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Antimicrobial potential of camu camu (*Myrciaria dubia*) against bacteria, yeasts, and parasitic protozoa: a review

Potencial antimicrobiano del camu camu (*Myrciaria dubia*) contra bacterias, levaduras y protozoos parásitos: una revisión

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ABSTRACT

Keywords:

Ascorbic acid
Inhibition
Pathogen
Phenolic compounds


Some microorganisms are responsible for food spoilage and foodborne infections worldwide. These microorganisms are becoming increasingly resistant to degradation or inhibition due to exposure to antibiotics, antifungal, and antiparasitics, posing a growing threat to human health. The aim of this study was to describe the antimicrobial properties of compounds present in *Myrciaria dubia* (pulp, seed, peel, and leaves) against bacteria (*Staphylococcus spp.*, *Escherichia coli*, *Salmonella* and others), yeasts (*Candida albicans* and *Saccharomyces cerevisiae*) and parasitic protozoa (*Leishmania amazonensis* and *Plasmodium falciparum*). Different papers published in the main databases (Scopus, ScienceDirect, PubMed, Wiley Online Library, as well as in university repositories) were reviewed. These results were analyzed and organized according to their inhibitory activity, attributable metabolic actions of this plant, mainly based on its phenolic compounds present (rhodomyrtone, isomyrtucommulone B, myrciarone B, trans-resveratrol, 2,4-dihydroxybenzoic acid, myricetin, syringic, ellagic acid and casuarictin), which can inhibit the synthesis or destabilize the microbial membrane, nucleic acids, cell walls in bacteria and mitochondrial dysfunction in protozoa.


RESUMEN

Palabras clave:

Ácido ascórbico
Inhibición
Patógenos
Compuestos fenólicos

Algunos microorganismos son responsables del deterioro de los alimentos y de las infecciones alimentarias en el mundo. Estos microorganismos se están volviendo cada vez más resistentes a la degradación o inhibición debido a la exposición de antibióticos, antifúngicos y antiparasitarios, lo que supone una amenaza creciente para la salud de las personas. El objetivo de este estudio fue describir las propiedades antimicrobianas de los compuestos presentes en *Myrciaria dubia* (pulpa, semilla, cáscara y hoja) contra bacterias (*Staphylococcus spp.*, *Escherichia coli*, *Salmonella* y otros), levaduras (*Candida albicans* y *Saccharomyces cerevisiae*) y protozoos parásitos (*Leishmania amazonensis* y *Plasmodium falciparum*). Se revisaron distintos trabajos publicados en las principales bases de datos (Scopus, ScienceDirect, PubMed, Wiley Online Library), así como en repositorios de universidades. Estos resultados fueron analizados y organizados de acuerdo a su actividad inhibitoria, capacidad atribuible a las acciones metabólicas de esta planta, basados principalmente en sus compuestos fenólicos presentes (rhodomyrtone, isomyrtucommulone B, myrciarone B, trans-resveratrol, ácido 2,4-dihidroxibenzoico, myricetin, syringic, ácido elágico y casuarictin), los que pueden inhibir la síntesis o desestabilizar la membrana microbiana, ácidos nucleicos, paredes celulares en bacterias y disfunción mitocondrial en protozoos.

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Infectious diseases are caused by pathogenic microorganisms such as bacteria, yeast, and parasitic protozoa (WHO, 2021). Their spread is increasing, producing economic crises and threatening people's safety (Gushulak and MacPherson, 2004; Vignier and Bouchaud, 2018). Over the years, microorganisms have acquired resistance to different antibiotics, antifungals, or antiparasitic; their mechanisms of resistance to different drugs have increased due to the non-specific rejection of hydrophobic chemical substances due to the impermeability of the outer membrane, the acquisition of non-specific efflux pumps, biofilms formation, and others. Thus, it is necessary to search for natural sources of antimicrobials agents that do not affect humans' and animals' health nor harm the environment (Carey and McNamara, 2015; Mir, 2022; Moglad *et al.*, 2020; Samanta and Bandyopadhyay, 2020; Santos and Santana, 2019; Yadav *et al.*, 2019).

