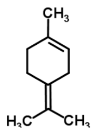
Majority Compound	Code Pubchem	2D Structure	Reference
Limonene	71423	 Source: Centro Nacional de Informações sobre Biotecnologia (2025)	Akhavan-Mahdavi et al. (2022), Al-Gendy et al. (2017), Aryal et al. (2017), Badawy et al. (2018), Bajaj et al. (2015), Bedini et al. (2021), Boudries et al. (2017), Brinza et al. (2024), Cao et al. (2024), Castro et al. (2018), Castro et al. (2020), Chandharakool et al. (2020), Chen et al. (2024), Čmiková et al. (2024), Gomes da Câmara et al. (2015), Denková-Kostová et al. (2021), Dias et al. (2020), Duletić-Laušević et al. (2019), Fahmy et al. (2022), Fouad & Gomes da Câmara (2017), Galindo et al. (2019), Geraci et al. (2024), Gowda et al. (2018), Goyal & Kaushal (2018), Hamdan et al. (2016), Haris et al. (2023), Heena et al. (2022), Ishfaq et al. (2021), Job et al. (2024), Kamal et al. (2013), Khaing et al. (2019), Khalaf et al. (2022), Mahdi et al. (2022), Martins et al. (2017), Mathias & Okajima (2024), Mite et al. (2022), Mya et al. (2024), Najem et al. (2024), Nguyen et al. (2024), Pardo et al. (2017), Song et al. (2020), Tao et al. (2014), Torshabi et al. (2023), Vieira et al. (2018), Wen et al. (2024), Yabalak et al. (2022), Yi et al. (2018), Zhang et al. (2022) and Zhu et al. (2021)

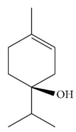
Source: Authorship (2025)

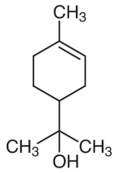
Table 2 – Relation of compounds described for citrus fruits with their respective PubChem code, chemical structure, and reference

<table>
<tr><th>Majority Compound</th><th>Code Pubchem</th><th>2D Structure</th><th>Reference</th></tr>
<tr><td>Hesperidin</td><td>10621</td><td>
Source: Centro Nacional de Informações sobre Biotecnologia (2025).</td><td>Tenorio-Domínguez (2016)</td></tr>
<tr><td>Linalool</td><td>4447</td><td>

Source: Centro Nacional de Informações sobre Biotecnologia (2025).</td><td>Tenorio-Domínguez (2016)</td></tr>
<tr><td>P-Cymene</td><td>7376</td><td>

Source: Centro Nacional de Informações sobre Biotecnologia (2025).</td><td>Nguyen et al. (2024)</td></tr>
<tr><td>α-Terpinene</td><td>3031</td><td>

Source: Centro Nacional de Informações sobre Biotecnologia (2025).</td><td>Nguyen et al. (2024)</td></tr>
<tr><td>Terpinen-4-ol</td><td>14187</td><td>

Source: Centro Nacional de Informações sobre Biotecnologia (2025).</td><td>Nguyen et al. (2024)</td></tr>
<tr><td>α-Terpineol</td><td>6580</td><td>

Source: Centro Nacional de Informações sobre Biotecnologia (2025).</td><td>Nguyen et al. (2024)</td></tr>
</table>

Source: Authorship (2025)

Limonene is a monoterpene that belongs to the class of terpenes, which are compounds formed from isoprene units. It is a cyclic compound with the molecular formula $C_{10}H_{16}$. Limonene exists in two optical isomer forms: D-limonene, which is dextrorotatory or (+) limonene, and L-limonene, which is levorotatory or (-) limonene. There is also a racemic mixture known as DL-limonene, which contains both isomers. These different forms of limonene exhibit distinct bioactivities, which can be attributed to variations in their spatial structures, resulting in differing affinities for active sites in biological organisms (Oliveira et al., 2022).

This secondary metabolite is considered one of the primary constituents of essential oils from citrus fruits such as oranges, lemons, bergamots, and tangerines, potentially accounting for up to 90% of the essential oil content. Its concentration is directly influenced by the method of extraction employed (Hacib et al., 2023).

