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UNCOVERING THE ANTIOXIDANT AND ANTIMICROBIAL POTENTIAL OF NON-CONVENTIONAL EDIBLE PLANTS COMMONLY FOUND IN BRAZIL: A REVIEW

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ABSTRACT:
Brazil, one of the most megadiverse countries, is home to numerous non-conventional edible plants (NCEP), whose functional applications are underexplored. This review highlighted the antimicrobial and antioxidant properties of *Schinus terebinthifolius* Raddi (pink pepper), *Pereskia aculeata* Miller (*ora-pro-nóbis*), and *Tropaeolum majus* L. (nasturtium). A literature review was conducted to identify key findings, bioactive compounds, extraction methods, gaps and challenges that affect the consistency of the results. The literature review covered studies published between 2012 and 2025, identified through keyword searches in scientific databases. Studies focusing on essential oils, undergraduate theses, dissertations, doctoral theses, and conference abstracts were excluded. After applying these criteria, a total of 45 studies were included in the final analysis. While antioxidant activity is consistently supported across various assays, antimicrobial evidence for P. *aculeata* and T. *majus* is often limited or inconclusive, despite frequent citations in the literature. There is a clear need to detailed compound profiling to establish correlations between biological activity and the specific metabolites responsible for such effects. Despite limitations, promising results support the potential of these plants for future applications in the food and pharmaceutical industries. By consolidating current findings and highlighting research limitations, this review provides a valuable resource to support and guide future investigations into the functional applications and bioactive constituents of NCEP.

Keywords: Bioactivity, Biodiversity, Unconventional plants, Underutilized plants.

REVELANDO O POTENCIAL ANTIOXIDANTE E ANTIMICROBIANO DE PLANTAS ALIMENTÍCIAS NÃO CONVENCIONAIS COMUMENTE ENCONTRADAS NO BRASIL: UMA REVISÃO

RESUMO:
O Brasil, reconhecido como um dos países mais megadiversos do mundo, abriga uma grande variedade de plantas alimentícias não convencionais (PANC), cujas aplicações funcionais ainda são pouco exploradas. Nesse contexto, esta revisão destacou as propriedades antimicrobianas e antioxidantes de *Schinus terebinthifolius* Raddi (pimenta-rosa), *Pereskia aculeata* Miller (*ora-pro-nóbis*) e *Tropaeolum majus* L. (capuchinha). Para isso, foi realizada uma revisão da literatura para identificar os principais resultados, compostos bioativos, métodos de extração, além de lacunas e desafios que impactam a consistência dos resultados. A revisão abrangeu estudos publicados entre 2012 e 2025, identificados por meio de buscas por palavras-chave em bases de dados científicas validadas. Além disso, foram excluídos estudos focados em óleos essenciais, trabalhos de conclusão de curso, dissertações, teses de doutorado e resumos de congressos. Após a aplicação desses critérios, um total de 45 estudos foi incluído na análise final. Enquanto a atividade antioxidante é consistentemente demonstrada em diferentes ensaios, as evidências sobre a atividade antimicrobiana de P. *aculeata* e T. *majus* são frequentemente limitadas ou inconclusivas. Esse cenário evidencia a necessidade de investigações mais aprofundadas, especialmente voltadas à caracterização detalhada dos compostos para uma melhor compressão da relação entre os metabólitos presentes e suas

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atividades biológicas. Mesmo diante dessas limitações, os resultados encontrados reforçam o potencial dessas plantas para aplicações futuras, especialmente nas indústrias alimentícia e farmacêutica. Ao reunir e discutir os dados disponíveis, esta revisão busca contribuir como base para novas pesquisas, incentivando o avanço do conhecimento sobre as propriedades funcionais e os compostos bioativos das PANC.

Palavras-chave: Bioatividade, Biodiversidade, Plantas não convencionais, Plantas subutilizadas.

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INTRODUCTION

Brazil ranks among the top ten most megadiverse countries and is recognized as the country with the highest number of plant species globally (Ranzato Filardi et al., 2018). This rich biodiversity is crucial not only for ecological balance but also for its potential contributions to medicine, agriculture, and industry. Among the extensive range of plant species present in Brazil are the non-conventional edible plants (NCEP) mentioned to in portuguese as *Plantas Alimentícias Não Convencionais* (PANC). NCEP refer to plants or parts of plants, that are not part of the regular diet of the general population. Those plants have restricted usage, and are characterized by limited geographic distribution, lacking integration into production chains like conventional vegetables (Tuler et al., 2019). Although less widespread in global contexts, they hold value for their unique nutritional benefits and cultural significance, supporting local livelihoods through their consumption (Singh et al., 2023).

NCEP include various herbs, greens, and fruits, are integral to the diets of many Brazilian communities. They offer a diverse range of flavors and nutrients that are often not available in conventional crops (Carvalho et al., 2023; Cruz et al., 2021; Haminiuk et al., 2011). Beyond their dietary uses, NCEP hold significant potential, as they support sustainable agricultural practices, and promotes the preservation of traditional knowledge (Moura et al., 2021). In addition, population growth projections are driving demand for alternative food sources, pushing agriculture toward monocultures, deforestation, increased greenhouse gas emissions, and higher water consumption, all of which contribute to climate change and biodiversity loss. In response, NCEP offer a sustainable solution, especially for improving nutrition in developing countries. Though underutilized, these nutrient-rich plants have the potential to support biodiversity and enhance global food sustainability, contributing to a more eco-friendly and resilient food chain (Milião et al., 2022).

Several properties have garnered significant attention for NCEP, particularly their potential health benefits. Recent studies have revealed that many representatives of NCEP are rich in bioactive compounds, including antioxidants and antimicrobial agents. These compounds not only enhance health outcomes but also offer promising applications in the food, clinical, pharmaceutical, and cosmetic (Carvalho et al., 2023; Porto et al., 2022; Chilanti et al., 2025).

Oxidation is a critical chemical reaction that leads to deterioration of food, reducing consumer acceptability by producing off-flavor compounds, depleting essential nutrients, and creating toxic compounds (Choe & Min, 2009). For this reaction to occur, free radicals play a central role, as they are molecular species with an unpaired electron, which make them highly unstable and reactive, seeking to stability by capturing electrons from other substances (Chib et al., 2020). In this context, antioxidants are essential in mitigating these oxidative processes, ensuring food quality and human health. Antioxidants work primarily by donating electrons or hydrogen atoms to stabilize free radicals. This action neutralizes the free radicals and prevents them from reacting with other molecules in the food, such as lipids (Chib et al., 2020; Choe & Min, 2009). Synthetic antioxidants, including Butylated Hydroxyanisole (BHA), Butylated Hydroxytoluene (BHT), Propyl Gallate (PG), and Tert-Butylhydroquinone (TBHQ) are commonly used in food preservation due to their effectiveness and low cost (Shahidi 2000).

Contamination caused by microbial growth is another important process that reduces shelf life and impacts food safety and quality. The proliferation of pathogenic microorganisms leads to infections when the food is consumed. Moreover, microbial contamination often results in the formation of toxins, which are also related to foodborne illnesses (Karanth et al., 2023; Pakdel et al., 2023). In addition to these health concerns, microbial growth can significantly alter the flavor of food. As microorganisms metabolize various food components, they generate byproducts that can create off-flavors and change the overall taste profile (Karanth et al., 2023). Thus, the impact of microbial growth extends beyond mere spoilage, affecting both safety and the overall eating experience. Consequently, antimicrobial agents are essential in preserving food quality and safety. Currently, various synthetic antimicrobials are approved by regulatory agencies and widely used as food preservatives (Mahmud & Khan, 2018).

However, consumers have long been seeking for natural ingredients in foods. This movement is supported by a demand for clean-label foods that often exclude synthetic preservatives and artificial flavoring (Chauhan & Rao, 2024). As a result, the food industry is increasingly moving towards

replacing synthetic antioxidants and antimicrobial agents with natural alternatives (Chauhan & Rao, 2024; Lourenço et al., 2019; Mahmud & Khan, 2018). The biological activity of several plant-derived substance has been proven effective (Pinto et al., 2023). Many research indicates that NCEP are particularly rich in phytochemicals, offering strong antioxidant and antimicrobial properties, making them promising sources of natural additives (Carvalho et al., 2023; Milião et al., 2022; Oliveira et al., 2020).

The primary aim of this review is to evaluate and synthesize existing research on the antioxidant and antimicrobial activities of three Brazilian non-conventional plants: *Schinus terebinthifolius* Raddi (pink pepper), *Pereskia aculeata* Miller (*ora-pro-nóbis*), and *Tropaeolum majus* (nasturtium). These species were selected for this review because they are edible plant species distributed in tropical regions of South America. These plants have attracted scientific and economic interest due to their richness in bioactive secondary metabolites. In addition, their use in traditional food systems and their potential applications in functional foods and natural health products highlight their relevance for bioprospecting and sustainable use of regional biodiversity. However, despite the growing interest in plant-derived natural additives, antioxidants, and antimicrobials, the available information regarding these activities remains fragmented and lacks a comprehensive synthesis, while detailed reviews addressing these properties specifically in the context of Brazilian NCEP are still scarce. Therefore, this review seeks to compile the available data on the bioactive properties of these plants, highlighting their potential for food and health applications. Additionally, this review addresses a significant gap in the literature by providing a comprehensive examination of these specific bioactivities in lesser-known Brazilian plants. By filling this gap, the review aims to offer valuable insights into the bioactive potential of these underexplored resources and to guide future research in this area.

METHODOLOGY

The review was conducted through a systematic search of research results on Brazilian NCEP, drawing from recognized scientific databases such as Scopus, Web of Science, PubMed, and Google Scholar, with the literature search performed between January and March 2025. A preliminary data survey was conducted to identify Brazilian NCEP most frequently investigated in recent studies. After the initial review of bibliographic references, it was decided to focus on *Schinus terebinthifolius* Raddi (pink pepper), *Pereskia aculeata* Miller (*ora-pro-nóbis*), and *Tropaeolum majus* L. (nasturtium). The following keywords were used: *non-conventional edible plants, Brazilian non-conventional edible plants, pink pepper, ora-pro-nóbis, nasturtium, Schinus terebinthifolius* Raddi, *Pereskia aculeata* Miller, *Tropaeolum majus*, *antioxidant activity, antimicrobial activity, bioactive compounds, phytochemical profile*. In addition, the search terms were combined using the Boolean operators AND and OR to refine the search strategy. Studies published in the past years that addressed the characteristics, antimicrobial activity, and antioxidant properties of extracts from the selected plants were included in this review. Articles focusing on essential oils, undergraduate thesis projects, dissertations, theses, and abstracts from conference proceedings were excluded; consequently, a total of 45 studies were incorporated into this work (Figure 1). Furthermore, the collected data regarding antioxidant and antimicrobial activity were organized into tables (Table 1 – 6), which detail the results and specifics of each analyzed study.