Myrciaria dubia is a shrub belonging to the *Myrtaceae* family; native to the Amazon rainforest and grows naturally in floodable areas of streams and on the banks of rivers, lakes, or swamps of the Peruvian, Brazilian, Colombian, Ecuadorian, and Venezuelan Amazon (Castro *et al.*, 2018; Hernández *et al.*, 2011; Lim, 2012). The phytochemical properties of this plant have been the subject of multiple studies. They have been characterized and named as functional food, due to their high content of ascorbic acid, which varies according to the part of the fruit and its state of maturity (Alves *et al.*, 2002; Castro *et al.*, 2013; Cunha-Santos *et al.*, 2019; Justi *et al.*, 2000; Rodrigues *et al.*, 2001; Santos *et al.*, 2022; Villanueva-Tiburcio *et al.*, 2010; Yuyama *et al.*, 2002; Obregón-La Rosa *et al.*, 2021).

M. dubia has been shown to contain carotenoids, such as β -carotene, violaxanthin, and luteoxanthin (Zanatta and Mercadante, 2007), saponins, tannins (Da Silva *et al.*, 2022) and essential oils such as α -pinene, α -phellandrene, terpinolene, E-caryophyllene, γ -cadinene (Da Costa *et al.*, 2022); in addition to phenolic compounds, proanthocyanidins (Fujita *et al.*, 2013), quercetin and kaempferol derivatives (Gonçalves *et al.*, 2010), delphinidin 3-glucoside, naringenin, cyanidin 3-glucoside, rutin, flavan-3-ol, flavonol, flavanone, and ellagic acid derivatives and catechin (Chirinos *et al.*, 2010; Reynertson *et al.*, 2008). Moreover, it presents phenolic compounds, such as vescalagin, castalagin (Fidelis *et al.*, 2020); myrciarone A

and B, isomyrtucommulone B, rhodomirtone (Kaneshima *et al.*, 2016), rosmarinic acid, trans-resveratrol, quercetin, syringic acid, methylvescalagin and cyanidin-3-glucoside, 2,4-dihydroxybenzoic acid (Do Carmo *et al.*, 2019), myricetin and ellagic acid (De Azevêdo *et al.*, 2014). The presence of these compounds varies according to the different parts of *M. dubia* (pulp, seed, peel, and leaves).

Some compounds present in *M. dubia* demonstrated antimicrobial activity (Figure 1) as myrciarone A from the peel (*Bacillus cereus*, *Bacillus subtilis*, *Micrococcus luteus*, *Staphylococcus aureus*, *Staphylococcus epidermidis*), rhodomirtone from the peel (*B. subtilis*, *B. cereus*, *M. luteus*, *S. aureus*, *S. epidermidis*, *Streptococcus mutans*), isomyrtucommulone B from the seed (*B. cereus*, *S. aureus*, *S. epidermidis*, *B. subtilis*) myrciarone B from the seed (*B. cereus*, *B. subtilis*, *S. aureus*, *S. mutans*, *S. epidermidis*) (Kaneshima *et al.*, 2017), trans-resveratrol (*Schistosoma mansoni*), methylvescalagin (*S. mansoni*, *Plasmodium falciparum*), quercetin, 2,4-dihydroxybenzoic acid (*S. mansoni*, *P. falciparum* from the seeds (Do Carmo *et al.*, 2020); myricetin, syringic acid, ellagic acid, and casuarictin from the lyophilized pulp powder proved to be effective against *S. aureus* (Fujita *et al.* 2015).

Some analyzes have shown that pure phenolic compounds such as quercetin, naringenin, and kaempferol have strong antimicrobial activity (Rauha *et al.*, 2000). Additionally, some compounds (Myricetin) present in *M. dubia* were found in other plant samples and demonstrated inhibitory action for *Proteus vulgaris* and *S. aureus* (Mori *et al.*, 1987).

