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Evaluation of the antimicrobial effect of Persea americana Mill: a scoping review (PRISMA-ScR)

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ABSTRACT

The use of medicinal plants is an ancient practice and a source of research for the development of new antimicrobial agents. The active compounds extracted from them can be important allies in the fight against microbial resistance, which is one of the major public health problems. *Persea americana*, popularly known as the avocado, is a fruit widely used empirically in folk medicine. Its antimicrobial potential is being investigated worldwide. The aim of this study was to perform a systematic scoping review using the PRISMA-ScR method, selecting scientific articles published in the databases PubMed, Science Direct, SciELO, Scopus, CAPES periodics, LILACS and Web of Science, between 2015 and March 2021, on the antimicrobial activity of Persea americana Mill against microorganisms of interest to the medical and agrochemical industries. The extract of this plant was found to be effective against several pathogens such as *Staphylococcus aureus*, *Bacillus cereus*, *Pseudomonas aeruginosa*, *Listeria monocytogenes*, *Candida albicans* and *Candida tropicalis*. Due to the lack of detailed studies, it is recommended that new studies be developed focusing on the isolation and elucidation of the chemical compound(s) from *P. americana* responsible for the antimicrobial activity.

RESUMO

O uso de plantas medicinais é uma prática milenar que constitui fonte de estudo para desenvolvimento de novos agentes antimicrobianos. As substâncias ativas extraídas dessas podem ser importantes aliadas no combate à resistência microbiana, que é um dos principais problemas de saúde pública. A *Persea americana*, conhecida popularmente como abacate, é um fruto muito utilizado de forma empírica na medicina popular. O seu potencial antimicrobiano é explorado por todo o mundo. O objetivo deste trabalho foi realizar uma revisão sistemática de escopo pelo método PRISMA-ScR, selecionando artigos científicos publicados em bancos de dados (PubMed, Science Direct, SciELO, Scopus, Periódicos CAPES, LILACS e Web of Science), entre os anos de 2015 até março de 2021, sobre o efeito antimicrobiano da *Persea americana* Mill frente a microrganismos de interesse para a indústria médica e agroquímica. O extrato dessa planta mostrou-se eficaz contra diversos patógenos, tais como *Staphylococcus aureus, Bacillus cereus, Pseudomonas aeruginosa, Listeria monocytogenes, Candida albicans, Candida tropicalis*. Devido à ausência de estudos detalhados, é recomendável o desenvolvimento de novos ensaios com foco no isolamento e elucidação de composto(s) químico(s) da *P. americana* responsáveis pela ação antimicrobiana.

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Introduction

The use of medicinal plants for therapeutic purposes is a practice that goes back generations and has been an important source of research for the development of new antimicrobial agents. This is due to the chemical and biological diversity of the species and the consequent potential for obtaining bioactive substances (Amparo et al., 2018; Ribeiro et al., 2018).

The avocado, belonging to the genus *Persea*, includes three species, *P. schiedeana*, *P. parvifolia* and *P. americana*, which are widely distributed in the Americas. *Persea americana* Mill. (Lauraceae) is a fruit native of Central America, more specifically Guatemala, Antilles and Mexico. Its botanical varieties are *Persea americana* var. *americana*, *Persea americana* var. *guatemalensis* and *Persea americana* var. *drymifolia*. (Robayo-Medina, 2016).

According to the Food and Agriculture Organization of the United Nations - FAO (2019), avocado production is concentrated in Northern South America, including Brazil, Peru and Chile, and extends to Mexico. In Brazil, avocado cultivation is spread across all regions, but São Paulo and Minas Gerais are the states that stand out in terms of avocado production (Souza et al., 2020).

The avocado tree is recognized as a medicinal plant in scientific literature and its use is widespread in folk medicine. Its leaves and seeds are used empirically as a diuretic through infusion, and its seeds are also used for anti-inflammatory purposes through maceration with alcohol (Rodrigues et al., 2015; Viana, 2019). In addition, studies show that *P. americana* has been used empirically for the treatment of post-malaria anaemia, bacterial and anti-parasitic diseases (Viega & Scudeller 2015).

The fruit is rich in polyphenolic compounds and other bioactive compounds such as tannins, flavones and catechins, which has antimicrobial, anti-inflammatory, antioxidant and even anticancer activities. The potential use of this fruit, which is often treated as industrial waste, can contribute to environmental management as well as economic and social aspects (Souza, 2016; Rosero et al., 2019).

Microbial resistance to conventional antibiotics and antifungals is one of the world's major public health problems. The inappropriate and long-term use of these drugs leads to various complications, such as cases of hospital-acquired infections due to the action of multidrug-resistant bacteria and fungi. Therefore, the search for new antimicrobials from natural extracts is an alternative against this resistance (Dutra et al., 2016; Loureiro et al., 2016; Bravo et al., 2018).

In this context, the aim of this review is to carry out a systematic scoping review based on scientific articles on the antimicrobial activity of *Persea americana* Mill against microorganisms of clinical and agricultural importance, with the purpose of exploring the existing knowledge on this activity and contributing to the dissemination of information in the

scientific field, as well as encouraging the search for new antimicrobial agents based on natural extracts.