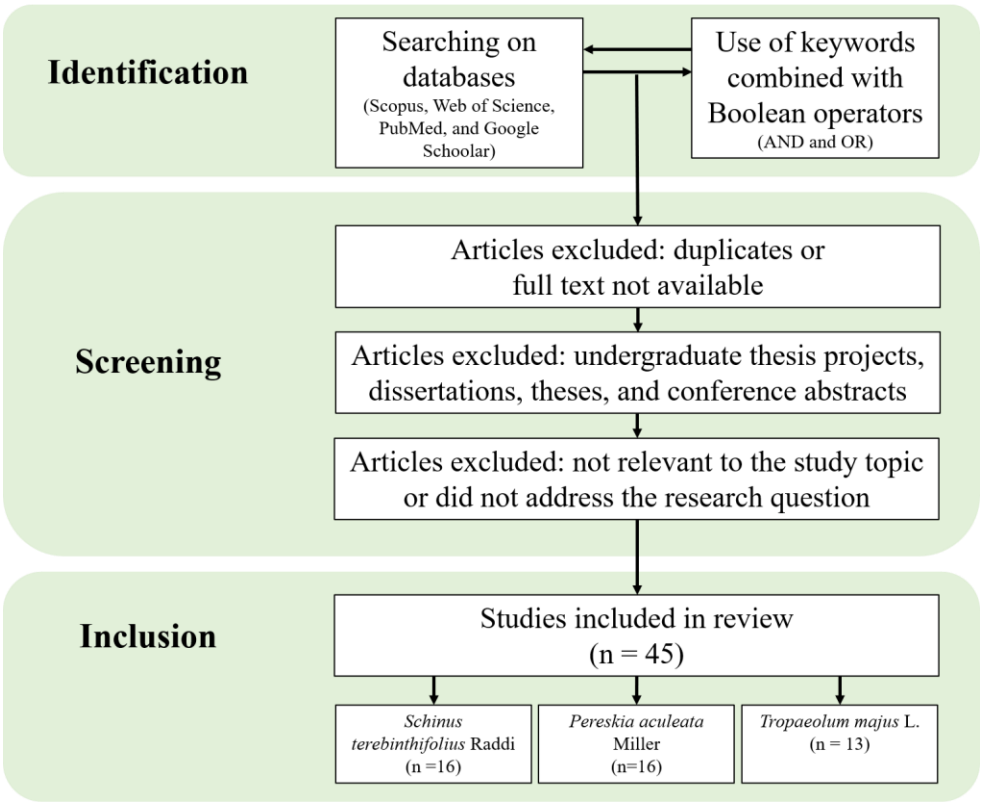

Figure 1. Flow diagram of the systematic review, detailing the steps of the process.

***Schinus terebinthifolius* Raddi**

Schinus terebinthifolius Raddi, commonly known in Brazil as pink pepper or *"aroeira"*, is an indigenous tree native to the Brazilian coast. It is predominantly harvested from native forests by local communities and is not extensively cultivated through agricultural practices. Pink pepper has been commercialized in the international market, being identified globally by numerous names, including "Brazilian pepper", "*aroeira-vermelha*", "*aroeira-pimenteira*", "*aroeira-mansa*", "*aroeira-da-praia*", "*aroeira-do-sertão*", "*aroeira-do-Paraná*", "*aroeira-de-Minas*", "araguaraiba", "corneiba", mastic tree, chichita, Christmas berry, Florida holly, poivre rose, and false pepper (Locali-Pereira et al., 2023).

The pink pepper tree is characterized by its broad canopy and rapid growth, reaching heights of up to 12 meters. Its short trunk, approximately 1 meter in diameter, supports branches that bear clusters of ivory-white, five-petaled flowers (Figure 2). These blooms are quickly followed by compact clusters of globular, resinous fruits, each containing a single seed. Initially green, glossy, and juicy, the fruits turn bright red upon ripening and may remain on the tree for several weeks after drying (Morton, 1978).

Although pink pepper is commonly used as a condiment in the preparation of meals, its phytotherapeutic potential is explored by local traditional communities for a long time. Thus, many studies have scientifically validated its therapeutic uses and discovered a range of bioactive properties. These include anti-inflammatory (Rosas et al., 2019), antimicrobial (Oliveira et al., 2024; Ferreira et al., 2022) and antioxidant activities (Oliveira et al., 2020; Oliveira et al., 2024), as well as the photoprotective activity (Oliveira et al., 2020), potential to protect fetus against ZIKV-related malformations (Oliveira et al., 2020) and promote wound healing (Nunes et al., 2022).

Figure 2. *Schinus terebinthifolius* Raddi. (A) Bush. (B) Fruits.

Antimicrobial activity of pink pepper extracts

Several studies have evaluated the antimicrobial properties of extracts derived from different parts of *Schinus terebinthifolius* Raddi, including its leaves, fruits, bark and flowers. The results demonstrate that the antimicrobial action is influenced by differences in methodology, extracting solvent chemistry, the specific plant part analyzed, and the particular characteristics of the microorganisms tested. However, despite this variability, these studies consistently report significant inhibitory effects against a broad spectrum of bacteria and fungi (Table 1).

The antimicrobial activity of ethanolic extracts from pink pepper leaves, assessed using broth microdilution test, has demonstrated significant antibacterial effects against *Escherichia coli*. Minimum Inhibitory Concentration (MIC) of 78 µg/mL (Silva et al., 2018), 250 µg/mL, and 750 µg/mL (Uliana et al., 2016) were observed. It was demonstrated that more effective MICs were achieved for extracts obtained through maceration extraction compared to ultrasonic extraction. This suggests that maceration, a widely used extraction method, better preserves the bioactive compounds responsible for inhibiting *E. coli* growth. In contrast, the higher MICs indicate that ultrasonic extraction may affect the stability or bioavailability of certain active components that work against *E. coli*.

On the other hand, ethanol extracts from leaves prepared through maceration failed to exhibit antimicrobial activity against *E. coli* when evaluated using the agar well diffusion method (Ghandour et al., 2021). This discrepancy between the two methods (broth microdilution and agar well diffusion) raises important considerations regarding the choice of method for assessing an extract's antimicrobial activity. One possible explanation for the reduced performance of the agar well diffusion method may be related to the differences in chemical stability of antimicrobial agents.

Table 1. Antimicrobial studies of pink pepper extracts in the last years (2012-2024)

Plant part	Solvent (Extraction Method)	Microorganism	Results	Antimicrobial Assay	Reference
Leaves	**Protein extract**	*Escherichia coli* (-) WDCM 00013	MIC: 28.75 µg/mL	MIC: Broth microdilution test plate well	(Gomes et al., 2012)
		Klebsiella pneumoniae (-) ATCC 29665	MIC: 3.59 µg/mL		
		Pseudomonas aeruginosa (-) WDCM 0025	MIC: 1.79 µg/mL		
		Proteus mirabilis (-) WDCM 00023	MIC: 3.59 µg/mL		
		Staphylococcus aureus (+) WDCM 00032	MIC: 1.79 µg/mL		
		Salmonella enteritidis (-) MM 6247	MIC: 0.45 µg/mL		
		Candida albicans	MIC: 6.5 µg/mL		
	Saline extract (Crushed)	*Escherichia coli* (-) WDCM 00013	MIC: 12750 µg/mL	MIC: Broth microdilution test plate well	(Gomes et al., 2012)
		Klebsiella pneumoniae (-) ATCC 29665	MIC: ND		
		Pseudomonas aeruginosa (-) WDCM	MIC: ND		
		Proteus mirabilis (-) WDCM 00023	MIC: 950 µg/mL		
		Staphylococcus aureus (+) WDCM 00032	MIC: 118 µg/mL		
		Salmonella enteritidis (-) MM 6247	MIC: ND µg/mL		
		Candida albicans	MIC: 12.75 µg/mL		
	Silver Nanopartiticles	*Staphylococcus aureus* (+) ATCC 6538	MIC: 500 µg/mL	MIC: Broth microdilution test plate well	(Ferreira et al., 2022)
		Bacillus subtilis (+) ATCC 6633	MIC: 250 µg/mL		
		Bacillus cereus (+) CCT 0096	MIC: 125 µg/mL		
		Pseudomonas aeruginosa (-) CCT 0090	MIC: 250 µg/mL		
		Candida albicans ATCC18804	MIC: 250 µg/mL		
		Candida glabrata CCT 0728	MIC: 250 µg/mL		
	Aqueous extract (Boiled)	*Staphylococcus aureus* (+) ATCC 6538	MIC: 1000 µg/mL	MIC: Broth microdilution test plate well	(Ferreira et al., 2022)
		Bacillus subtilis (+) ATCC 6633	MIC: 2000 µg/mL		
		Bacillus cereus (+) CCT 0096	MIC: 1000 µg/mL		
		Pseudomonas aeruginosa (-) CCT 0090	MIC: 2000 µg/mL		
		Candida albicans ATCC18804	MIC: 500 µg/mL		
		Candida glabrata CCT 0728	MIC: ND		
	Aqueous extract (Maceration)	*Escherichia coli* (-) ATCC 11229	MIC: >1000 µg/mL	MIC: Broth microdilution test plate well	(Silva et al., 2018)
		Staphylococcus aureus (+) BMB 9393	ND		
		Cryptococcus neoformans T1-444	MIC: >1000 µg/mL		

Plant part	Solvent (Extraction Method)	Microorganism	Results	Antimicrobial Assay	Reference
		Candida albicans ATCC 10231	ND		
	Ethanol extract (Maceration)	*Escherichia coli* (-)	ND	Agar well diffusion method	(Ghandour et al., 2021)
		Proteus mirabilis (-)	MIC: 50000 µg/mL		
		Salmonella typhi (-)	MIC: 100000 µg/mL		
		Acinetobacter baumannii (-)	MIC: 100000 µg/mL		
		Pseudomonas aeruginosa (-)	MIC: 100000 µg/mL		
		Staphylococcus aureus (+)	MIC: 12500 µg/mL		
		Klebsiella pneumoniae (-)	MIC: 12 µg/mL		
		Coagulase-negative staphylococci (+)	MIC: 50000 µg/mL		
		Enterococcus fecalis (+)	MIC: 50000 µg/mL		
		Aspergillus fumigatus	ND		
		Candida albicans	MIC: 12 µg/mL		
	Ethanol extract (Maceration)	*Staphylococcus aureus* (+) ATCC 25923	MIC: 500 µg/mL	MIC: Broth microdilution test plate well	(Uliana et al., 2016)
		Escherichia coli (-) ATCC 8739	MIC: 250 µg/mL		
		Candida albicans ATCC 10231	MIC: 750 µg/mL		
	Ethanol extract (Ultrasound)	*Staphylococcus aureus* (+) ATCC 25923	MIC: 500 µg/mL	MIC: Broth microdilution test plate well	(Uliana et al., 2016)
		Escherichia coli (-) ATCC 8739	MIC: 750 µg/mL		
		Candida albicans ATCC 10231	MIC: 75 µg/mL		
	Ethanol extract (Maceration)	*Escherichia coli* (-) ATCC 11229	MIC: 78 µg/mL	MIC: Broth microdilution test plate well	(Silva et al., 2018)
		Staphylococcus aureus (+) BMB 9393	MIC: >1000 µg/mL		
		Cryptococcus neoformans T1-444	MIC: 156 µg/mL		
		Candida albicans ATCC 10231	ND		
Bark	**Aqueous extract (Boiled)**	*Escherichia coli* (-) ATCC 25922	ND	MIC: Broth microdilution test plate well	(Moura-Costa et al., 2012)
		Staphylococcus aureus (+) ATCC 25923	MIC: 250 µg/mL		
		Pseudomonas aeruginosa (-) ATCC 27853	MIC: 1000 µg/mL		
		Bacillus subtilis (+) ATCC 6623	MIC: 1000 µg/mL		
		Candida albicans ATCC 10231	MIC: 0.49 µg/mL		
		Candida parapsilosis ATCC 22019	MIC: 3.90 µg/mL		
		Candida tropicalis ATCC 28707	MIC: 15.60 µg/mL		
		Escherichia coli (-) ATCC 25922	ND		