In this context, this review aimed to describe the antimicrobial properties of the compounds present in the pulp, seed, peel and leaves from *M. dubia* against bacteria, yeasts, and parasitic protozoa.

MATERIALS AND METHODS

From main databases, a search for papers published about this topic was performed (Scopus, ScienceDirect, PubMed, Wiley Online Library). Also, university repositories were consulted using the following descriptors *camu camu* or *Myrciaria dubia* and antimicrobial or bacteria or microorganisms or antimicrobial activity, preferably within the last 15 years. The information was organized according to the use of *M. dubia*, considering the antimicrobial properties of the compounds present

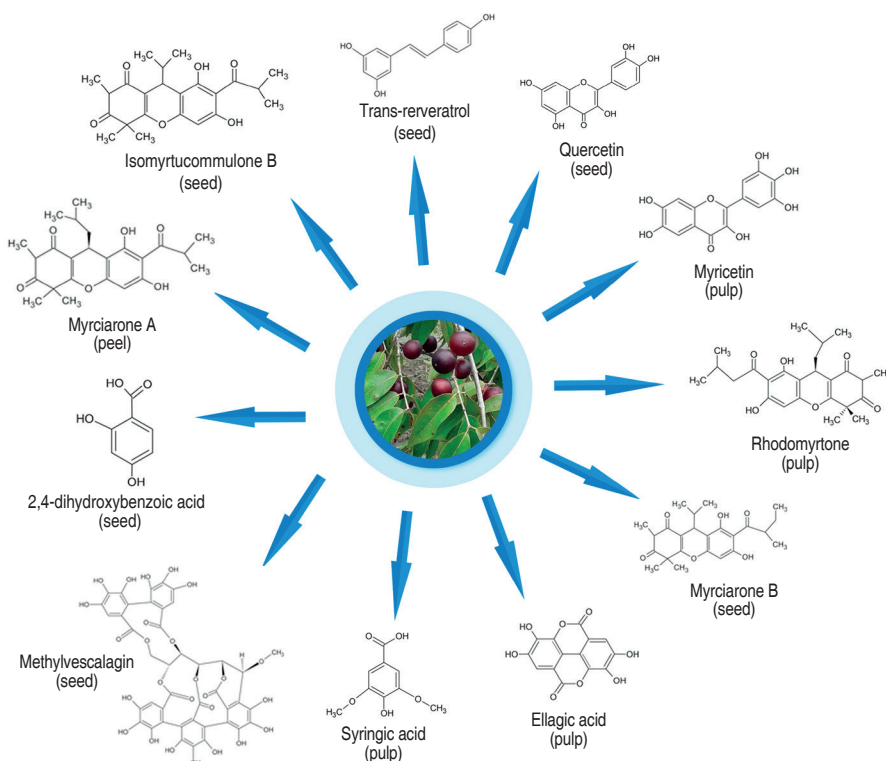


Figure 1. Phenolic compounds with antimicrobial properties from *M. dubia* (Kaneshima *et al.*, 2017; Do Carmo *et al.*, 2020; Fujita *et al.* 2015).

in the different parts of *M. dubia* against different microorganisms.

RESULTS AND DISCUSSION

Inhibitory capacity of *M. dubia*

M. dubia contains phenolic compounds (flavonoids and phenolic acids), and they can inhibit microorganisms (Kaneshima *et al.*, 2017; Do Carmo *et al.*, 2020; Fidelis *et al.*, 2020).

The antimicrobial activity of phenolic compounds is related to the kinetic curve of microbial death and minimum inhibitory concentration (MIC) (Fujita *et al.*, 2015; Levison, 2004; Pankey and Sabath, 2004).

Antibacterial activity is due to the compounds that degrade the cell wall and/or functionally interfere with the bacterial enzymes present in these structures (Finberg *et al.*, 2004). They cause the death of microorganisms through a process known as bactericidal action. On the other hand, bacteriostatic action occurs when the

ribosomal function and protein synthesis that allows the reduction of microbial population growth are inhibited (French, 2006).