Methodology

This Scoping review was based on Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews: Checklist and Explanation (PRISMA-ScR) (Tricco et al., 2018). The aim of the review is to identify gaps in knowledge, scope a body of literature and clarify concepts to better evaluate the antimicrobial activity of *Persea americana* against the main microorganisms of clinical and agricultural importance. The following databases were screened: PubMed, Science Direct, SciELO (Scientific Eletronic Library Online), Scopus, CAPES periodics, LILACS and Web of Science.

The search strategy was performed by two independent reviewers and the terms used for each database were: "(antimicrobial activity or antifungal activity or antibacterial activity or antiviral activity) and *Persea americana" and "*(atividade antimicrobiana or atividade antifúngica or atividade antibacteriana or atividade antiviral) and *Persea americana"*. The focused question is as follows: What is the antimicrobial potential of the *Persea americana*?

Original studies were eligible for this review with the criteria adopted: (i) publication date between 2015 and October 2021; (ii) being an empirical study; (iii) written in English or Portuguese language; (iv) published in a scholarly peer-reviewed journal, and (v) conducted an antimicrobial assay with oil essential, crude extracts or compounds obtained of *Persea americana*. Books, book chapters, and technical reports were not considered. The data was tabulated with the help of Microsoft Office Excel 365 and analyzed using simple descriptive statistics (n; %).

Results

Of the 212 articles screened from all databases [PubMed (41), Scopus (34), Web of Science (54), SciELO (3), CAPES Portal (32), LILACS (5), Science Direct (43)] and duplicates removed, 162 studies were identified (Figure 1). After title and abstract screening, 121 met the exclusion criteria (review articles, doctoral theses, book chapters), leaving 41 studies, which were reduced to 25 after full-text screening because the studies were not related to the antimicrobial assay or showed results with other *Persea* species. The last electronic search was performed on March, 19th 2021.

Table 1 describes the authors and year of publication of the study, place/region where the plant material was collected, part of *Persea americana* used, type of extract (solvent), microorganisms tested, type of antimicrobial activity (antiviral, antifungal or antibacterial), methodology and tests results. All articles were published between 2015 and 2021 (Figure 2).

It was observed that the leaves and seeds were the most used parts in the studies and that antibacterial and antifungal activities were the most reported. However, there was a lack of publications investigating the antiviral activity of the extract.

Figure 1.

Records identified through article search databases

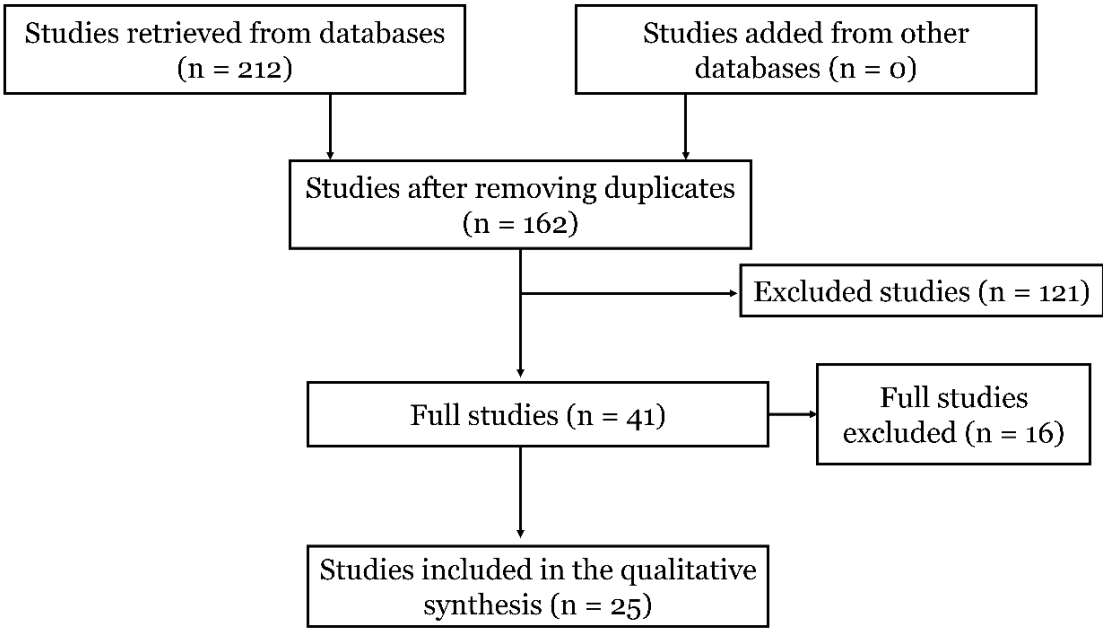

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Table 1.
Articles on Persea americana extract and its antimicrobial activity

Author	Location/ region	Part used	Variety	Type of extract (solvent)	Test Microorganisms	Antimicrobial activity	Methods	Results
Akalazu & Uchegbu, 2020	Data gaps	Seeds	Data gaps	Ethanolic extract	*Botryodiploidia theobromae Rhizopus stolonifer Aspergillus flavus Fusarium oxysporium Geothricum candidum*	Antifungal	Paper disc diffusion method (PDDM)	Inhibition of *B. theobromae* (13.20%), *R. stolonifera* (14.02%), *A. flavus* (12.10%), *F. oxysporium* (9.30%), *G. candidum* (7.00%)
Akinpelu et al., 2020	Ife - Nigeria	Stem bark	Data gaps	Hydro-alcoholic extract	*Bacillus cereus*	Antibacterial	Ágar diffusion method (ADM) and Determi-nation of the minimum inhibitory concentra-tion (MIC).	MIC = 0,78 mg/mL to 12,5 mg/mL