Plant part	Solvent (Extraction Method)	Microorganism	Results	Antimicrobial Assay	Reference
	Hydroalcoholic extract (Turbo extraction)	*Staphylococcus aureus* (+) ATCC 25923	MIC: 250 µg/mL	MIC: Broth microdilution test plate well	(Moura-Costa et al., 2012)
		Pseudomonas aeruginosa (-) ATCC 27853	MIC: 1000 µg/mL		
		Bacillus subtilis (+) ATCC 6623	MIC: 1000 µg/mL		
		Candida albicans ATCC 10231	MIC: 0.49 µg/mL		
		Candida parapsilosis ATCC 22019	MIC: 62.50 µg/mL		
		Candida tropicalis ATCC 28707	MIC: 62.50 µg/mL		
Flowers	**Methanol extracts (Ultrasonic Bath)**	*Staphylococcus aureus* (+) ATCC14458	MIC: 250 µg/mL	MIC: Broth microdilution test plate well	(Carneiro et al., 2016)
		Streptococcus mutans (+) ATCC25175	MIC: 1 µg/mL		
		Escherichia coli (-) ATCC10538,	MIC: ND		
Fruits	**Ethanol extract (Maceration)**	*Escherichia coli* (-) ATCC 11229	MIC: 78 µg/mL	MIC: Broth microdilution test plate well	(Silva et al., 2018)
		Staphylococcus aureus (+) BMB 9393	MIC: >1000 µg/mL		
		Cryptococcus neoformans T1-444	MIC: 625 µg/mL		
		Candida albicans ATCC 10231	MIC: 625 µg/mL		
	Aqueous extract (Maceration)	*Escherichia coli* (-) ATCC 11229	MIC: ND	MIC: Broth microdilution test plate well	(Silva et al., 2018)
		Staphylococcus aureus (+) BMB 9393	MIC: ND		
		Cryptococcus neoformans T1-444	MIC: >1000 µg/mL		
		Candida albicans ATCC 10231	MIC: >1000 µg/mL		
	Acetone extract (Hydrodistilation)	*Acinetobacter baumannii* (-) ATCC 17978	MIC: 8 µg/mL	MIC: Broth microdilution test plate well	(Salem et al., 2018)
		Bacillus subtilis (+) ATCC 6633	MIC: 4 µg/mL		
		Escherichia coli (-) ATCC 35210	MIC: 16 µg/mL		
		Micrococcus flavus (+) ATCC 10240	MIC: 4 µg/mL		
		Pseudomonas aeruginosa (-) Ds0432–1	MIC: 128 µg/mL		
		Sarcina lutea (+) ATCC 9341	MIC: 128 µg/mL		
		Staphylococcus aureus (+) ATCC 6538	MIC: 8 µg/mL		
	n-hexane extract (Hydrodistilation)	*Acinetobacter baumannii* (-) ATCC 17978	MIC: 1000 µg/mL	MIC: Broth microdilution test plate well	(Salem et al., 2018)
		Bacillus subtilis (+) ATCC 6633	MIC: 1000 µg/mL		
		Escherichia coli (-) ATCC 35210	MIC: 1000 µg/mL		
		Micrococcus flavus (+) ATCC 10240	MIC: 1000 µg/mL		
		Pseudomonas aeruginosa (-) Ds0432–1	MIC: >2000 µg/mL		
		Sarcina lutea (+) ATCC 9341	MIC: 2000 µg/mL		

Plant part	Solvent (Extraction Method)	Microorganism	Results	Antimicrobial Assay	Reference
		Staphylococcus aureus (+) ATCC 6538	MIC: > 2000 µg/mL		
	Acetone extract (Hydrodistilation)	*Acinetobacter baumannii* (-) ATCC 17978	IZ: 18.3 ± 0.3 mm	Disc diffusion method (2000 µg/mL)	(Salem et al., 2018)
		Bacillus subtilis (+) ATCC 6633	IZ: 14.6 ± 0.6 mm		
		Escherichia coli (-) ATCC 35210	IZ: 15.3 ± 0.8 mm		
		Micrococcus flavus (+) ATCC 10240	IZ: 20.3 ± 0.3 mm		
		Pseudomonas aeruginosa (-) Ds0432–1	IZ: 18.3 ± 0.3 mm		
		Sarcina lutea (+) ATCC 9341	IZ: 13.3 ± 0.3 mm		
		Staphylococcus aureus (+) ATCC 6538	IZ: 18.3 ± 0.3 mm		
	n-hexane extract (Hydrodistilation)	*Acinetobacter baumannii* ATCC 17978	IZ: 6.6 ± 0.3 mm	Disc diffusion method (2000 µg/mL)	(Salem et al., 2018)
		Bacillus subtilis (+) ATCC 6633	IZ: 8.6 ± 0.6 mm		
		Escherichia coli (-) ATCC 35210	IZ: 10.0 ± 0.6 mm		
		Micrococcus flavus (+) ATCC 10240	IZ: 7.3 ± 0.3 mm		
		Pseudomonas aeruginosa (-) Ds0432–1	IZ: 0		
		Sarcina lutea (+) ATCC 9341	IZ: 10.6 ± 0.6 mm		
		Staphylococcus aureus (+) ATCC 6538	IZ: 0		
Fruit peel	**Hydroethanolic extract (Maceration)**	*Staphylococcus aureus* (+) 10A	MIC: 1500 µg/mL	MIC: Broth microdilution test plate well	(Gomes et al., 2020)
		Staphylococcus aureus (+) 23A	MIC: 1200 µg/mL		
		Staphylococcus aureus (+) 35A	MIC: 1500 µg/mL		
		Staphylococcus aureus (+) 67A	MIC: 1500 µg/mL		
		Staphylococcus aureus (+) 114A	MIC: 1200 µg/mL		
		Staphylococcus aureus (+) ATCC 29213	MIC: 1800 µg/mL		
		Enterococcus faecium (+) 70E	MIC: > 2700 µg mL^{-}		
		Enterococcus faecium (+) 101E	MIC: 2100 µg/mL		
		Enterococcus faecalis (+) 1277	MIC: > 2700 µg mL^{-}		
		Enterococcus faecalis (+) 6885	MIC: > 2700 µg mL^{-}		
		Enterococcus faecalis (+) 168557	MIC: > 2700 µg mL^{-}		
		Enterococcus faecalis (+) ATCC 2921	MIC: 1500 µg/mL		
		Acinetobacter baumannii (-) 30B	MIC: > 2700 µg/mL		
		Acinetobacter baumannii (-) 101B	MIC: 2700 µg/mL		
		Acinetobacter baumannii (-) ATCC19606	MIC: > 2700 µg mL^{-}		

Plant part	Solvent (Extraction Method)	Microorganism	Results	Antimicrobial Assay	Reference
		Pseudomonas aeruginosa (-) 34B	MIC: > 2700 µg mL^{-}		
		Pseudomonas aeruginosa (-) 39B	MIC: > 2700 µg mL^{-}		
		Pseudomonas aeruginosa (-) 121B	MIC: > 2700 µg mL^{-}		
		Pseudomonas aeruginosa (-) ATXX27853	MIC: > 2700 µg/mL		
Residues (leaves and unusable fruits)	**Hydroethanolic extract (Maceration)**	*Staphylococcus aureus* (+) 10A	MIC: 900 µg/mL	MIC: Broth microdilution test plate well	(Gomes et al., 2020)
		Staphylococcus aureus (+) 23A	MIC: 600 µg/mL		
		Staphylococcus aureus (+) 35A	MIC: 600 µg/mL		
		Staphylococcus aureus (+) 67A	MIC: 900 µg/mL		
		Staphylococcus aureus (+) 114A	MIC: 600 µg/mL		
		Staphylococcus aureus (+) ATCC 29213	MIC: 900 µg/mL		
		Enterococcus faecium (+) 70E	MIC: 2100 µg/mL		
		Enterococcus faecium (+) 101E	MIC: 1800 µg/mL		
		Enterococcus faecalis (+) 1277	MIC: 1800 µg/mL		
		Enterococcus faecalis (+) 6885	MIC: 2100 µg/mL		
		Enterococcus faecalis (+) 168557	MIC: 1800 µg/mL		
		Enterococcus faecalis (+) ATCC 2921	MIC: 1200 µg/mL		
		Acinetobacter baumannii (-) 30B	MIC: > 2700 µg/mL		
		Acinetobacter baumannii (-)101B	MIC: 1800 µg/mL		
		Acinetobacter baumannii (-) ATCC19606	MIC: > 2700 µg/mL		
		Pseudomonas aeruginosa (-) 34B	MIC: 2700 µg/mL		
		Pseudomonas aeruginosa (-) 39B	MIC: 2700 µg/mL		
		Pseudomonas aeruginosa (-) 121B	MIC: 2400 µg/mL		
		Pseudomonas aeruginosa (-) ATXX27853	MIC: > 2700 µg mL^{-}		
	Methanolic extract (Maceration)	*Staphylococcus aureus* (+) 10A	MIC: 900 µg/mL	MIC: Broth microdilution test plate well	(Gomes et al., 2020)
		Staphylococcus aureus (+) 23A	MIC: 900 µg/mL		
		Staphylococcus aureus (+)35A	MIC: 600 µg/mL		
		Staphylococcus aureus (+) 67A	MIC: 600 µg/mL		
		Staphylococcus aureus (+) 114A	MIC: 600 µg/mL		
		Staphylococcus aureus (+) ATCC 29213	MIC: 600 µg/mL		
		Enterococcus faecium (+) 70E	MIC: 1500 µg/mL		

Plant part	Solvent (Extraction Method)	Microorganism	Results	Antimicrobial Assay	Reference
		Enterococcus faecium (+) 101E	MIC: 1500 µg/mL		
		Enterococcus faecalis (+) 1277	MIC: 1500 µg/mL		
		Enterococcus faecalis (+) 6885	MIC: 1200 µg/mL		
		Enterococcus faecalis (+) 168557	MIC: 1200 µg/mL		
		Enterococcus faecalis (+) ATCC 2921	MIC: 1200 µg/mL		
		Acinetobacter baumannii (-) 30B	MIC: > 2700 µg mL^{-}		
		Acinetobacter baumannii (-) 101B	MIC: 1200 µg/mL		
		Acinetobacter baumannii (-) ATCC19606	MIC: > 2700 µg mL^{-}		
		Pseudomonas aeruginosa (-) 34B	MIC: 2400 µg/mL		
		Pseudomonas aeruginosa (-) 39B	MIC: 2400 µg/mL		
		Pseudomonas aeruginosa (-) 121B	MIC: 2400 µg/mL		
		Pseudomonas aeruginosa (-) ATXX27853	MIC: > 2700 µg/mL		

(-): Gram-negative; (+): Gram-positive; IZ: Inhibition zone; MIC: Minimum Inhibitory Concentration; ND: not demonstrated.