Some compounds such as myricetin have shown a bacterial inhibition of RNA synthesis (*S. aureus*), this inhibitory action on DNA or RNA synthesis occurs due to the B ring of flavonoids, which interacts with hydrogen bonds causing stacking of nucleic acid bases (Mori *et al.*, 1987). Likewise, Ohemeng *et al.* (1993) demonstrated that flavones (ellagic acid) inhibit the catalytic activity of DNA gyrase. Similarly, some alkaloids can act as agonists or antagonists of neuroreceptors/ion channels, leading parasites (*S. mansoni*) to death due to neurotoxic effects (Do Carmo *et al.*, 2020).

Kaneshima *et al.* (2017) and Fidelis *et al.* (2020) demonstrated the antimicrobial activity of *M. dubia* on yeasts (*Candida albicans* and *Saccharomyces cerevisiae*). There is no knowledge about the mechanism of cellular action. Nevertheless, the inhibition of protozoa is possibly

due to the action of quercetin in causing mitochondrial dysfunction in these parasites (Correia *et al.*, 2016).

***M. dubia* benefits.** The inhibitory capacity of *M. dubia* constitutes an excellent alternative as a functionalized ingredient in food; it can also be used in the pharmaceutical and cosmetic industries by presenting compounds with the biological activity of interest, in which ascorbic acid and phenolic compounds stand out (Conceição *et al.*, 2020; Inocente-Camones *et al.*, 2014; Fidelis *et al.*, 2020).

The phenolic compounds present in *M. dubia* (pulp, seed, peel and leaves) have potential alternative uses, once they show inhibitory capacity against bacteria (*S. aureus*, *B. cereus*, *B. subtilis*, *S. mutans*, *S. epidermidis*, *E. coli*, *Streptococcus sanguinis*) and yeasts (*C. albicans*, *S. cerevisiae*) (Camere-Colarossi *et al.*, 2016; Conceição *et al.*, 2020; Fidelis *et al.*, 2020; Fujita *et al.* 2015; Kaneshima *et al.*, 2017; Myoda *et al.*, 2010; Roumy *et al.*, 2020). Additionally, the by-products can be used after a pre-treatment of drying with hot air, spray drying, or lyophilization (De Azevêdo *et al.*, 2014; De Azevêdo *et al.*, 2015). Furthermore, the lyophilized pulp of *M. dubia* has shown greater inhibition capacity than ampicillin (Fujita *et al.*, 2013).

Another advantage of this plant is that contributes to human health as was demonstrated in different studies (Camere-Colarossi *et al.*, 2016; De Azevêdo *et al.*, 2014; Moromi *et al.*, 2016; Myoda *et al.*, 2010). It is traditionally used in the indigenous communities of Loreto, Peru to heal various illnesses, including gingivitis, and to keep the gums of human teeth healthy (Flores, 2010; Pinedo *et al.*, 2011).

Inhibitory capacity of *M. dubia* against different microorganisms

The following is a summary of studies related to the inhibition of microorganisms (bacteria, yeasts and protozoa) for compounds present in the pulp, seed, peel, and leaves from *M. dubia*.

***M. dubia* against *Staphylococcus* spp.** The lyophilized optimized Camu-Camu seed extract (1g:20 mL of the mixture of 43.3% propanone, 40.7% water and 16% ethyl alcohol) showed inhibition against *S. aureus* ATCC13565