Limonene has garnered increasing interest due to its widespread use in biological activities and potential pharmacological effects (Wen et al., 2024). Its simple chemical structure, combined with proven therapeutic properties, renders this constituent a multifaceted compound with extensive applicability in various health fields (Chen et al., 2024). Among its pharmacological effects, noteworthy properties include antimicrobial, anticancer, analgesic, anti-inflammatory, and antioxidant activities, as well as its capability to regulate the immune system, promote neuroprotection, and provide therapeutic benefits in metabolic and cardiovascular disorders (Santiago et al., 2012; Jing et al., 2013; Lorigooini et al., 2021).

In this context, this systematic review recorded fourteen biological actions derived from the essential oil extracted from various parts of the plant species *C. reticulata*, with the most frequently listed activities presented in Table 3 and additional activities detailed in Table 4.

Table 3 – Record of antibacterial and antioxidant activities derived from the essential oil of parts of the species *Citrus reticulata* identified in 51 studies

Biologic Activity	n	%	Reference
Antibacterial	21	30,0	Al-Gendy et al. (2017), Bajaj et al. (2015), Boudries et al. (2017), Čmikov á et al. (2024), Denková-Kostová et al. (2021), Dias et al. (2020), Gallegos Flores et al. (2019), Geraci et al. (2024), Hamdan et al. (2016), Haris et al. (2023), Heena et al. (2022), Job et al. (2024), Khaing et al. (2019), Khalaf et al. (2022), Li et al. (2022), Najem et al. (2024), Pardo et al. (2017), Song et al. (2020), Torshabi et al. (2023), Yabalak et al. (2022) and Zhang et al. (2022)
Antioxidant	19	27,1	Bhatia et al. (2024), Boudries et al. (2017), Denková-Kostová et al. (2021), Duletić-Laušević et al. (2019), Goyal & Kaushal (2018), Heena et al. (2022), Heena et al. (2024), Ishfaq et al. (2021), Job et al. (2024), Lawal et al. (2014), Li et al. (2022), Mathias & Okajima (2024), Mite et al. (2022), Najem et al. (2024), Oliveira (2020), Tenorio-Domínguez (2016), Torshabi et al. (2023) and Yi et al. (2018)

Source: Authorship (2025)

Table 4 – Recording of biological activities derived from essential oil of parts of the species *Citrus reticulata* identified in 51 studies

(To be continued...)

Biologic Activity	n	%	Reference
Insecticide, larvicide, ovicide, repellent, fumigant, and post-harvest protector	9	12,9	Badawy et al. (2018), Bedini et al. (2021), Cao et al. (2024), Gomes da Câmara et al. (2015), Everton *et al.* (2025), Fouad & Gomes da Câmara (2017), Haris et al. (2023), Mya et al. (2024) and Pure (2024)
Antifungal	6	8,6	Tao et al. (2014), (2018), Hamdan et al. (2016), Yabalak et al. (2022), Geraci et al. (2024), Khaing et al. (2019), Al-Gendy et al. (2017)
Antiparasitic	3	4,3	Aryal et al. (2017), Gowda et al. (2018) and Martins et al. (2017)
Anticancer	3	4,3	Al-Gendy et al. (2017), Castro et al. (2018) and Heena et al. (2024)
Antidepressant, mood regulator, and sedative	2	2,9	Chandharakool et al. (2020) and Nguyen et al. (2024)
Neurodegenerative and neuroprotective agent	1	1,4	Brinza et al. (2024)
Anti-inflammatory and analgesic	1	1,4	Wen et al. (2024)
Anti-atherogenic	1	1,4	Castro et al. (2020)

Table 4 – Recording of biological activities derived from essential oil of parts of the species *Citrus reticulata* identified in 51 studies

(Conclusion)

Biologic Activity	**n**	**%**	**Reference**
Antidiabetic	1	1,4	Duletić-Laušević et al. (2019)
Wound healing agent	1	1,4	Kamal et al. (2013)
Emulsion stabilizers	1	1,4	Mahdi et al. (2022)
Cosmetics	1	1,4	Heena et al. (2022)

Source: Authorship (2025)

The high incidence of antibacterial activity found (30%) in essential oil extracted from parts of *C. reticulata* can be attributed to the presence of bioactive compounds, such as terpenoids, flavonoids, and phenolics, which possess antimicrobial properties (Song et al., 2020). This activity may be specifically attributed to the previously mentioned compound, limonene (Gallegos-Flores et al., 2019). This compound exhibits properties that can alter the integrity of bacterial cell membranes, leading to cell death. Moreover, it has been shown to cause membrane disorganization, increase permeability, and result in the loss of essential cellular components, which may explain the antibacterial efficacy of essential oils derived from *C. reticulata* (Goulart et al., 2018).