During prolonged incubation in broth media, antimicrobial agents may retain their activity better than on solid agar, where environmental conditions such as drying, oxidation, or uneven diffusion might lead to the degradation or inactivation of bioactive compounds. Additionally, the availability of antimicrobial agents in liquid media may remain higher over time compared to their availability in solid agar (Ambaye et al., 1997). In liquid broth, compounds are more evenly distributed, which facilitates their interaction with cells structures of microorganisms and ensures sustained exposure. This hypothesis suggests that the matrix in which the antimicrobial agents are suspended may plays an important role in determining their overall efficacy, and the choice of method could significantly affect the observed outcomes in susceptibility testing (Balouiri et al., 2016).

Gram-negative bacteria are considered more resistant to antimicrobial compounds than Gram-positive bacteria due to their elaborate cell wall structure (Breijyeh et al., 2020; Rapacka-Zdonczyk et al., 2021). However, this assertion is not always applicable. For instance, extracts from *S. terebinthifolius* Raddi have demonstrated variability in efficacy between Gram-positive and Gram-negative bacteria across the analyzed studies. For example, when evaluating the antimicrobial capacity of ethanolic extracts from pink pepper leaves obtained through maceration, a divergence in results becomes evident. Ghandour et al. (2021) reported the minimum inhibitory concentration for *Staphylococcus aureus* as 12500 µg/mL, while no effective inhibition was observed against *Escherichia coli* (Ghandour et al., 2021). In contrast, Silva et al. (2018) noted that the MIC necessary to inhibit *E. coli* was 78 µg/mL, with no effective inhibition for *S. aureus* at the concentration tested (MIC > 1,000 µg/mL) (Silva et al., 2018). Furthermore, Uliana et al. (2016) found a higher MIC required to inhibit the growth of *S. aureus* (500 µg/mL) compared to *E. coli* (250 µg/mL).

Moreover, the efficacy of the extracts varies based on the specific strain. Gomes et al. (2020) evaluated the antibacterial activity of various extracts from *Schinus terebinthifolia* Raddi against multidrug-resistant bacteria. The results presented by the authors demonstrated that different strains of the same bacterial species respond differently to the same extract, exhibiting varying MICs.

Additionally, the preparation and concentration of the extract are crucial factors. Furthermore, it is important to highlight that the majority of the studies do not provide sufficient details in their methodology sections to allow the calculation of the final concentration of the extracts. For instance, several studies concentrated the extract obtained after the extraction process, but fail to specify the initial mass of the plant material used, the volume of solvent added, or the final volume of the concentrated extract. As a result, the lack of this information makes it difficult to make a simple and direct comparison between the MIC of the extracts, even when the same source, the same type of extraction process and the same evaluation method were used.

Antioxidant activity of pink pepper extracts

In recent years, *Schinus terebinthifolius* Raddi has garnered attention for its bioactive compounds, particularly those with antioxidant properties. Phenolic compounds, particularly galloyl derivatives such as gallotannins and gallic acid, are reported as the main constituents of *Schinus terebinthifolius* Raddi extracts and are largely responsible for its antioxidant activity (Gomes et al., 2020; Rocha et al., 2019; Zouaoui et al., 2024; Oliveira et al., 2020; Oliveira et al., 2020). Another important phenolic group associated with antioxidant activity in pink pepper extracts is flavonoids, including catechin, luteolin, myricetin, quercetin, and kampferol derivatives (Gomes et al., 2020; Tlili et al., 2018; Zouaoui et al., 2024).

Extracts derived from different parts of the pink pepper tree, such as fruits, leaves, bark, and root, have been explored using different extractions methods and antioxidant assays to assess their efficacy in neutralizing free radicals (Table 2). These studies are crucial for understanding the potential of pink pepper extracts as natural antioxidants, with promising applications in the food industry for preservation, as well in pharmaceuticals applications.

Table 2. Antioxidant studies of pink pepper extracts in the last years (2016-2024).

Plant Part	Solvent - Extraction Method	Antioxidant Assay	Result	Reference
Fruits	Acetone extract (Hydrodistilation)	DPPH	IC_{50}: 118.16±1.7 µg/mL	(Salem et al., 2018)
	n-hexane extract (Hydrodistilation)	DPPH	IC_{50}: 324.26±2.45 µg/mL	
	Ethanolic extracts (Soxhlet)	DPPH	ND	(Oliveira et al., 2020)
		DPPH (RSA %)	24.1±0.5	
		FRAP	488.6±81.1 $TEAC_{FRAP}$ µmol/g	
	Methanolic Extracts (Static maceration)	DPPH	87.6 – 95.6 %	(Bernardes et al., 2014)
	Methanolic extracts (Maceration)	DPPH	IC_{50}: 190±1 µg/mL	(Zouaoui et al., 2024)
		ABTS	IC_{50}: 210.0±0.1 µg/mL	
		Iron Chelating Activity	IC_{50}: 400±5 µg/mL	
		FRAP	17.6±0.7 mg AAE/g dE	
	Methanolic extracts (Stirred)	DPPH (area 1)	IC_{50}: 182.48 ± 2.48 µg/mL	(Tlili et al., 2018)
		DPPH (area 2)	IC_{50}: 202.74 ± 3.78 µg/mL	
Fruits's peel	Ethanolic extracts (Soxhlet)	DPPH	IC_{50}: 6.1±0.4 µg/mL	(Oliveira et al., 2020)
		DPPH (RSA %)	78.4±0.9	
		FRAP	3484.7±255.5 $TEAC_{FRAP}$ µmol/g	
Leaves	Methanolic Extracts	DPPH	IC_{50}: 4.17±0.69 µg/mL	(Rocha et al., 2019)
		ABTS	3.83±0.36 µg/mL	
		FRAP	EC_{50}: 68.78±2.01 µg/mL	
		Reducing Power	95.30±3.64	
		β-Carotene bleaching	IC_{50}: 67.06±3.78 µg/mL	
	Ethanolic Extracts (Maceration)	DPPH	IC_{50}: 15.33 µg/mL	(Uliana et al., 2016)
	Ethanolic Extracts (Ultrasound)	DPPH	IC_{50}: 92.00 µg/mL	
	Methanolic extracts	DPPH	IC_{50}: 3.7±1.6 µg/mL	(Rocha et al., 2018)
	Methanolic extracts (Maceration)	DPPH	IC_{50}: 19±1 µg/mL	(Zouaoui et al., 2024)
		ABTS	IC_{50}: 31.0±0.2 µg/mL	
		Iron Chelating Activity	IC_{50}: 210±9 µg/mL	
		FRAP	218±3 mg AAE/gdE	
	Flour (air circulation oven)	FRAP	21.58±0.15 µmol TEAC/g	(Silva et al., 2024)
		ABTS	75.25±0.10 µmol TEAC/g	
		FRAP	20.03±0.01 µmol TEAC/g	

Plant Part	Solvent - Extraction Method	Antioxidant Assay	Result	Reference
	Flour (freeze-dried)	ABTS	66.59±0.01 µmol TEAC/g	
Roots	Methanolic Extracts	DPPH	IC_{50}: 6.31±0.0 µg/mL	(Rocha et al., 2019)
		ABTS	3.25±0.22 µg/mL	
		FRAP	EC_{50}: 85.11±4.27 µg/mL	
		Reducing Power	133.52±1.11	
		β-Carotene bleaching	IC_{50}: 176.56±21.30 µg/mL	
Stem Bark	Methanolic Extracts	DPPH	IC_{50}: 4.50±0.11 µg/mL	
		ABTS	4.45±0.49	
		FRAP	EC_{50}: 116.33±3.53 µg/mL	
		Reducing Power	169.76±1.90	
		β-Carotene bleaching	IC_{50}: 220.37±35.99 µg/mL	
Flowers	Methanolic Extracts (Ultrasonic Bath)	DPPH	IC_{50}: 0.14±0.07 µg/mL	(Carneiro et al., 2016)

IC_{50}: Concentrations of the extracts resulting in 50% inhibition, EC_{50}: Maximal effective concentration, TEAC: Trolox Equivalent Antioxidant Capacity.

Studies conducted with methanolic extracts, using the DPPH methodology, revealed that the antioxidant potential of *Schinus terebinthifolius* is significantly influenced by the part of the plant used in the extraction process. The fruit extracts exhibited the highest antioxidant activity, with IC_{50} 190 µg/mL (Zouaoui et al., 2024), while the flower extracts demonstrated the lowest potential antioxidant, with IC_{50} 0.14 µg/mL (Carneiro et al., 2016). Zouaoui et al. (2024), along with Rocha et al. (2019) and Rocha et al. (2018), reported notable variations in the antioxidant activity of *Schinus terebinthifolius* leaf extracts, with IC_{50} values of 19 µg/mL, 4.17 µg/mL, and 3.7 µg/mL, respectively (Zouaoui et al., 2024; Rocha et al., 2019; Rocha et al., 2018). These findings again emphasize the necessity of knowing the amount used of plant parts when preparing the extracts and the extracts concentration, as previously cited in the antimicrobial section.

The antioxidant potential of pink pepper extracts is also influenced by the method of extraction and the solvents used. Among the most commonly used solvents are methanol, ethanol, acetone, and n-hexane, each of which varies in polarity and affects the ability to extract different antioxidant compounds. Methanolic and ethanolic extracts are commonly used due to be more effective for extracting lower molecular weight polyphenols, whereas aqueous acetone is better for extracting higher molecular weight flavanols. Additionally, ethanol has the advantage of being safe for human consumption (Dai & Mumper, 2010). As the polarity of the solvent directly influences the composition of the extract obtained. The results of antioxidant activities vary significantly depending on the solvent used in the extraction process.

In addition to extraction methods, a range of assays have been used, such as DPPH, ABTS, FRAP, and iron-chelating activity, each measuring different antioxidant mechanisms. This is important because the antioxidant potential of an extract is not determined by a single process, but rather by a combination of factors, including electron donation, free radical scavenging, and reducing power (Shahidi and Zhong 2007). Therefore, each assay evaluates a specific aspect of the extract's overall antioxidant activity, providing a more comprehensive assessment. For example, methanolic leaf extracts of *Schinus terebinthifolius* exhibit high activity (IC_{50}) in the DPPH assay (4.17±0.69 µg/mL) and ABTS assay (3.83±0.36 µg/mL) in a study conducted by Rocha et al. (2018), as well as DPPH activity (19±1 µg/mL) and ABTS activity (31.0±0.2 µg/mL) in research by Zouaoui et al. (2024). These results indicate a broad antioxidant capacity of the *Schinus terebinthifoliu*s extracts.

***Pereskia aculeata* Miller**

Pereskia aculeata Miller commonly known *as ora-pro-nóbis* or Barbados gooseberry, is a NCEP from the Cactaceae family (Figure 3). Native to tropical regions, particularly in Latin American countries, this NCEP is predominantly found and consumed in Brazil (Fioroto et al., 2024; Tofanelli et al., 2023). The *ora-pro-nóbis* plant is a climbing shrub with long stems, typically extending 4 to 10 meters. Its lanceolate, succulent leaves measure between 3 to 10 cm in length and 1.5 to 5 cm in width (Ferreira et al., 2024).