with an inhibition zone of 9.7 mm; it could block the transcription due to its castalagin and vesicalagin contents (Fidelis *et al.*, 2020). In another study, using n-hexane extract from *M. dubia* peel and seed; fractions of n-hexane extract (n-hexane layers and 90% acetonitrile layers) and acylphloroglucinols of n-hexane extract (1: Myrciarone A; 2: Rhodomyrtone; 3: Isomyrtucommulone B and 4: Myrciarone B) presented antimicrobial activity against *S. aureus*. In n-hexane extracted from the peel, MIC values were 12.50 (n-Hexane extract), 6.25 (n-hexane layers), 12.5 (90% acetonitrile layers), 1.56 (Myrciarone A) and 0.78 $\mu\text{g mL}^{-1}$ (Rhodomyrtone). In n-hexane extracted from the seed obtained MIC value of 6.25 (n-Hexane extract, n-hexane layers, and 90% acetonitrile layers) and 1.56 $\mu\text{g mL}^{-1}$ (Isomyrtucommulone B and Myrciarone B). Similarly, inhibitory activity was evidenced against *S. epidermidis* with MIC values of 6.25 (n-Hexane extract and n-hexane layers), 12.5 (90% acetonitrile layers), 3.13 (Myrciarone A) and 0.78 $\mu\text{g mL}^{-1}$ (Rhodomyrtone) for the n-hexane extract from the peel and for the n-hexane extract from the seed were obtained MIC values of 12.5 (n-Hexane extract and n-hexane layers), 6.25 (90% acetonitrile layers and Isomyrtucommulone B) and 3.13 $\mu\text{g mL}^{-1}$ (Myrciarone B), respectively (Kaneshima *et al.*, 2015 and Kaneshima *et al.*, 2017). Due to the presence of proanthocyanidins, anthocyanins, flavonoids, and phenolic acids in the lyophilized ethanol extract, *M. dubia* (aqueous extracts of seeds and peel) showed antimicrobial activity against *S. aureus* with an inhibition zone of 12 mm (De Azevêdo *et al.*, 2014).

The methanolic extract obtained from *M. dubia* leaves (1.2 mg mL^{-1}) inhibited *S. epidermidis* 5001 by the action of β -sitosterol and betulinic acid, which allowed the activation of drug-like chemosensory signals (Roumy *et al.*, 2020).

Additionally, antimicrobial activity of the methanolic extract (5 mg mL^{-1}) obtained from seed and peel of *M. dubia* for *S. aureus* was observed; the zone of inhibition for the seed extract was 2.7 mm while for the peel extract it was 3.1 mm. This is attributed to the high content of phenolic compounds (Myoda *et al.*, 2010).

Another study showed that the antimicrobial activity of the lyophilized pulp extract of *M. dubia* diluted in 70% methanol inhibited *S. aureus* ATCC 29213 with a

MIC of 0.08 mg mL⁻¹ (0% maltodextrin or gum arabic) presenting a higher activity than ampicillin (0.26 mg mL⁻¹), this antimicrobial activity is due to the presence of ellagic acid, tannins, cyanidin, quercetin, catechin, kaempferol, and rutin (Fujita *et al.*, 2015).

The methanolic extracts obtained from seeds, peels, and leaves of *M. dubia* showed antimicrobial activity against *Staphylococcus* spp. as shown in Table 1. The extracts studied did not show inhibition against *S. aureus*. For *S. epidermidis* 8157, the inhibition occurred due to the action of β -sitosterol and betulinic acid present in the methanolic extract of leaves (Roumy *et al.*, 2020).

Table 1. Antimicrobial effect of different parts of the fruit of *M. dubia*

Bacterium	MIC (mg mL ⁻¹)		
	Peel	Seed	Leaves
<i>S. epidermidis</i> 5001	0.30	0.30	
<i>S. epidermidis</i> 8157	0.15	0.15	1.20
<i>S. epidermidis</i> 10282	0.15	0.30	
<i>S. lugdunensis</i> T26A3	0.30	0.30	
<i>S. warneri</i> T12A12	0.30	0.30	

Another study carried out on lyophilized extracts obtained from 1 g of lyophilized *M. dubia* peel, pulp, and seeds and solvent ethanol and water (80/20, v/v) proved that the MIC for *E. coli* from the peel was 10 mg mL⁻¹. Extract with the most relevant antimicrobial potential was from pulp and seed parts (Conceição *et al.*, 2020). This action was possible due to the formation of biofilms by their flavonoids myricetin and quercetin (Arita-Morioka *et al.*, 2018).