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Almeida et al., 2017	Vargem Grande Paulista - Brazil	Data gaps	Data gaps	Essential oil	*Candida glabrata* resistant to Fluconazole	Antifungal	ADM and MIC	Inhibition halo = 0. MIC > 1000 µg/mL
Báez-Maganã et al., 2019	Mexico	Seeds	Drymi-folia	Lipid-rich extract	*Staphylococcus aureus*	Antibacterial	Turbidi-metry test	The growth of *S. aureus* was not affecte
Biasi-Garbin et al., 2016	Brazilian Caatinga	Leaves	Data gaps	Ethanolic, aqueous and acetone extracts	*Trichophyton rubrum* and *Trichophyton mentagrophytes* complex	Antifungal	MIC	MIC = 62,5 µg/mL
Cardoso et al., 2016	Londrina – Paraná – Brazil	Seeds	Marga-rida	Ethanolic extract	*Streptococcus agalactiae*	Antibacterial	PDDM	Inhibition halo = 7 to 9,5 mm
da Cruz et al., 2019	Brazilian Caatinga	Leaves	Data gaps	Data gaps	*Staphylococcus aureus*	Antibacterial	PDDM and MIC	Inhibition halo = 13 to 20 mm. MIC= 3,12 to 12,5 mg/mL.
de Freitas et al., 2020	Crato-CE - Brazil	Leaves	Data gaps	Ethanolic extract	*Candida albicans and C. tropicalis*	Antifungal	MIC and biofilm test	MIC = 512 µg/mL (*C. tropicalis*). MIC ≥ 1024 µg /mL (*C. albicans*) Biofilm formation within 48 h.
Deuschle et al., 2019	Cruz Alta, RS - Brazil	Leaves	Ameri-cana	Hydro-ethanolic extract and chloroform, ethyl acetate and butanol fractions.	*Candida glabrata*, *C. glabrata* resistant to Fluconazole, *C. tropicalis*, *C. parapsilosis*, *C. dubliniensis*, *C.*	Antifungal Antibacterial	MIC	Hydroethanol extract and the ethyl acetate and butanol fractions with an MIC of 32 µg/ml against *Candida glabrata*

					dubliniensis resistant to Fluconazole, *C. albicans*, *C. guilliermondii*, *Cryptococcus neoformans*, *Saccharomyces cerevisae*, *Aspergillus fumigatus*, *A. flavus*, *Mycobacterium abscessos*, *M. fortuitum*, *M. Massiliense*, *M. smegmatis*, *M. avium*			and *Candida glabrata* resistant to fluconazole. The ethyl acetate fraction with an MIC of 156.25 µg/ml against all species tested
Dzotam & Kuete, 2017	Koung-Khi - Cameroon	Leaves	Data gaps	Methanol extracts	*Escherichia coli, Enterobacter aerogenes, Enterobacter cloacae, Klebsiella pneumoniae, Providencia stuartii, Pseudomonas aeruginosa*	Antibacterial	MIC and MBC	MIC = 64 to 512 μg/mL, MBC = 512 μg/mL (*E. coli*); MIC = 128 to 512 μg/mL, MBC = 1024 μg/mL (*E. aerogenes),* MIC = 256 to 512 μg/mL (*K. pneumoniae),* MIC = 256 to 1024 μg/mL (*P. Stuartii and E. cloacae),* MBC = 1024 μg/mL (*P. Stuartii*)

Fagundes et al., 2018	São Sebastião do Paraíso, MG - Brazil	Seeds	Breda e Marga-rida	Ethanolic extracts	*Colletotrichum gloeosporioides, Monilinia fructicola e Prunus persica*	Antifungal	Inhibition of mycelial growth (IMG)	Ethanolic extracts *3%, IMG* = 93,56% against *M. fructicola (21 days of incubation) and IMG*= 58,41% to 59,37% *against C. gloeosporioides (7 days of incubation)*
García-Moreno et al., 2017	Zaragoza and Aramberri, Nuevo León Mexico	Leaves	Drymi-folia	Polyphenols were extracted by ultrasound-assisted extraction from leaves of 18 cultivars of mexican avocado	*Methicillin-resistant Staphylococcus aureus (MRSA)*	Antibacterial	ADM, MIC and MBC	18 cultivars tested, inhibition halo ≤ 20 mm. Cultivar María Elena, MIC =116 µg/mL and MBC = 133 µg/mL against MRSA µ3 strain
Jesus et al., 2015	*P. americana* glycolic extract was provided by company Mapric (São Paulo, SP, Brazil)	Data gaps	Data gaps	Glycolic extract	*Candida albicans*	Antifungal	MIC and biofilm test	MIC = 6,25 mg/mL and with 12.5 mg/mL there was elimination of 100% of planktonic cultures. Significant reduction ($P < 0.001$) of the biofilm at concentrations of 50 (0.580 ± 0.209 log10), 100 (0.998 ±