Ora-pro-nóbis is a versatile and highly valued plant, recognized for its nutritional properties. Its leaves are rich in protein (23%, dry basis) and often referred to as "the meat of the poor" "green meat", or "vegetable meat" (Massocatto et al., 2022; Tofanelli et al., 2023; Takeiti et al., 2009; Silva et al., 2023). It is widely used in Brazilian cuisine in a variety of dishes, including salads, stews, omelets, breads, savory pies, and as a side for meat dishes. The leaves can also be processed into flour, which is incorporated into bread, pasta, cakes, and even ice cream. Additionally, the plant's flowers are edible, consumed raw or sautéed in salads and omelets (Ferreira et al., 2024).

Figure 3. *Pereskia aculeata* Miller. (A) Tree. (B) Leaves.

Beyond its culinary applications, *Pereskia aculeata* Mill. has a long history in traditional and folk medicine (Egea and Pierce 2021; Silva et al., 2018). On traditional medicine it has been utilized for the treatment of various conditions, including skin injuries, inflammation, iron deficiency anemia, cancer, osteoporosis, and intestinal constipation (Almeida & Corrêa, 2012). Due to its unique composition and numerous benefits, in recent years scientific researches have been conducted to explore its potential biological activities and support these traditional applications. These studies have supported the potential benefits of *ora-pro-nóbis*, including its anti-inflammatory (Pinto et al., 2020; Torres et al., 2022), antioxidant (Ciríaco, Mendes, and Carvalho 2023; Jacobsen et al., 2024; Massocatto et al., 2022; Carvalho et al., 2023), antimicrobial (Garcia et al., 2019; Macedo et al., 2023), wound-healing (Carvalho et al., 2014), antinociceptive, reduce visceral fat (Souza et al., 2015), cytotoxic and antiproliferative, and anticholinesterase activity (Massocatto et al., 2022).

Antimicrobial activity of *ora-pro-nóbis* extracts

Studies examining the antimicrobial properties of *Pereskia aculeata* extracts reveal that, despite its traditional use as an antimicrobial agent, its antimicrobial activity spectrum is limited, indicating a need for further studies. The Table 3 presents several studies highlighting the antimicrobial activity of *Pereskia aculeata* extracts obtained through various solvents and extraction methods. Across eleven different scenarios evaluated and presented in 7 research papers, the study conducted by Garcia et al. (2019) was the only one to demonstrate that *Pereskia aculeata* exhibited antimicrobial activity against *Escherichia coli*. In contrast, the other 6 studies assessed the antimicrobial activity of extracts obtained directly from the leaves of *Pereskia aculeata* (using different solvents and methodologies) against *E. coli* and did not observe inhibitory activity. It is important to highlight that, to carry out the experiments, Garcia et al. (2019) used commercial *Pereskia aculeata* flour, the exact composition of which was not described. In this scenario, commercial flour may contain preservative additives in its formulation to extend its shelf life. Therefore, the results suggested that the observed antimicrobial activity may be related to these additional components in the flour, rather than exclusively to the plant constituents.

Table 3. Antimicrobial studies of *Pereskia aculeate* Miller extracts in the last 6 years (2019-2024).

Plant part	Solvent (Extraction Method)	Microorganism	Results	Antimicrobial Assay	Reference
Leaves	**Comercial Flour -Hydroalcoholic (Agitation)**	*Escherichia coli* (-)	MIC: 20 µg/mL	MIC: Broth microdilution test plate well	(Garcia et al., 2019)
		Klebsiella pneumoniae (-)	MIC: 5 µg/mL		
		Morganella morganii (-)	MIC: 20 µg/mL		
		Proteus mirabilis (-)	MIC: > 20 µg/mL		
		Pseudomonas aeruginosa (-)	MIC: 20 µg/mL		
		Enterococcus faecalis (+)	MIC: 10 µg/mL		
		Listeria monocytogenes (+)	MIC: 5 µg/mL		
		Staphylococcus aureus (+)	MIC: 5 µg/mL		
	Aqueous extract (Ultrasonic by 10 min)	*Escherichia coli* (-)	ND	MIC: Broth microdilution test plate well	(Macedo et al., 2023)
		Staphylococcus aureus (+) ATCC 29213	MIC: 6250 µg/mL		
		Staphylococcus aureus (+) resistant to methicillin ATCC 43300	MIC: 25000 µg mL^{-}		
	Aqueous extract (Ultrasonic by 20 min)	*Escherichia coli* (-) ATCC 35218	ND		
		Staphylococcus aureus (+) ATCC 29213	MIC: 1560 µg/mL		
		Staphylococcus aureus (+) resistant to methicillin ATCC 43300	MIC: 12500 µg mL^{-}		
	Aqueous extract (Ultrasonic by 30min)	*Escherichia coli* (-) ATCC 35218	ND		
		Staphylococcus aureus (+) ATCC 29213	MIC: 3130 µg/mL		
		Staphylococcus aureus (+) resistant to methicillin ATCC 43300	MIC: 50000 µg mL^{-}		
	Aqueous extract (Ultrasonic by 40 min)	*Escherichia coli* (-) ATCC 35218	ND		
		Staphylococcus aureus (+) ATCC 29213	MIC: 6250 µg/mL		
		Staphylococcus aureus (+) resistant to methicillin ATCC 43300	ND		
	Ethanolic extract (Maceration)	*Escherichia coli* (-) ATCC 35218	ND	MIC: Broth microdilution test plate well	(Colacite et al., 2022)
		Klebsyella pneumonie (-)	ND		
		Staphylococcus aureus (+)	ND		
		Streptoccocuss pneumoniae (+)	ND		

Plant part	Solvent (Extraction Method)	Microorganism	Results	Antimicrobial Assay	Reference
	Methanol extract (Maceration)	*Escherichia coli* (-)	ND		
		Klebsyella pneumoniae (-)	+		
		Staphylococcus aureus (+)	+		
		Streptoccocuss pneumoniae (+)	ND		
	Methanol extract (Dubnoff water bath)	*Bacillus subtilis* ATCC 6051	ND	MIC: Broth microdilution test plate well	(Souza et al., 2021)
		Staphylococcus aureus (+) ATCC 6538	ND		
		Salmonella choleraesuis ATCC 10708	MIC: 2000 µg/mL		
		Streptococcus epidermidis ATCC 12228	ND		
		Escherichia coli (-) ATCC 11775	ND		
		Pseudomonas aeruginosa (-) ATCC 13388	ND		
		Candia albicans ATCC 10231	ND		
	Ethanol + acetone extract (Maceration +Ultrasond)	*Staphylococcus aureus* (+) ATCC 25923	ND	Disc diffusion method	(Silva et al., 2020)
		Escherichia coli (-) ATCC 25922	ND		
	Aqueous extract (Maceration + Boiled)	*Staphylococcus aureus* (+)	IZ: 9.5 mm	Inhibition halo	(Lopes & Cattelan, 2022)
		Escherichia coli (-)	ND		
Leaves and Stem	**Aqueous extract (Microwave)**	*Staphylococcus aureus* (+) ATCC 29213	ND	MIC: Broth microdilution test plate well	(Delvechio et al., 2022)
		Staphylococcus aureus (+) resistant to methicillin	ND		
		Escherichia coli (-) ATCC 25922	ND		
		Pseudomonas aeruginosa (-) ATCC 27853	ND		

(-): Gram-negative; (+): Gram-positive; IZ: Inhibition zone; MIC: Minimum Inhibitory Concentration; ND: not demonstrated.

In addition to *E. coli*, the antimicrobial effects of *Pereskia aculeata* extracts have also been well investigated against *Staphylococcus aureus*. The antimicrobial activity of hydroethanolic extracts from *ora-pro-nóbis* leaves was evaluated using an ultrasound-assisted extraction method and tested through broth microdilution, demonstrating inhibitory potential against *Staphylococcus aureus* strains (Macedo et al., 2023). Notably, chlorogenic acid was identified as the main compound in these extracts, and promising results regarding its antibacterial activity against *S. aureus* have also been reported in the literature (Li et al., 2014).

All extracts obtained from ultrasound extraction (Macedo et al., 2023) and agitation (Garcia et al., 2019) inhibited the growth of *S. aureus* when evaluated using the broth microdilution method. Notably, the magnitude of concentration for the MIC against *S. aureus* reported by Macedo et al. (2023) was significantly higher (ranging from 1560 to 50000 µg/mL, depending on the *S. aureus* strain tested) than that found by Garcia et al. (2019) (5 µg/mL). This discrepancy may suggest the possibility that a food additive was incorporated into the formulation of the commercial flour used, as previously mentioned. In contrast, as shown in Table 3, studies using other extraction methods (maceration, Dubnoff water bath, and microwave) along with the broth microdilution test, did not show antimicrobial activity against *S. aureus*. These results suggest that the compounds present in *ora-pro-nóbis* leaves are more effectively extracted through the initial use of ultrasound.

Antioxidant activity of *ora-pro-nobis* extract

Pereskia aculeata demonstrated a broad antioxidant capacity, as shown in Table 4. This finding can be confirmed through different antioxidant analyses, such as DPPH, ABTS, and FRAP, under varying conditions using different parts of the plant. The antioxidant capacity is well validated by these results, as the consistency of the antioxidant properties across different assays enhances confidence and robustness of the measured antioxidant activity. The studies extensively identified phenolic compounds as the major contributors to the antioxidant activity of *ora-pro-nóbis*. *Phenolic* acids are frequently highlighted as the most abundant phenolic group found in *ora-pro-nóbis*, such as caffeic acid, coumaric acid, vanillic acid, chlorogenic acid, caftaric acid, gallic acid, and ellagic acid (Garcia et al., 2019; Jacobsen et al., 2024; Macedo et al., 2023; Souza et al., 2022). Other phenolic compounds, such as flavonoids, including quercetin and its derivates (rutin and isoquercetin), were identified as most abundant in different extracts (Jacobsen et al., 2024; Garcia et al., 2019; Souza et al., 2022)

Among the studies, variation in the composition of the extracts is notable. This variation can be influence by the properties of the solvent used in extraction, including factors such as hydrogen bonding capabilities and polarities. For instance, Jacobsen et al. (2024) conducted a comparative analysis of the composition of the extracts and fractions from *Pereskia aculeata* leaves, identifying differences in the composition based in the solvent employed. Notably, quercetin, rutin, and coumaric acid were not identified in extracts produced with hexane solvents. In contrast, rutin was the most abundant compound in extracts produced with ethanol and butanol.

***Tropaeolum majus* L.**

Tropaeolum majus L., commonly referred to as Garden Nasturtium, Indian cress, monk's cress, or *capuchinha*, is a flowering plant belonging to the Tropaeolaceae family (Ailane & Bennadja, 2023; Christenhusz, 2012). Garden nasturtium is native to Central and South America, where it typically grows as a perennial plant. However, over time this plant achieved widespread distribution all over the world, including Europe and North Africa (Christenhusz, 2012; Panstw Zakl et al., 2018).

Table 4. Antioxidant studies of *ora-pro-nobis* extracts in the last years (2016-2024).