***M. dubia* against yeasts.** The dry extract of *M. dubia* seed diluted with n-hexane (500 mg 10 mL⁻¹) showed inhibitory activity against *C. albicans* (MIC > 100 μ g mL⁻¹); but the resulting layer of n-hexane and 90% acetonitrile layer obtained by countercurrent partitioning (acetonitrile: water = 9:1 v/v) and two isolated compounds such as isomyrtucommulone B and myrciarone B had no effect on the yeast (Kaneshima *et al.*, 2017). In addition, Roumy *et al.*, 2020 showed MIC values of 0.3, 0.3 and 1.2 mg mL⁻¹ when they used diluted methanolic extracts (12 mg mL⁻¹) from peel, seed, and leaves respectively against *C. albicans* 10286. On the other hand, dry extracts from peel and seed diluted in water or DMSO

***M. dubia* against *Escherichia coli*.** The lyophilized optimized camu-camu seed extract (1:20 g:mL of the mixture of 43.3% propanone, 40.7% water, and 16% ethyl alcohol) presented antibacterial activity against *E. coli* IAL2064 with an inhibition zone of 6.64 mm. (Fidelis *et al.*, 2020). This inhibition is probably caused by their phenolic compounds such as quercetin, catechin, gallic acid, ellagic acid, ellagitannins, and proanthocyanidins (Fujita *et al.*, 2015). *M. dubia* fruit juice presented greater inhibitory capacity against *E. coli*, while for *Salmonella typhi*, its inhibition capacity was lower, with inhibition zones of 16.9 and 11.19 mm, respectively. This inhibition against *E. coli* and *S. typhi* is attributed to the low pH (2.09) of the fruit juice (López, 2017).

to obtain concentrations of 0.1-5.0 mg mL⁻¹ had no activity against *S. cerevisiae* (Myoda *et al.*, 2010). In another study, an evaluation of the antimicrobial activity for *S. cerevisiae* NCYC1006 was carried out using the lyophilized optimized *M. dubia* seed extract (1:20 g:mL of the mixture of 43.3% propanone, 40.7% water, and 16% ethyl alcohol) presented an inhibition zone of 5.74 mm (Fidelis *et al.*, 2020).

***M. dubia* against parasitic protozoa.** The action of dichloromethanolic extract from *M. dubia* leaves against *P. falciparum* (clone W2), *Leishmania amazonensis* (IFLA/BR/67PH8), *Leishmania braziliensis* (IOCL 566), and *Leishmania chagasi* (IOCL 579) through bioassays was evaluated. This extract showed inhibitory activity against *P. falciparum* (chloroquine-resistant strain W2). Also, it presented greater inhibitory activity against the *L. amazonensis* (200 μ g mL⁻¹ of extract inhibited in 85% of the promastigote form growth) than against *L. braziliensis* and *L. chagasi*. In addition, this extract presented a growth inhibition of 50% of the parasites (IC₅₀) equal to 2.35 μ g mL⁻¹ for *P. falciparum*,

190.73 $\mu\text{g mL}^{-1}$ for *L. amazonensis*, and $\geq 200 \mu\text{g mL}^{-1}$ for *L. chagasi* and *L. braziliensis* (Correia *et al.*, 2016).