A prominent activity is the antioxidant action, widely recognized in scientific studies (Bhatia et al., 2024; Boudries et al., 2017; Denkova-Kostova et al., 2021; Duletić-Laušević et al., 2019; Goyal & Kaushal, 2018; Heena et al., 2022, 2024; Ishfaq et al., 2021; Job et al., 2024; Lawal et al., 2014; Li et al., 2022; Mathias & Okajima, 2024; Mite et al., 2022; Najem et al., 2024; A. Oliveira, 2020; Tenorio-Domínguez, 2016; Torshabi et al., 2023; Yi et al., 2018). This activity is primarily attributed to the presence of bioactive compounds such as monoterpenes and flavonoids, which can neutralize free radicals, protecting cells from oxidative damage. D-limonene, the principal component of tangerine essential oil, is particularly noted for its antioxidant properties, which extend beyond the mere elimination of free radicals, potentially regulating antioxidant enzymes in the body and enhancing protection against oxidative stress (Mahmudiono et al., 2022).

Additionally, the antioxidant efficacy of *C. reticulata* essential oil is supported by numerous studies indicating health benefits, such as protection against chronic diseases, inflammation, and premature aging (Câmara et al., 2024). Research reveals that d-limonene not only participates in metal chelation and reduction of lipid peroxidation but also modulates cellular signaling pathways associated with the antioxidant response (Gutiérrez-del-Río et al., 2021). Thus, tangerine essential oil emerges as a valuable source of bioactive compounds and a promising alternative for dietary supplementation and potential therapeutic interventions aimed at promoting health.

In this study, it was demonstrated that out of the 51 articles analyzed, 9 showed the multifaceted biological effects of these oils, including insecticidal, larvicidal, ovicidal, repellent, fumigant, and post-harvest protective actions. These actions are often attributed to the presence of volatile compounds such as d-limonene, hesperidin, and linalool, known for their bioactive properties across various organisms. The research suggests that these compounds might inhibit essential enzymatic systems in insects, resulting in mortality or repulsion of these organisms (Koul et al., 2008; Qasim et al., 2024).

Studies have demonstrated that volatile compounds present in this oil, such as d-limonene and other monoterpenes, have the capacity to inhibit the growth of several pathogenic fungal species, including *Candida* and *Aspergillus* (A. Oliveira, 2020), corroborating the results of the present review. This antifungal activity can be attributed to the interaction of these compounds with the fungal cell membrane, resulting in structural damage and compromising cellular integrity (Azevedo, 2020). Furthermore, the application of essential oils such as that from *C. reticulata* offers a promising and less toxic alternative compared to traditional antifungals, especially in a context of increasing drug resistance (Azevedo, 2020). Thus, tangerine essential oil not only exhibits significant efficacy against fungal infections but also represents a sustainable and innovative approach to the treatment of mycotic diseases.

Furthermore, new studies have also shown that essential oils from *Citrus reticulata* can extend the shelf life of agricultural products by acting as protective agents against post-harvest pests and diseases. As identified by Pure (2024), the fumigant activity of the essential oil allows for an effective means of inhibiting the development of pests in grains and fruits, providing a natural alternative to synthetic pesticides. The use of such natural products not only represents a sustainable approach to integrated pest management but also reduces risks associated with chemical toxicity (Ceylan & Ünlü, 2023).

This study also described other biological activities of *C. reticulata* essential oil, such as antidepressant and mood-regulating properties that aid mental health, in addition to exhibiting sedative activities that may be beneficial in the treatment of sleep disorders (Kumar et al., 2020). Its antiparasitic and antifungal properties broaden its application in phytotherapy, while its anticancer and neuroprotective actions suggest significant potential in the prevention of chronic and neurodegenerative diseases (Zhang et al., 2019).

Additionally, the anti-inflammatory and analgesic activity, coupled with antiatherogenic and antidiabetic effects, positions the essential oil as a promising candidate in integrated treatment regimens for inflammatory and metabolic conditions. The wound healing and emulsion-stabilizing properties also make *Citrus reticulata* essential oil a valuable component in the cosmetic industry, benefiting skin health and promoting tissue regeneration (Martins et al., 2021). Its versatility and effectiveness across various applications make tangerine's essential oil an important resource for future research and the development of new therapeutic and cosmetic products, reinforcing the need for more in-depth studies to fully explore its biological potentialities and safety for use. Thus, this essential oil not only illustrates the richness of plant biodiversity but also offers promising avenues for innovations in health and well-being.