Plant Part	Solvent (Extraction Method)	Antioxidant Assay	Result	Reference
Leaves	**Comercial Flour - Hydroalcoholic (Agitation)**	DPPH	IC_{50}:39.0 ± 3 µg/mL	(Garcia et al., 2019)
		ABTS	IC_{50}: 40.5 ± 1 µg/mL	
		OH	IC_{50}: 373.5 ± 13 µg/mL	
	Hydroethanolic extract (Ultrasonic by 10 min)	DPPH	24.48 ± 0.15 µM of TE/g	(Macedo et al., 2023)
		ABTS	10.24 ± 0.40 µM of TE/g	
		FRAP	30.00 ±0.27 µM ferrous sulp/g	
	Hydroethanolic extract (Ultrasonic by 20 min)	DPPH	28.22 ± 0.99 µM of TE/g	
		ABTS	9.00 ±0.08 µM of TE/g	
		FRAP	24.34 ± 0.87µM ferrous sulp/g	
	Hydroethanolic extract (Ultrasonic by 30 min)	DPPH	70.20 ± 1.05 µM of TE/g	
		ABTS	6.38 ± 0.17 µM of TE/g	
		FRAP	32.13 ± 0.60 µM ferrous sulp/g	
	Hydroethanolic extract (Ultrasonic by 40 min)	DPPH	61.20 ± 1.12 µM of TE/g	
		ABTS	7.14 ± 0.17 µM of TE/g	
		FRAP	27.37 ± 0.83 µM ferrous sulp/g	
	Methanol extract (Dubnoff water bath)	ROO^{*}	1327.68 ± 126.01 µmol TE/g d.w.	(Souza et al., 2021)
		HOCl	16.94 ± 1.18 µg/mL	
		H_2O_2	ND	
		$O_2^{\bullet-}$	ND	
	Hydroethanolic extract (Stirring)	FRAP	865 ± 70 µmol FeSO4/g	(Jacobsen et al., 2024)
		DPPH	239 ± 20 µmol TEAC/g	
		ABTS	882 ± 53 µmol TEAC/g	
	Hexane extract (Stirring)	FRAP	273 ± 20µmol FeSO4/g	
		DPPH	50.3 ± 4.6 µmol TEAC/g	
		ABTS	484 ± 33 µmol TEAC/g	
	Dichloromethane (Stirring)	FRAP	536 ± 41 µmol FeSO4/g	
		DPPH	39.5 ± 2.1 µmol TEAC/g	
		ABTS	610 ± 15 µmol TEAC/g	
	Ethyl acetate (Stirring)	FRAP	939 ± 35 µmol FeSO4/g	
		DPPH	99.9 ± 4.3 µmol TEAC/g	

Plant Part	Solvent (Extraction Method)	Antioxidant Assay	Result	Reference
		ABTS	517 ± 37 µmol TEAC/g	
	Acetone extract (Stirring)	FRAP	1095 ± 77 µmol FeSO4/g	
		DPPH	155 ± 8.0 µmol TEAC/g	
		ABTS	577 ± 32µmol TEAC/g	
	Butanol extract (Stirring)	FRAP	696 ± 69 µmol FeSO4/g	
		DPPH	130 ± 20 µmol TEAC/g	
		ABTS	831 ± 24 µmol TEAC/g	
	Raw material (autumn)	DPPH	1345.22 ± 46.24 µmol TE/g	(Souza et al., 2022)
	Raw material (winter)	DPPH	996.31 ± 30.00 µmol TE/g	
	Hydroethanolic extract (Stirring)	DPPH	44000 µg AAE/g	(Cruz et al., 2021)
	Hydroalcoholic extracts (Maceration)	DPPH	IC_{50} 3351.5 ± 109.1 µg/mL	(Massocatto et al., 2022)
		ABTS	IC_{50} 2851.7± 101.4 µg/mL	
		FRAP	17.7 ± 1.7 µmol TE.100/g d.w.	
	Hexane extract (Soxhlet)	DPPH	IC_{50}: 7830 ± 130	(Torres et al., 2022)
		FRAP	90 ± 10 µmol TE/g	
	Ethanolic extract (Soxhlet)	DPPH	IC_{50} 1000 ± 30 µg/mL	
		FRAP	160 ± 10 µmol TE/g	
	CO_2 (Supercritical Fluid – 40 °C)	DPPH	IC_{50} 3090 ± 170 µg/mL	
		FRAP	20 ± 10 µmol TE/g	
	CO_2 (Supercritical Fluid – 50 °C)	DPPH	IC_{50} 6350 ± 220µg/mL	
		FRAP	30 ± 10 µmol TE/g	
	CO_2 (Supercritical Fluid – 60 °C)	DPPH	IC_{50} 5050 ± 220 µg/mL	
		FRAP	50 ± 10 µmol TE/g	
	Ethanolic extract (Pressurized Liquid - 50 °C)	DPPH	IC_{50} 2880 ± 80 µg/mL	
		FRAP	120 ± 10 µmol TE/g	
	Ethanolic extract (Pressurized Liquid - 80 °C	DPPH	IC_{50} 2540 ± 30 µg/mL	
		FRAP	110 ± 10 µmol TE/g	
	Ethanolic extract (Pressurized Liquid -100 °C)	DPPH	IC_{50} 1640 ± 40 µg/mL	
		FRAP	170 ± 10 µmol TE/g	
	Aqueous extract (Pressurized Liquid - 50 °C)	DPPH	IC_{50} 1380 ± 180 µg/mL	
		FRAP	100 ± 10 µmol TE/g	

Plant Part	Solvent (Extraction Method)	Antioxidant Assay	Result	Reference
	Aqueous extract (Pressurized Liquid - 80 °C)	DPPH	IC_{50} 310 ± 20 µg/mL	
		FRAP	250 ± 10 µmol TE/g	
	Aqueous extract (Pressurized Liquid - 110 °C)	DPPH	IC_{50} 720 ± 70 µg/mL	
		FRAP	210 ± 20 µmol TE/g	
	Hydroethanolic extract (Shaker)	DPPH	1400 µg/g	(Ciríaco et al., 2023)
		ABTS	6.30 µmol TE/g	
	Aqueous (Maceration)	DPPH	IC_{50}: 106.1 ± 3.9 1 µg/mL	(Sousa et al., 2014)
	Ethanolic extract (Maceration)	DPPH	IC_{50}: 56.6 ± 2.1 1 µg/mL	
	Aceton extract (Maceration)	DPPH	IC_{50}: 49.1 ± 0.5 1 µg/mL	
	Aqueous extract (Triturated)	DPPH	68698 ± 2850 µg/g	(Colacite et al., 2022)
		FRAP	0.909 ± 0.026 µmol TE/g	
		ORAC	36.691 ± 2.722 µmol TE/g	
Fruit	**Hydroethanolic extract (Shaker)**	DPPH	1500 µg/g	(Ciríaco et al., 2023)
		ABTS	3.20 µmol TE/g	
	Hydroalcoholic extracts (Maceration)	DPPH	IC_{50} 1612.9 ± 50.2 µg/mL	(Massocatto et al., 2022)
		ABTS	IC_{50} 1209.8 ± 61.1 µg/mL	
		FRAP	5.9 ± 1.1 µmol TE.100/g d.w.	
	Crude pulp	DPPH	ND	(Silva et al., 2018)
		ABTS	ND	
		ORAC (unripe pulp)	1.95 mmol trolox 100/g d.w.	
		ORAC (intermediate pulp)	0.80 mmol trolox 100/g d.w.	
		ORAC (ripe pulp)	3.85 mmol trolox 100/g d.w.	
Stem	**Hydroethanolic extract (Shaker)**	DPPH	1200 µg/g	(Ciríaco et al., 2023)
		ABTS	13.82 µmol TE/g	
	Aqueous extract (Maceration + boiled)	DPPH	IC_{50}: 503.34 ± 31.55 µg/mL	(Moraes et al., 2020)
	Aqueous (Maceration + boiled) 7 days under freeze	DPPH	IC_{50}: 579.86 ± 51.45 µg/mL	
	Aqueous (Maceration + boiled) 7 days under freeze	DPPH	IC_{50}: 684.84 ± 125.46 µg/mL	

Plant Part	Solvent (Extraction Method)	Antioxidant Assay	Result	Reference
Leaves and Stem	**Aqueous extracts (Microwave)**	DPPH	95.19% redution of DPPH radical	(Delvechio et al., 2022)

Scavenging capacity of peroxyl radical (ROO^{*}), hypochlorous acid (HOCl), hydrogen peroxide (H_2O_2) and superoxide radical ($O_2^{\bullet-}$). IC_{50} Concentrations of the extracts resulting in 50% inhibition; TEAC: Trolox Equivalent Antioxidant Capacity; TE: Trolox Equivalent; AAE/g: Ascorbic Acid Equivalents per gram; µmol TE/gd.w.: µmol Trolox equivalent per 100g of dried weight.

Known for its beauty, *Tropaeolum majus* L. is cultivated extensively as an ornamental plant. Moreover, *T. majus* is valued not only for its aesthetic appeal but also for its culinary uses, including its leaves, flowers, and green seeds (Al-Jassani, 2017; Garzón et al., 2015). The plant is characterized by a fleshy, trailing stem and orbicular leaves with slightly wavy edges. It has yellow, red, or orange flowers in the shape of an open funnel, which are among the most popular source of edible flowers (Figure 4). All parts of *T. majus* are edible, with the leaves and flowers having a pungent, peppery flavor (Ailane et al., 2022; Garzón et al., 2015).

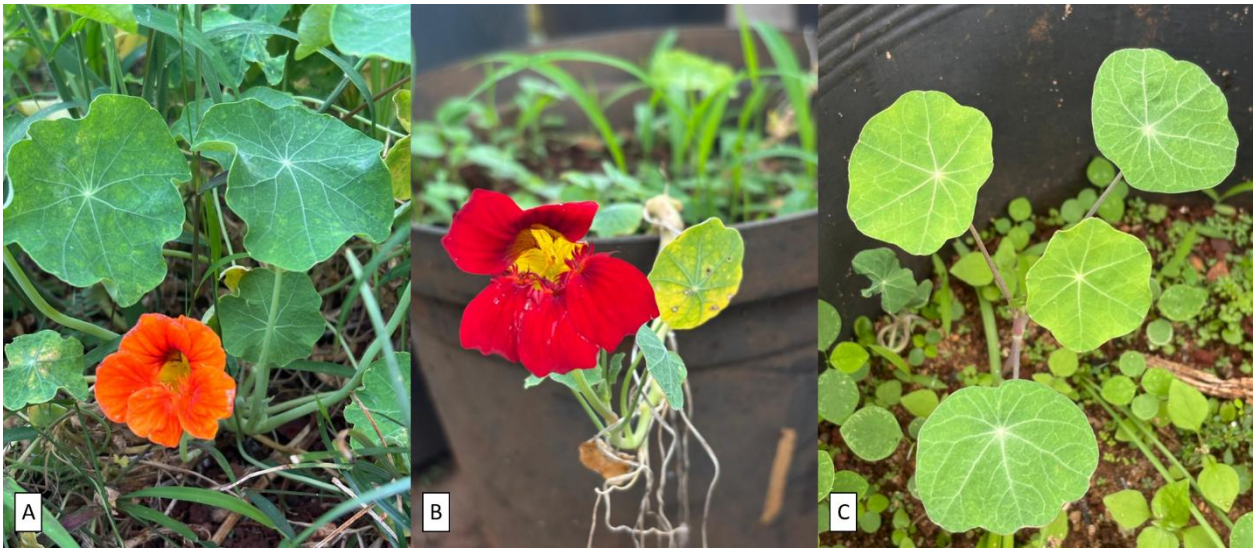

Figure 4. *Tropaeolum majus* L. (A) Orange flower. (B) Red flower. (C) Leaves.