								0.508 log10), and 200 mg/mL (1.093 ± 0.462 log10)
Kahaliw et al., 2017	Bure town, North West Ethiopia	Leaves	Data gaps	Acetone and 80% methanol extracts	*Mycobacterium tuberculosis*	Antibacterial	Colony count assay (CFU method)	Total inhibition of growth of mycobacteria was observed at a concentration of 0.125 µg/ml for 80% methanol extract and 2,50 mg/mL for acetone extract
Makopa et al., 2020	Chitungwiza Baptist (Greater Harare, Zimbabwe)	Leaves	Data gaps	DCM:methanol (1 : 1), ethanol:water (1 : 1), hexane, dichloromethane (DCM), ethyl acetate, acetone, ethanol, methanol, and water extracts	*Klebsiella pneumoniae*, *Staphylococcus epidermidis,* *Candida albicans* and *Candida tropicalis*	Antibacterial and antifungal	MIC	< 50% of cell viability for Ethanol:water extract against all test strains. DCM and methanol extracts was 28% of cell viability against *C. albicans* and 8% against *C. tropicalis*, respectively. MIC =100 µg/mL (Ethanol:water, DCM:methanol extracts) and 50 µg/mL (acetone extract) against *S. epidermidis*
Melgar et	Bragança -	Kernels	Hass	Hydro-	*Staphylococcus*	Antibacterial and	MIC, MBC	Seed extracts

al., 2018	Portugal	and peels		alcoholic extract	*aureus, Bacillus cereus, Micrococcus flavus, Listeria monocytogenes, Escherichia coli, Pseudomonas aeruginosa, Salmonella typhimurium, Enterobacter cloacae. Aspergillus fumigatus, A. ochraceus, A. versicolor, A. niger, Penicillium funiculosum, P. ochrochloron, P. verrucosum var. cyclopium, Trichoderma viride*	antifungal	and minimum fungicidal concentra-tions (MFC)	showed MCB (0.070 µg/mL) in 6 of the 8 strains, with CIM ranging from 0.020 - 0.15 µg/mL. For the bark extract, the MIC = 0.010 - 0.30 µg/mL and the MCB = 0.030 - 0.45 µg/mL. Fungicidal activity was demonstrated in 2 strains with seed extracts, of which the best fungicidal activity was against *T. viride* (0.03 µg/mL). When comparing the fungistatic activity, both extract by-products were effective against all 8 strains (0.2-0.3 µg/mL).
Nahak et al., 2017	Data gaps	Leaves	Data gaps	Ethanol extract	*Streptococcus mutans*	Antibacterial	PDDM	Halo diameters of 9.06 ± 2.120 mm and 10.13 ± 2.996 mm for 25% and 50% ethanolic extracts, respectively.

Pacheco et al., 2017	Uruapan (Michoacan, México)	Seeds	Hass	Acetogenin extract (EAE) and semi-commercia-lly Avosafe®	*Clostridium sporogenes*	Antibacterial	PDDM, MIC and MBC	Halo diameters ≅ 2.75 cm (EAE) and ≅ 2,1 cm (Avosafe®). EAE: MIC = 7.8–15.6 and 9.8 mg/mL, MBC = >125 and >39 mg/mL against *C. sporogenes* for vegetative cells and endospores, respectively. Avosafe®: MIC = 3.9 mg/mL and MBC = >125 mg/mL against endospore germination
Roumy et al., 2017	District of Loreto (Peruvian Amazon)	Seeds	Hass	Methanolic extract	Enterobacteria lactose-positive and VP positive, Enterobacteria lactose-negative, Gram-positive cocci, Gram-negative bacteria, and miscellaneous microorganisms	Antibacterial	MIC	MIC = 0,07 to 0,3 mg/mL against Gram positive cocci (*Staphylococcus epidermidis*, *Staphylococcus lugdunensis*, *Staphylococcus warneri*, *Enterococcus* sp, *Enterococcus faecalis*, *Streptococcus agalactiae*, *Streptococcus dysgalactiae*) and miscellaneous

								strains (*Mycobacterium smegmatis*, *Corynebacterium striatum* and *Candida albicans*)
Salinas-Salazar et al., 2017	Sabinas, Mexico	Seeds	Hass	Acetogenin extract (EAE), Avosafe® and Mirenat®	*Listeria monocytogenes*	Antibacterial	PDDM, MIC and MBC	Halo diameters = 1.6 ± 0.7 cm (EAE), 1.3 ± 0.3 cm (Avosafe® 1.4 ± 0.0 cm (Mirenat®). EAE, MIC and MBC= 15.6 and 7.8 mg/L at 37 and 4 °C, respectively. Avosafe® and Mirenat®, MIC = 15.6 and 7.8 to 15.6 mg/L at 37 and 4 °C, respectively. MBC = 31.2 and 15.6 to 31.2 mg/L at 37 and 4 °C, respectively.
Sierra Castrillo et al., 2020	Antioquia - Colômbia	Peels, pulp and seeds	Choque-tte	Chloroform, hexane, ethyl acetate, methanol extracts	*Staphylococcus aureus, Eschericha coli*	Antibacterial	PDDM, MIC and MBC	Presence of inhibition halo for *S. aureus* using seed hexane extract, peel chloroform and ethyl acetate extracts and for *E. coli* using the peel chloroform and peel hexane extracts. Peel