Table 5 below presents the 33 identified pathogens that are potentially inhibited, repelled, and/or eliminated in the presence of the essential oil extracted from parts of the plant species *Citrus reticulata*, as detected in the 27 journals involved in the present study.

Table 5 – List of identified pathogens that are inhibited and/or eliminated in the presence of the essential oil from *Citrus reticulata*

Patógeno	n	%	Autor e ano
Staphylococcus aureus	6	19,4	Geraci et al. (2024), Hamdan et al. (2016), Heena et al. (2024), Khaing et al. (2019), Song et al. (2020) and Yabalak et al. (2022)
Escherichia coli	6	19,4	Al-Gendy et al. (2017), Geraci et al. (2024), Heena et al. (2022), Khaing et al. (2019), Najem et al. (2024) and Yabalak et al. (2022)
Candida albicans	5	16,1	Al-Gendy et al. (2017), Geraci et al. (2024), Hamdan et al. (2016), Khaing et al. (2019) and Yabalak et al. (2022)
Aedes aegypti *Aedes albopictus*	3	9,7	Cao et al. (2024), Haris et al. (2023) and Mya et al. (2024)
Sitophilus zeamais	2	6,5	Fouad & Gomes da Câmara (2017) and Pure (2024)
Fusobacterium nucleatum	1	3,2	Pardo et al. (2017)
Schistosoma mansoni	1	3,2	Martins et al. (2017)
Tribolium castaneum	1	3,2	Pure (2024)
Samonella sp	1	3,2	Heena et al. (2022)
Leishmania	1	3,2	Everton *et al.* (2025)
Penicillium italicum *Penicillium digitatum*	1	3,2	Tao et al. (2014)
Plutella xylostella	1	3,2	Gomes da Câmara et al. (2015)
Culex pipiens	1	3,2	Badawy et al. (2018)
Meloidogyne incognita	1	3,2	Gowda et al. (2018)

Source: Authorship (2025)

A promising outlook is evident regarding the potential of this oil in inhibiting pathogens relevant to human health, as it has shown efficacy against 14 pathogens, demonstrating the versatility of the bioactive compounds present in the oil. This suggests that the mechanisms of action may vary based on the chemical structure of different microorganisms. This diversity of action can be attributed to the rich and complex composition of the essential oil, which includes compounds such as *limonene*, *linalool*, and other terpenes, all of which possess well-documented antimicrobial properties (Al-Gendy et al., 2017; Boudries et al., 2017; Čmiková et al., 2024; Denkova-Kostova et al., 2021; Geraci et al., 2024; Hamdan et al., 2016; Heena et al., 2022, 2024; Job et al., 2024; Khaing et al., 2019; Khalaf et al., 2022; Lawal et al., 2014; Li et al., 2022; Najem et al., 2024; A. Oliveira, 2020; Pardo et al., 2017; Song et al., 2020; Torshabi et al., 2023; Yabalak et al., 2022; Zhang et al., 2022). Particularly noteworthy is the identification of six articles documenting the efficacy of *C. reticulata* essential oil against *Staphylococcus aureus*, a pathogen recognized for its resistance to multiple drugs and associated with hospital-acquired infections (Michelin et al., 2015). The oil's ability to inhibit this microorganism underscores its potential as a therapeutic alternative or adjunct in managing cutaneous and systemic infections. Moreover, the use of this oil as an antimicrobial control agent raises important issues regarding the reduction of dependency on traditional antibiotics, enabling a more integrated and sustainable approach in combating resistant infections (Santos et al., 2016).

Additionally, six articles documenting activity against *Escherichia coli*, an intestinal pathogen frequently linked to diarrheal outbreaks and urinary tract infections, further reinforce the relevance of this oil in the context of public health (Pakbin et al., 2021). The antimicrobial properties of the oil represent a valuable contribution to research in nutrition and phytotherapy, suggesting new possibilities for the development of alternative products that combine safety and efficacy in combating infections by common and critical pathogens.