Similarly, in an evaluation using different concentrations (10–500 $\mu\text{g mL}^{-1}$) from lyophilized extracts of *M. dubia* seeds (100/200 g:mL solvent (ultrapure water: ethanol)) with parasite suspensions (0.5% parasitaemia and 2% hematocrit), obtained IC_{50} of 24.2 $\mu\text{g mL}^{-1}$ for *P. falciparum* (juvenile stage-12h) resistant to chloroquine (W2) with 100% H_2O and IC_{50} of 26.8 $\mu\text{g mL}^{-1}$ for *P. falciparum*

(trophozoite-24h) sensible to chloroquine (3D7) with 75% of H_2O + 25% ethanol extract, *in vitro* (Do Carmo *et al.*, 2020), this may have occurred due to the action of phenolic compounds, flavonoids (quercetin) that allows the inhibition of enzymes (β -ketoacyl-ACP-reductase, β -hydroxacyl-ACP-dehydratase and enoyl-ACP-reductase) involved in the type II fatty acid biosynthesis pathway (Tasdemir *et al.*, 2006).

Some microorganisms which were inhibited by the action of *M. dubia* can be seen in Figure 2.

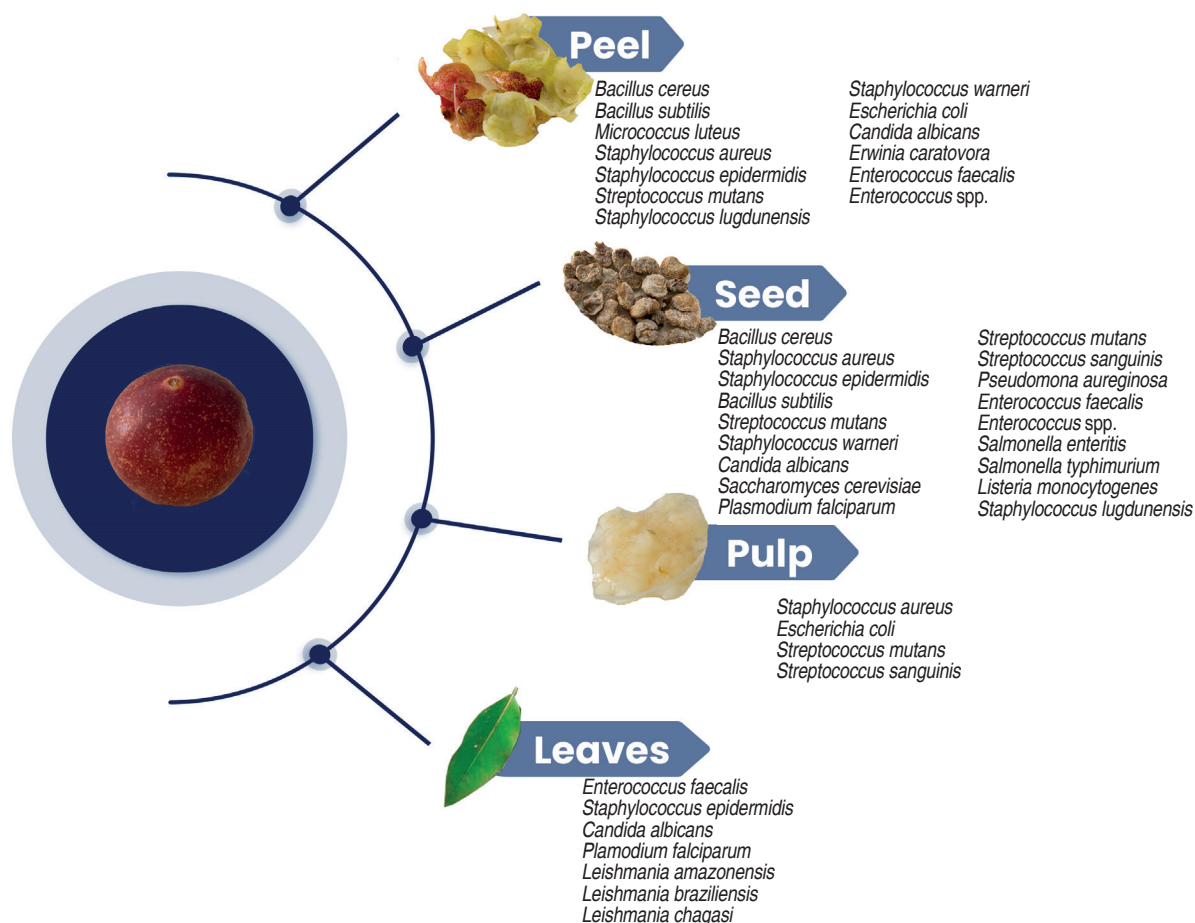


Figure 2. Microorganisms that can be inhibited by *M. dubia* (Kaneshima *et al.*, 2017; Do Carmo *et al.*, 2020; Fujita *et al.* 2015).