								(chloroform,hexano extracts) and seed (hexano extract): MIC and MBC = 1000 mg/ml against *S. aureus* and *E. coli*
Sudhasupriya et al., 2017	Local market in and around Thiuvana-malai district. India	Seeds	Data gaps	Methanol, ethylacetate, and petroleum ether extracts	*Klebsiella pneumoniae; E.coli; Pseudomonas aeruginosa; Salmonella typhi; Bacillus subtilis, Staphylococcus aureus*	Antibacterial	Agar well diffusion method and MIC	Presence of inhibition halo for all extracts against all strains tested. MIC = 50 and 100µg/ml against *E. coli*, *S. aureus*, *K. pneumonia* and *P. aeuroginosa*.
Trujillo-Mayol et al., 2021	North part of Chile	Peel	Hass	Peel extract (APE), organic fraction (OF); aqueous fraction (AF); acid-microwave hydrolyzed avocado peel extract (HAPE)	*Pseudomonas aeruginosa, Bacillus cereus, Staphylococcus aureus, Salmonella spp., Listeria monocytogenes, Escherichia coli*	Antibacterial	MIC	*P. aeruginosa* and *B. cereus* with MIC = 500 µg/mL, *E. coli*, *S. aureus, and Salmonella spp. with MIC = ≥750 to ≥1000* µg/mL, *L. monocytogenes with MIC = ≥125 to ≥1000* µg/mL to all the extracts.
Velarde et al., 2020	Uruapan, Michoacan, Mexico.	Leaves	Hass	Hydro-alcoholic extract	*Listeria monocytogenes; Enterococcus sp.; Staphylococcus sp; Escherichia*	Antibacterial	PDDM and MIC	Avocado extracts showed no antimicrobial activity.

					coli; Salmonella enterica serotipo Enteriditis, Klebsiella sp., *Pseudomonas* sp.			
Xoca-Orozco et al., 2019	Nayarit, Mexico	Fruit epicarp at the maturity stage of physiolo-gical (PMS), interme-diate (IMS) and consump-tion (CMS) treated with chitosan.	Data gaps	Phenolic compounds extracts	*Colletotrichum gloeooriospides*	Antifungal	PDDM	Inhibition >50% of mycelial growth was 16 mg/mL for chitosan-treated IMS and CMS, and a reduction in sporulation and spore germination of *C. gloeosporioides*.

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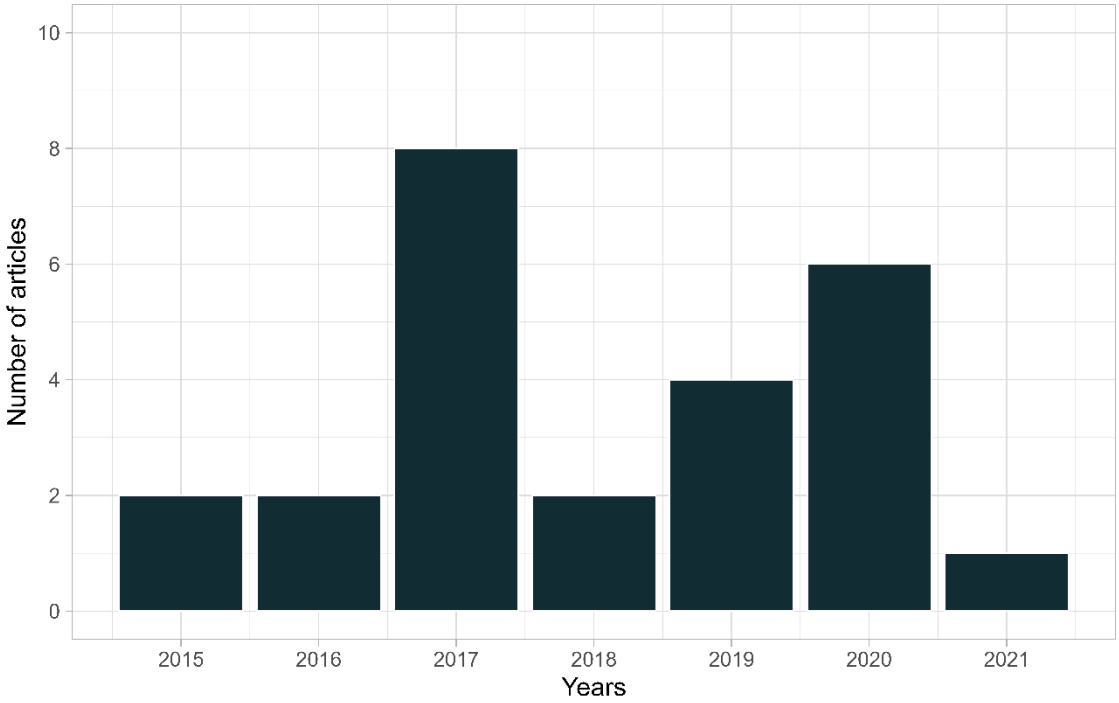
Figure 2.

Number of articles selected by year of publication.



Discussion

The results of this literature review indicate that *Persea americana* has the potential to be an effective antimicrobial agent. The most frequently reported activity was antibacterial, with a total of 18 out of 25 articles selected for review. As illustrated in Table 2, the extract of this plant has been demonstrated to inhibit the growth of a range of bacteria, including *Klebsiella pneumoniae*, *Staphylococcus epidermidis*, *Streptococcus mutans*, *Staphylococcus aureus*, *Bacillus cereus*, *Pseudomonas aeruginosa*, *Salmonella* spp., *Listeria monocytogenes* and *Escherichia coli* (Figure 3).