In traditional medicine, *T. majus* has been used in a wide range of applications. According Correa (1926), nasturtium was used on sailing ships as an antiscorbutic remedy to prevent scurvy. The author also mentioned that the mature fruits of nasturtium were used as a purgative (Corrêa, 1926). Furthermore, nasturtium is popularly used in the treatment of ulcers, tonsillitis, wounds, infections, weakness, diuretic, and cancer (Andrzejak et al., 2024; Brondani et al., 2016; Ferreira, Vieira, and Zárete 2004; Popoca et al., 1998).

Although commonly used in traditional medicine, numerous studies have explored and confirmed its potential therapeutic activity, including antioxidant (Ailane and Bennadja 2023; (Ailane, Djahoudi, and Bennadja 2022), anticancer (Pintão et al., 1995), antimicrobial (Vrca et al., 2022), diuretic (Gasparotto et al., 2009), hypotensive (Gasparotto et al., 2011), anxiolytic (Melo et al., 2018), antimalarial (Pintão et al., 2024), antithrombotic (Manuel et al., 2000), hepatoprotective (Koriem et al., 2010) , anti-adipogenic and anti-inflammatory effects (Jurca et al., 2018). Nasturtium contains various bioactive compounds, including glucosinolates (Česlová et al., 2023; Pintão et al., 2024), carotenoids, flavonoids (Česlová et al., 2023; Gasparotto et al., 2011), and phenolic acids (Jurca et al., 2018) which contribute to its therapeutic effects.

Antimicrobial activity of garden nasturtium extracts

Recently, only a few studies have focused on the antimicrobial activity of *T. majus* extracts (Table 5), and their findings have been contradictory. All parts of the *T. majus* contain benzyl glucosinolates (benzyl GSL), however this intact compound is not biologically active when compared to its degradation products. One of the degradation products of benzyl GSL is benzyl isothiocyanate (BITC), a compound that can be found in *T. majus* extracts and the primary candidate responsible for the antimicrobial effects when observed (Vrca et al., 2022).

Table 5. Antimicrobial studies of *Tropaeolum majus* L. extracts in the last years (2013-2024).

Plant part	Solvent (Extraction Method)	Microorganism	Results	Antimicrobial Assay	Reference
Seeds	**Aqueous (microwave hydrodiffusion and gravity)**	*Staphylococcous aureus* (+) ATCC 25923	62.5 µg/mL	MIC: Broth microdilution test plate well	(Vrca et al., 2022)
		Escherichia coli (-) ATCC 11229	250 µg/mL		
	Aqueous (microwave hydrodiffusion and gravity)	*Staphylococcous aureus* (+) ATCC 25923	125 µg/mL	MBC: Broth microdilution test plate well	
		Escherichia coli (-) ATCC 11229	500 µg/mL		
	Hydrosols (microwave hydrodiffusion and gravity)	*Staphylococcous aureus* (+) ATCC 25923	>2000 µg/mL	MIC: Broth microdilution test plate well	(Vrca et al., 2023)
		Escherichia coli (-) ATCC 11229	>2000 µg/mL		
	Hydrosols (microwave-assisted distillation)	*Staphylococcous aureus* (+) ATCC 25923	>500 µg/mL	MIC: Broth microdilution test plate well	
		Escherichia coli (-) ATCC 11229	>500 µg/mL		
Flowers	**Phenol extracts**	*Escherichia coli* (-) *ATCC 25922*	IZ 6 mm	Disc diffusion method	(Jurca et al., 2018)
		Pseudomonas aeruginosa (-) *ATCC 27853*	IZ 6 mm		
		Staphylococcus aureus (+) *ATCC 25923*	IZ 6 mm		
		Streptococcus pneumoniae (+) *ATCC 49619*	IZ 8 mm		
		Candida albicans ATCC 90029	IZ 6 mm		
		Staphylococcus aureus methicillin-sensible (+)	IZ 6 mm		
		Staphylococcus epidermidis methicillin-resistant (+)	IZ 6 mm		
		Streptococcus pyogenes Group A Beta haemolytic (+)	IZ 8 mm		
		Streptococcus agalactiae Group B Beta haemolytic (+)	IZ 6 mm		
		Streptococcus agalactiae Group G Beta haemolytic (+)	IZ 8 mm		

Plant part	Solvent (Extraction Method)	Microorganism	Results	Antimicrobial Assay	Reference
Aboveground parts	**Juice**	*Bacillus subtilis* (+) ATCC 6633	IZ 15 ± 1.1 mm	Agar well diffusion method	(Marchyshyn et al., 2021)
		Escherichia coli (-) ATCC 25922	IZ 17 ± 0.9 mm		
		Staphylococcous aureus (+) ATCC 6538	IZ 27 ± 0.96 mm		
		Pseudomonas aeruginosa (-) ATCC 9027	IZ 18 ± 0.9 mm		
		Candida albicans ATCC 885-653	IZ 20 ± 1.64 mm		
Raw material (not specified)	**Hydroethanolic and Aqueous**	*Staphylococcous aureus* (+) ATCC 29213	ND	Disc diffusion method	(Bazylko et al., 2013)
		Bacillus subtilis (+) ATCC 6633	ND		
		Micrococcus luteus ATCC 9341	ND		
		Escherichia coli (-) ATCC 25922	ND		
		Pseudomonas aeruginosa (-) ATCC 27853	ND		
		Bordetella bronchiseptica (-) ATCC 4617	ND		

(-): Gram-negative; (+): Gram-positive; IZ: Inhibition zone; MIC: Minimum Inhibitory Concentration; MBC: Minimal Bactericidal concentrations; ND: not demonstrated.

Bazylko et al. (2013) and Vrca et al. (2022) reported minimal or no antimicrobial activity, which is probably associated with the low content of BITC in the extracts. This supports the fact that BITC is the primary compound responsible for the antimicrobial activity. On the other hand, a study conducted with juice extracted from the aboveground parts of *T. majus* demonstrated a satisfactory antimicrobial activity against a wide range of microorganisms (Marchyshyn et al., 2021). This result is noteworthy due to the strong antimicrobial activity observed, even with the use of the agar well diffusion method. However, the authors did not describe the composition of the extract or the preparation method of the juice. Furthermore, the authors did not evaluate the composition of the extracts, making it impossible to determine the compounds or factors responsible for the observed antimicrobial activity.

Several studies have been conducted on *Tropaeolum majus* in recent years. However, researchers have shifted their focus away from studying its antimicrobial properties, choosing instead to explore other attributes. This change in focus suggests a consensus among researches that *T. majus* exhibits limited or negligible antimicrobial activity, resulting in fewer recent studies dedicated to this particular aspect. Consequently, scientific efforts have concentrated on exploring its antioxidant, anti-inflammatory, diuretic, hepatoprotective properties, among others. This shift has broadened the understanding of the plant's multifunctional potential in various contexts.

Antioxidant activity of garden nasturtium extracts

The antioxidant activity of *T. majus* extracts has been evaluated using various assays, extraction methods, and solvents (Table 6). Overall, the results highlight the plant's potential as a source of antioxidants. However, the studies demonstrated notable variability in efficacy depending on the specific conditions and methods used.

Table 6. Antioxidant studies of *Tropaeolum majus* L. extracts in the last years (2013 - 2024).

Plant Part	Solvent (Extraction Method)	Antioxidant Assay	Result	Reference
Leaves	**Methanol (Soaked)**	DPPH	IC_{50} 17.39 ± 0.354 µg/mL	(Ailane et al., 2022)
		HO•	IC_{50} 30.49 ± 0.470 µg/mL	
	Raw extract (Maceration)	DPPH	IC_{50} 79.86 ± 1.27 µg/mL	(Musolino et al., 2023)
		β-carotene bleaching test (30 min)	IC_{50} 38.15 ± 1.34 µg/mL	
		β-carotene bleaching test (60 min)	IC_{50} 62.58 ± 2.51 µg/mL	
	Aqueous extract (Maceration)	DPPH	IC_{50} 77.55 ± 2.81 µg/mL	
		β-carotene bleaching test (30 min)	ND	
		β-carotene bleaching test (60 min)	ND	
	n-hexane fraction (Maceration)	DPPH	ND	
		β-carotene bleaching test (30 min)	ND	
		β-carotene bleaching test (60 min)	ND	
	Dichloromethane (Maceration)	DPPH	IC_{50} 53.72 ± 0.52 µg/mL	
		β-carotene bleaching test (30 min)	IC_{50} 49.0 ± 0.93 µg/mL	
		β-carotene bleaching test (60 min)	ND	
	Ethyl acetate (Maceration)	DPPH	IC_{50} 14.08 ± 0.29 µg/mL	
		β-carotene bleaching test (30 min)	IC_{50} 41.68 ± 1.38 µg/mL	
		β-carotene bleaching test (60 min)	IC_{50} 63.41 ± 0.17 µg/mL	
	Ethanol (Soxhlet)	DPPH	52.5%	(Valsalam et al., 2019)
		ABTS	43.4%	
		Total Antioxidant Activity	530 µg/mL	

Plant Part	Solvent (Extraction Method)	Antioxidant Assay	Result	Reference
	Aqueous (Soxhlet)	DPPH	66.1%	
		ABTS	56.6%	
		Total Antioxidant Activity	550 µg/mL	
	Aqueous methanolic (Ground)	ABTS and DPPH	Average around 55 µmol/g	(Česlová et al., 2023)
	Methanolic (Rotary evaporator)	DPPH	IC_{50} 17.39 ± 0.354 µg/mL	(Ailane & Bennadja, 2023)
		HO•	IC_{50} 30.49 ± 0.470 µg/mL	
Flowers	**Methanol (Soaked)**	DPPH	IC_{50} 21.32 ± 0.066 µg/mL	(Ailane et al., 2022)
		HO•	IC_{50} 60.80 ± 0.330 µg/mL	
	Phenol extract	DPPH	84.5 ± 1.11 %	(Jurca et al., 2018)
		FRAP	56.69 ± 0.05 µmol Trolox equivalent/g d.w.	
		CUPRA*C*	8.98 ± 5.98 µmol Trolox equivalent/g d.w.	
	Lyophilized crude extract	Reducing Power	EC_{50} 320 ± 10 µg/mL	(Koike et al., 2015)
		DPPH radical-scavenging	EC_{50} 640 ± 50 µg/mL	
		Inhibition of β-carotene bleaching	EC_{50} 1000 ± 100 µg/mL	
	Irradiated Lyophilized Crude Extract (0.5 kGy)	Reducing Power	EC_{50} 290 ± 40 µg/mL	
		DPPH radical-scavenging	EC_{50} 690 ± 50 µg/mL	
		Inhibition of β-carotene bleaching	EC_{50} 1500 ± 500 µg/mL	
	Irradiated Lyophilized Crude Extract (0.8 kGy)	Reducing Power	EC_{50} 310 ± 50 µg/mL	
		DPPH radical-scavenging	EC_{50} 680 ± 40 µg/mL	
		Inhibition of β-carotene bleaching	EC_{50} 1300 ± 500 µg/mL	
	Irradiated Lyophilized Crude Extract (1.0 kGy)	Reducing Power	EC_{50} 320 ± 20 µg/mL	
		DPPH radical-scavenging	EC_{50} 660 ± 40 µg/mL	
		Inhibition of β-carotene bleaching	EC_{50} 600 ± 300 µg/mL	
	Orange flowers aqueous methanol (Ground)	ABTS	40.0 - 46.3 µmol/g	(Česlová et al., 2023)
		DPPH	25.7 - 29.9 µmol/g	
	Yellow flowers aqueous methanol (Ground)	ABTS	30.1 - 35.6 µmol/g	
		DPPH	20.8 – 22.4 µmol/g	
	Methanolic (Rotary evaporator)	DPPH	IC_{50} 21.32 ± 0.066 µg/mL	(Ailane & Bennadja, 2023)
		HO•	IC_{50} 60.80 ± 0.0330 µg/mL	