An important opportunistic fungal pathogen identified in the review was *Candida albicans*, which has garnered increasing interest in the scientific literature, particularly due to the resistance of *Candida* strains to conventional antifungals. Six publications have reported on the inhibitory efficacy of the oil under study against this fungus (Al-Gendy et al., 2017; Geraci et al., 2024; Hamdan et al., 2016; Khaing et al., 2019; Yabalak et al., 2022). This indicates that volatile compounds present in this oil, such as *limonene* and *myrcene*, play a crucial role in antifungal activity. In a study by Weng et al. (2024), *C. reticulata* essential oil demonstrated a significant inhibitory effect on the proliferation of *Candida albicans*, with minimum inhibitory concentration (MIC) values showing promise for the development of new therapeutic agents. Moreover, research by Borges et al. (2021) indicated that the application of this oil at various concentrations not only reduced the cellular viability of *Candida albicans* but also exhibited a synergistic effect when combined with traditional antifungals.

Research on *Citrus reticulata* oil is relevant not only for its antifungal activity but also for its potential use in alternative treatments and the formulation of natural products, which may present a lower risk of resistance development by pathogens. According to Sultana et al. (2012), the extraction and characterization of bioactive compounds present in the essential oil, along with the investigation of their interaction with the cell membrane of *Candida albicans*, can open new avenues for understanding mechanisms of action and developing innovative drugs (Denkova-Kostova et al., 2021). Thus, the promising results obtained with *Citrus reticulata* oil underscore the importance of deepening investigations and validating the therapeutic potential of essential oils in combating *Candida albicans*.

Other microorganisms identified as vectors of tropical diseases include the mosquitoes *Aedes aegypti* and *Aedes albopictus*. These insects, adaptable to various urban and rural environments, pose a significant challenge to global public health in controlling arboviruses such as dengue, Zika, and chikungunya (Laporta et al., 2023). The increasing resistance to insecticides and the lack of effective control strategies further exacerbate this situation, making it urgent to foster collaborative efforts among communities, governments, and health organizations to mitigate the impacts of these diseases and protect public health (Serejo et al., 2021).

It is also important to note that other organisms identified, including *Sitophilus zeamais*, *Fusobacterium nucleatum*, *Schistosoma mansoni*, *Tribolium castaneum*, *Salmonella sp.*, *Leishmania*, *Penicillium italicum*, *Penicillium digitatum*, *Plutella xylostella*, *Culex pipiens* and *Meloidogyne incognita* have been subjects of study concerning their interactions with *Citrus reticulata* essential oil. This oil, known for its antimicrobial and insecticidal properties, has demonstrated significant inhibitory activity against various bacterial strains, fungi, parasites, and agricultural pests. The efficacy of the essential oil has been observed in reducing the growth of fungi such as *Penicillium*, which affect fruit preservation, as well as in inhibiting pathogenic bacteria like *Salmonella*, thus contributing to food safety. Furthermore, its insecticidal potential has shown promising effectiveness in controlling pests such as *Plutella xylostella* and *Sitophilus zeamais*, along with repellent effects on mosquitoes like *Culex pipiens*. Its application represents a sustainable and practical alternative in the fight against pathogenic organisms and pests, standing out in the quest for methods that minimize the use of synthetic chemicals.

In addition to their antimicrobial and insecticidal properties, essential oils are biocompatible and considered a safer alternative compared to synthetic pesticides, contributing to sustainability in agricultural and health practices (Amaiach et al., 2024). The use of essential oils may be a valuable approach in integrated pest management (IPM) strategies, as it promotes the reduction of chemical product usage and consequently minimizes environmental impacts.

4 FINAL CONSIDERATIONS

The research highlighted the high therapeutic potential of *C. reticulata* essential oil, particularly when extracted from organic waste, such as tangerine peels. Its chemical composition, rich in monoterpenes like limonene, exhibits antimicrobial, antioxidant and anti-inflammatory properties. The study also emphasizes the environmental importance of repurposing these waste materials, promoting sustainability practices and circular economy.

In addition to its biological properties, such as antimicrobial activity against resistant pathogens and antioxidant actions, the essential oil shows promise for applications in the pharmaceutical, food and agricultural industries. Thus, its sustainable exploitation not only contributes to the reduction of organic waste but also fosters ecological innovations that benefit health and the environment, underscoring the essential oil derived from the *C. reticulata* plant species as a significant multifunctional resource.

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