The antifungal activity of the *P. americana* extract was also evaluated, demonstrating efficacy against a range of fungal pathogens, including *Trichoderma viride, Aspergillus fumigatus, Aspergillus ochraceus, Aspergillus versicolor, Aspergillus niger, Candida albicans, Candida tropicalis, Colletotrichum gloeosporioides, Monilinia fructicola, Botryodiploidia theobromae, Rhizopus stolonifer, Aspergillus flavus, Fusarium oxysporium, Geothricum candidum, Trichophyton rubrum* and the *Trichophyton mentagrophytes* complex (Table 2).

The most cited plant parts used to attest to antimicrobial activity were leaves and seeds, as reported in 36% of the studies. This was followed by bark, which was cited in 24% of the

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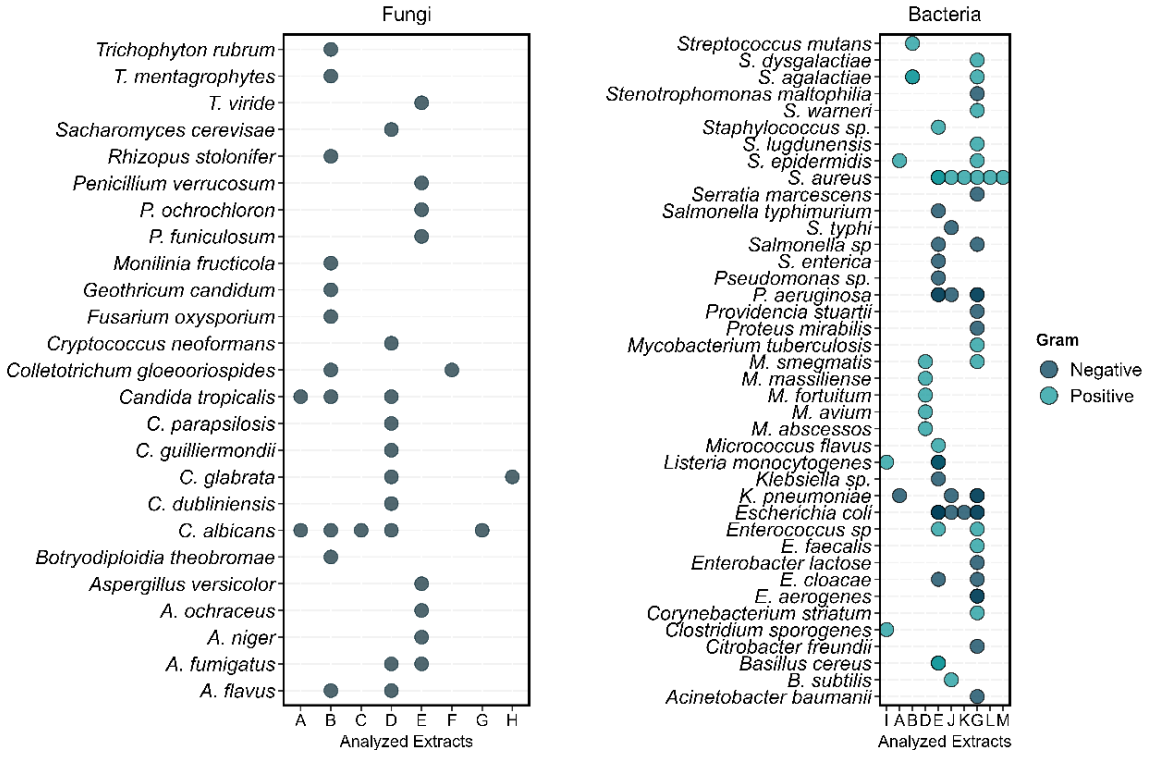
studies, and pulp, which was cited in 8% of the studies. A review of the selected articles revealed that 12% did not specify the part of the plant that was tested.

As indicated by Segovia et al. (2018), the most prevalent groups of phytochemical compounds in avocado seeds are condensed tannins, saponins, phenolic acids and flavonoids. The concentration of the phenolic compound in the seed is greater than that observed in the leaves and pulp of the fruit, with a mean value of 44.89 mg/kg (Tugivanti et al., 2019).

Figure 3.

Microorganisms tested by type of extract. ***Legend****. Extracts analyzed:* ***A*** *- Acetone; methanol; n-hexane.* ***B*** *- Ethanol.* ***C*** *- Glycolic.* ***D*** *- Hydroethanolic extract and chloroform fractions, ethyl acetate and butanol.* ***E*** *- Hydroethanolic.* ***F*** *- Methanol; water.* ***G*** *– Me-thanolic.* ***H*** *- Essential oil.* ***I*** *- Acetogenins.* ***J*** *- Extract of methanol, ethyl acetate and petroleum ether.* ***K*** *- methanol, n-hexane, ethanol: water, ethyl acetate, dichloromethane (DCM) and chloroform.* ***L*** *- Not informed.* ***M*** *- Rich in lipids.*



Phenolic compounds, also known as polyphenols, are defined as a group of phytochemicals that possess at least one aromatic ring linked to one or more hydroxyl groups (Neves, 2015). The position and number of these groups are associated with their toxicity to specific microorganisms. The greater the oxidation state of a phenol, the greater its antimicrobial potential. This property is a result of the ability of these compounds to inhibit ATP synthesis, which consequently induces cell lysis (Bueno, 2019).

Tannins are defined as a complex group of secondary metabolites that are soluble in polar solutions and distributed throughout vascular plants. They can be found in large concentrations in numerous plant tissues (Neves, 2015). They have antiseptic, antimicrobial (owing to their capacity to rupture the cell wall of protozoa, fungi and bacteria), healing and hemostatic effects (Silva et al., 2016).