Plant Part	Solvent (Extraction Method)	Antioxidant Assay	Result	Reference
	Yellow flowers Ethanolic + HCl	ABTS	2.99 ± 0.20 µmol Trolox/g	(Souza et al., 2020)
	Orange flowers Ethanolic + HCl	ABTS	4.10 ± 0.15 µmol Trolox/g	
	Red flowers Ethanolic + HCl	ABTS	13.59 ± 0.55 µmol Trolox/g	
Stem	**Aqueous methanol (Ground)**	ABTS and DPPH	Average around 14 µmol/g	(Česlová et al., 2023)
Leaves and Flowers (Lyophilization + water bath)	**Aqueous**	DPPH	24.1 ± 0.7%	(Bazylko et al., 2014)
		H_2O_2	SC_{50} 87.6 ± 24.4 µg/mL	
		$O_2^{\bullet-}$	SC_{50} 57.6 ± 4.7 µg/mL	
	Hydroethanolic	DPPH	37.5 ± 2.4%	
		H_2O_2	SC_{50} 68.5 ± 16.3 µg/mL	
		$O_2^{\bullet-}$	SC_{50} 51.2 ± 5.8 µg/mL	
Leaves, flowers, and stems	**Juice (Squeezer)**	DPPH	34.7 ± 1.3%	
		H_2O_2	ND	
		$O_2^{\bullet-}$	SC_{50} 60.4 ± 2.0 µg/mL	
Raw material (not specified)	**Aqueous (Dried material)**	H_2O_2	SC_{50} 38.63 ± 9.28 µg/mL	(Bazylko et al., 2013)
		$NO^{\bullet}$	SC_{50} 8.40 ± 1.55 µg/mL	
		$ONOO^-$	SC_{50} 5.55 ± 1.57 µg/mL	
	Aqueous (Dried material - 90 °C)	H_2O_2	SC_{50} 26.13 ± 3.49 µg/mL	
		$NO^{\bullet}$	SC_{50} 4.54 ± 0.26 µg/mL	
		$ONOO^-$	SC_{50} 5.74 ± 1.34 µg/mL	
	Hydroethanolic (Dried material)	H_2O_2	SC_{50} 14.90 ± 3.91 µg/mL	
		$NO^{\bullet}$	SC_{50} 7.31± 1.29 µg/mL	
		$ONOO^-$	SC_{50} 6.01± 1.88 µg/mL	
	Hydroethanolic (Dried material - 90 °C)	H_2O_2	SC_{50} 18.08 ± 1.93 µg/mL	
		$NO^{\bullet}$	SC_{50} 6.16 ± 0.79 µg/mL	
		$ONOO^-$	SC_{50} 6.20± 2.09 µg/mL	
	Aqueous (Freeze-dried material)	H_2O_2	SC_{50} 35.13 ± 7.30 µg/mL	
		$NO^{\bullet}$	SC_{50} 10.90 ± 1.39 µg/mL	
		$ONOO^-$	SC_{50} 4.65 ± 2.80 µg/mL	
	Aqueous (Freeze-dried material -90 °C)	H_2O_2	SC_{50} 33.72 ± 4.16 µg/mL	
		$NO^{\bullet}$	SC_{50} 8.41 ± 0.71 µg/mL	
		$ONOO^-$	SC_{50} 6.37 ± 1.86 µg/mL	

Plant Part	Solvent (Extraction Method)	Antioxidant Assay	Result	Reference
	Hydroethanolic (Freeze-dried material)	H_2O_2	SC_{50} 27.40 ± 4.10 µg/mL	
		$NO^{\bullet}$	SC_{50} 4.56 ± 0.95 µg/mL	
		$ONOO^-$	SC_{50} 2.49 ± 1.50 µg/mL	
	Hydroethanolic (Freeze-dried material - heat)	H_2O_2	SC_{50} 17.06 ± 4.71 µg/mL	
		$NO^{\bullet}$	SC_{50} 4.84 ± 0.81 µg/mL	
		$ONOO^-$	SC_{50} 3.07 ± 1.18 µg/mL	

H_2O_2: Hydrogen peroxid; $O_2^{\bullet-}$: superoxide radical; $ONOO^-$: peroxynitrite; $NO^{\bullet}$: nitric oxide; IC_{50}: Concentrations of the extracts resulting in 50% inhibition; SC_{50}: 50% scavenging capacity; EC_{50}: 50% of antioxidant activity.

Although there is variability in the results, a pattern is observed regarding the antioxidant activity linked to different flower colors (yellow, orange, and red). Red flowers demonstrate the highest antioxidant activity, followed by orange, with yellow flowers exhibiting the lowest activity. This result can be attributed to the composition and predominant presence of bioactive compounds unique to each color of the nasturtium flower (Česlová et al., 2023; Garzón et al., 2015).

A study conducted by Gárzon et al. (2015) identified red flowers of *T. majus* as having the highest flavonol content, with myricetin derivates as the predominant flavonoids, followed by kaempferol and quercetin derivates. The authors highlighted the quercetin levels present in red flowers, comparing it to those found in certain food and medicinal plants. Moreover, red flowers demonstrated the greater ORAC radical-scavenging activity compared to orange and yellow flowers, indicating a superior antioxidant capacity. The unique chemical structures and high concentrations of phenolic compounds in red flower extracts are likely responsible for their strong antioxidant properties, distinguishing them as a potent source of bioactive compounds.

The antioxidant activity of *T. majus* is attributed to its diverse range of bioactive compounds, including sulfur compounds, flavonoids, anthocyanins, phenolic acids, and vitamin C (Bazylko et al., 2013; Jurca et al., 2018). Flavonoids, a subclass of polyphenols, are well-known for their antioxidant activity and play an important role in the bioactive properties of *T. majus*, including its antioxidant activity. Notably, quercetin, epicatechin, luteolin and their derivates are common flavonoids identified in this plant (Bazylko et al., 2013; Garzón et al., 2015; Jurca et al., 2018).

Although antioxidant activity is most commonly reported as IC_{50} values, the studies included in this review revealed considerable variability in the parameters used to express the final results. This heterogeneity was observed not only in studies evaluating *Tropaeolum majus* L. extracts, but also in those involving the other two plant species analyzed. A similar pattern was observed in studies evaluating antimicrobial activity, where the MIC was the most commonly reported parameter. Consequently, different reporting metrics were used across studies, which limits the direct comparability of the bioactivity potential among the evaluated extracts. This variation in the way the parameters are expressed makes direct comparisons between studies more difficult and highlights the need for standardization in methodological approaches and data reporting. Improved consistency in experimental parameters and in the reporting of antioxidant and antimicrobial results would facilitate more reliable comparisons and strengthen the interpretability of evidence generated in phytochemical research.

CONCLUSION

This review explored the antioxidant and antimicrobial potential of three non-conventional edible plants found in Brazil: *Schinus terebinthifolius*, *Pereskia aculeata*, and *Tropaeolum majus*. It highlighted their potential applications in the food and pharmaceutical industry, particularly in the development of clean label products, as natural alternatives to synthetic additives. Comparatively, *Tropaeolum majus* was supported by a slightly lower number of recent studies (n=13) addressing antioxidant and antimicrobial activities, whereas the other two plant species were each evaluated in 16 studies. The evidence regarding the antimicrobial activity of *T. majus* appears less robust, as only a limited number of studies have specifically focused on this aspect, often reporting limited of no activity. Although several studies on *T. majus* have been published in recent years, there has been a noticeable shift away from investigating its antimicrobial properties toward other bioactivities. This suggests that its antimicrobial potential may be limited, which has redirected research efforts toward exploring its broader functional properties.

However, discrepancies between methodologies for evaluating antimicrobial activity were identified, confirming that the broth microdilution method proved to be more reliable than the agar well diffusion method, as the latter can be affected by factors that compromised the results.

In addition, the methodological heterogeneity observed among studies highlights the need for greater standardization of result parameters, in order to improve the reproducibility and comparability of future research. Moreover, although *Pereskia aculeata* (*ora-pro-nóbis*) and *Tropaeolum majus* (nasturtium) are frequently mentioned in the literature for their antimicrobial activity, the findings revealed that their antimicrobial properties were limited or non-existing. On the other hand, their antioxidant capacity is well-supported, with consistent results

across different assays. Despite these variations in the findings, the use of these plants remains promising for further practical applications.

There were notable gaps in the current research. Most studies did not thoroughly evaluate the compounds responsible for the observed properties. Future studies should prioritize a comprehensive characterization of the extracts' composition, along with a thorough analysis of their bioactive properties. Furthermore, the existing studies primarily assessed antimicrobial and antioxidant activity *in vitro*. The bioactive compounds identified may undergo changes, interact with food matrices, or exhibit different behavior within the human body. Therefore, *in vivo* studies are crucial to confirm their effectiveness and further explore their potential applications in the food and pharmaceutical industries.

Moreover, the studies predominantly focused on the antimicrobial activity of extracts against bacteria, with few evaluating their effects on fungi. Among those that did, the research was mostly limited to species of the *Candida* genus. However, fungi are increasingly associated with significant losses due to food contamination, highlighting the need to expand the scope of antimicrobial assessments. Evaluating the antifungal potential of these extracts would be an important step for the food industry, as antimicrobial activity is not restricted to bacteria alone. Therefore, future studies should broaden their approach to include a wider range of microorganisms, providing a more comprehensive understanding of the extracts' bioactive properties.

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DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

NOMENCLATURE

ABTS: [2,2'-Azinobis(3-Ethylbenzothiazoline-6-Sulphonic Acid)] Free Radical Scavenging Activity Assay;
DPPH: (1, 1-Diphenyl-2-Picrylhydrazyl) Free Radical Scavenging Activity Assay;
FRAP: Ferric Reducing Antioxidant Power;
CUPRAC: Cupric Reducing Antioxidant Capacity;
ORAC: Oxygen Radical Absorbance Capacity;
IC_{50}: 50% inhibitory capacity;
SC_{50}: 50% scavenging capacity;
EC_{50}: Maximal effective concentration;
MIC: Minimal Inhibitory Concentrations;
MBC: Minimal Bactericidal Concentrations.

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