Saponins are glycoside compounds of steroids or polycyclic terpenes, distributed among a wide variety of plant species. The chemical structure of these compounds includes an aglycone, which has a hydrophobic character and can be triterpene or steroidal, as well as a sugar unit (hydrophilic portion) (Ramos-Morales et al., 2019). The antimicrobial action of these metabolites is due to their capacity to damage the integrity of the microbial cell membrane by forming complexes with steroids, thereby altering permeability and resulting in cell lysis (Souza, 2016).

Flavonoids, which are classified according to their chemical structure, comprise a diverse range of compounds, including flavonol, flavanone, flavanol or catechins, flavone, anthocyanidin and isoflavonoid. Their chemical structure typically features two aromatic rings, which are joined by three carbons to form a heterocyclic pyran ring (Assunção, 2016). Their antimicrobial action is associated with their mechanism of action against cellular interactions, including enzyme inhibition and the formation of complexes between proteins and the bacterial cell wall. This results in damage to the functions of the microorganisms and, in some cases, the total rupture of their biological membranes (Abrantes, 2017).

Terpenoids are defined as compounds comprising the association of isoprene units (C_5H_8) with oxygen molecules (Abrantes, 2017). The antimicrobial action is associated with the presence of triterpenoids, which are organic compounds comprising three terpene units and which exert their effect on both Gram-positive and Gram-negative bacteria and phytopathogenic fungi. The hydrophobic nature of terpenoids and their association with hydroxyl groups results in the modification of lipoprotein interactions within microbial membranes, leading to an ionic imbalance and the subsequent interruption of ATP synthesis. This, in turn, impairs essential cellular processes and ultimately results in microbial death (Souza, 2016).

Results presented by Deuschle et al., (2019) shows that the extracts of the fresh leaves of P. americana presented antifungal and antimicrobial activity, quite relevant and the results denoted that the secondary metabolites possess this antimicrobial activity. Kahaliw et al. (2017) also obtained significant results with the leaf extract, but only against *Mycobacterium tuberculosis*.

According to Rodrigues et al. (2016), ethanol and methanol are among the most used solvents for extracting tannins, polyphenols, flavonoids, terpenes and saponins. In view of the

data collected, it was found that in the methodology employed, the hydroalcoholic extract was cited most frequently, in 8 studies, for the purpose of extracting the active compounds of *P. americana*. This was followed by methanolic extract, cited in 7 studies, ethanolic extract, reported in 5 studies, ethyl acetate, cited in 4 studies, acetone and chloroform extract in 3 studies and hexane, reported in only 2 studies.

As reported by Akinpelu et al. (2015) and Dzotam & Kuete (2017), the bark extract of *P. americana* demonstrated antimicrobial activity against both Gram-positive and Gram-negative bacteria. However, the tests were conducted using hydroalcoholic and methanolic extracts, respectively, with the methanolic extract demonstrating a greater inhibitory capacity. In 2017, the ethanolic extracts of the leaves of *P. americana* at concentrations of 25% and 50% demonstrated inhibitory activity against *Streptococcus mutans*, with halos measuring 9.06 ± 2.120 mm and 10.13 ± 2.996 mm in diameter, respectively.

Roumy et al. (2020) observed that the fruit extract demonstrated notable antimicrobial activity against 36 distinct microorganisms, with a minimum inhibitory concentration (MIC) value of ≤ 0.15 mg/mL. Notably, a considerable proportion of these microorganisms exhibited resistance to at least one type of antibiotic, including *Escherichia coli* resistant to penicillin, *Citrobacter freundii* resistant to cephalosporin, *Klebsiella pneumoniae* resistant to penicillin and *Enterobacter cloacae* resistant to cephalosporin.

The most sensitive microorganisms to *P. americana* extracts were *S. aureus*, *E. coli*, *L. monocytogenes*, *P. aeruginosa*, *K. pneumoniae*, *C. albicans* and *C. gloeosporioides*. As reported by Makopa et al. (2020), the hydroalcoholic extract demonstrated the greatest potential when tested on strains of *Klebsiella pneumoniae*, *Candida albicans*, *Candida tropicalis* and *Staphylococcus epidermidis*, exhibiting maximum activity with total inhibition at 100 µg/mL. In 2017, the hydroalcoholic extract demonstrated minimal bactericidal activity against methicillin-resistant *Staphylococcus aureus* (MRSA), exhibiting an inhibition zone of less than 20 mm in diameter. This was observed to have a moderate bactericidal effect when compared to the positive control, which was kanamycin.

In the study by Salinas-Salazar et al. (2017), the seed and pulp extract enriched with acetogenin demonstrated antibacterial activity against *L. monocytogenes* that was comparable to that of the bactericidal antimicrobials Avosafe and Mirenat, with MIC values ranging from 7.8 to 15.6 mg/L. Similarly, Pacheco et al. (2017) employed enriched acetogenin extracts and Avosafe, yielding comparable MIC values.

In a study conducted by Trujillo-Mayol et al. (2021), the hydroethanolic extract demonstrated notable efficacy against both *P. aeruginosa* and *B. cereus*, with an inhibition halo exceeding 95% across all tested concentrations. In a separate study, Sudhasupriya et al. (2017) demonstrated that the methanolic extract of avocado seeds exhibited a greater zone of inhibition against both *E. coli* and *P. aeruginosa*, while the ethyl acetate extract demonstrated superior inhibitory activity against *S. aureus*. Additionally, Da Cruz et al. (2019) observed inhibitory activity against *S. aureus*, with inhibition halos ranging from 13 to 20 mm in diameter and MICs ranging from 3.12 to 12.5 mg/mL.

In their study (2018), tests were conducted to evaluate the antimicrobial activity of the hydroalcoholic extract of the bark and seed of *P. americana* against strains of bacteria and fungi. The experiments demonstrated effective antibacterial activity against six of the eight strains and moderate antifungal activity, with an effective fungistatic effect against the eight strains tested.

Akalazu and Uchegbu (2020) highlighted in their study the antifungal activity of avocado seed extract against pathogenic fungi isolated from yam tubers, with varying degrees of inhibition observed for *Botryodiploidia theobromae*, *Rhizopus stolonifera*, *Aspergillus flavus*, *Fusarium oxysporium* and *Geothricum candidum*. Furthermore, Xoca-Orozco et al. (2019) and Fagundes et al. (2018) demonstrated antimicrobial activity against the phytopathogenic fungi *Colletotrichum gloeosporioides* and *Monilinia fructicola*. This evidence supports the assertion that the *P. americana* extract has the potential to exert an antimicrobial effect in the control of agricultural crops.

Biasi-Garbin et al. (2016) demonstrated the robust antifungal activity of the *P. americana* extract when tested on clinical isolates of *T. rubrum* and *T. mentagrophytes* complex, with MICs ranging from 15.6 to 62.5 µg/mL and 7.8 to 62.5 µg/mL, respectively. Furthermore, Jesus et al. (2015) reported the antifungal efficacy of avocado glycolic extract against *C. albicans*, with an MIC of 6.25 mg/mL and a MIC of 12.50 mg/mL. This resulted in a considerable reduction in the fungal biofilm from a concentration of 50 mg/mL. In contrast, De Freitas et al. (2020) reported that the ethanolic extract demonstrated less efficacy in inhibiting the biofilm of *C. albicans* and *C. tropicalis* when compared to the antifungal drug fluconazole.

Sierra-Castrillo et al. (2020) reported in their study the sensitivity of *S. aureus* to the ex-treatments of seed-hexane, peel-chloroform and peel-ethyl acetate, as well as the inhibition of *E. coli* in the presence of the same peel extracts. However, the tests conducted on the avocado pulp did not yield any antimicrobial activity. Báez-Magaña et al. (2019), Almeida et al. (2017) and Velarde et al. (2020) did not demonstrate antimicrobial activity from their extracts. Similarly, Cardoso et al. (2016) tested an ethanolic extract against isolates of *Streptococcus*

agalactiae and observed low antimicrobial activity, with a zone of inhibition between 7mm and 9.5 mm in diameter.

The potential of nanotechnology as an alternative method for combating pathogenic microorganisms has been the subject of research, with particular attention paid to the bactericidal properties and low microbial resistance of metallic nanoparticles (Guedes, 2019). Rajeshkumar & Rinitha (2018) demonstrated the antimicrobial potential of copper nanoparticles (CuNPs) derived from avocado extract against a range of bacterial isolates, including *E. coli*, *Streptococcus* sp., *Klebsiella* sp. and *Rhizobacterium* sp., as well as against several phytopathogenic fungi, such as *Aspergillus niger*, *Aspergillus fumigates* and *Fusarium oxysporum*. The greatest zone of inhibition was observed in *Streptococcus* sp., with a diameter of 22.23 ± 0.15 mm. This suggests that the treatment of wounds and skin infections, septicemia and endocarditis caused by *Streptococcus* sp. may be facilitated by this method.

Nevertheless, Girón-Várquez et al. (2019) observed that the antimicrobial action of silver nanoparticles synthesized from varying concentrations of *P. americana* extract did not yield significant results against *E. coli*, which they attributed to the disparate sizes of the nanoparticles synthesized. The study indicates that additional factors, including the shape and concentration of the extract and the structural characteristics of the cells under examination, may also influence the efficacy of these nanoparticles.

In conclusion, a significant number of pathogenic microorganisms demonstrated sensitivity to the *Persea americana* extract, which was identified as a highly potent antimicrobial agent. Moreover, the utilization of nanotechnology represents a promising prospect, although further research is required to enhance this methodology.

Conclusion

The analysis of the articles revealed that *Persea americana* extract demonstrated potential antimicrobial activity against fungi and bacteria, which is of interest to the medical and agrochemical industries. Recently, studies have been conducted to develop more effective strategies to produce antimicrobials against pathogenic microorganisms, including the use of nanoparticles synthesized from the extract of *P. americana*. This constitutes an excellent alternative for optimizing the inhibition of resistant pathogenic microorganisms.

Despite the antimicrobial properties exhibited by *P. americana*, no comprehensive chemical analysis of the antimicrobial extracts prepared from the plant's diverse tissues has been conducted. Thus, it is recommended that further studies be conducted with the objective of isolating and elucidating the chemical compound(s) present(s) in *P. americana* that are responsible for its antimicrobial activity. This should be done to gain a deeper understanding of

the respective mechanisms of action of these compounds. The proposed approach is to develop prototype antimicrobial drugs with safe levels of toxicity and efficacy in the treatment of clinically important microorganisms, as well as those of importance to the agrochemical industry in the development of biopesticides (biofungicides and biobactericides).

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