***M. dubia* against different microorganisms.**

Streptococcus mutans and *S. sanguinis* were inhibited using 100 μL of methanolic extracts from *M. dubia* pulp and seed. For both *S. mutans* and *S. sanguinis*, *M. dubia* seed extract had a major antibacterial (with inhibition zones of 21.36 and 19.21 mm, respectively)

effect compared with the pulp extract. The MIC of methanolic seed extract against both strains could not be determined due to antibacterial activity even at very low concentrations of the extract. However, for the pulp extract, a MIC value of 62.5 $\mu\text{g mL}^{-1}$ was observed for both strains (Camere-Colarossi *et al.*, 2016). The use of

hydroethanolic extracts of *M. dubia* at concentrations of 25, 50, and 75 mg mL⁻¹ on antibacterial activity *in vitro* for *S. mutans* ATCC 35668 was evaluated, evidencing an increase in antibacterial activity directly proportional to the concentration of the extract. The concentration of 75 mg mL⁻¹ presented an average inhibition of 18.2±0.774 mm, followed by the concentration of 50 mg mL⁻¹ with an average inhibition of 14.6±1.055 mm and the concentration of 25 mg mL⁻¹ with an average inhibition of 10.1±0.833 mm. The zone of inhibition of the positive control was 16.5±0.516 mm, probably rhodomirtone is responsible for the antibacterial activity since in addition to being present in the peel and seeds it is also found in the pulp (Ruiz-Barrueto *et al.*, 2021).

Similarly, some authors demonstrated the inhibition of *Erwinia carotovora subsp. carotovora* by *M. dubia*, the following peel extracts revealed that 50% acetonic extract presented high inhibition, followed by ethanolic extract (50%), and chloroform extract (50%). For *Pseudomonas cichorium*, ethanolic extract (50%) presented greater inhibitory capacity followed by acetonic and chloroformic extracts (Flores and Naupari, 2017).

The methanolic extract of *M. dubia* seed showed activity against *P. aureginosa* ATCC25783 with MIC values of 1.2 mg mL⁻¹ while *P. aureginosa* 8131 had no activity. On the other hand, the methanolic extracts of peel, seed and leave of *M. dubia* showed activity against *Enterococcus faecalis* T25-17 with MIC values of 0.3 mg mL⁻¹ (peel and leave), 1.2 mg mL⁻¹ (seed); in the same way, for *Enterococcus* spp. 8153 with MIC values of 0.3 mg mL⁻¹ (peel and seed) (Roumy *et al.*, 2020).

In another study, Nile tilapia (*Oreochromis niloticus*) tests were carried out on fish supplemented with 500 mg of *M. dubia* per kilogram of feed, it was observed a greater immune response of the fish against *Aeromonas hydrophila* in their swim bladder. The high ascorbic acid content of this plant increases the activity of leukocytes against pathogens and makes neutrophils in the blood increase and migrate to the site of infection to recognize and destroy pathogens, as well as the number of lymphocytes that generate antibodies. Furthermore, lysozyme serum exhibits the ability to hydrolyze peptidoglycans from the cell wall of pathogens (Yunis-Aguinaga *et al.*, 2016).

Additionally, the B rings of the flavonoids interact with the hydrogens of the nucleic acids, inhibiting their synthesis; others can act at the cellular level of the bacteria, causing the release of components that can inactivate the bacteria (Cushnie and Lamb, 2005).

In another study, the optimized lyophilized *M. dubia* seed extract (1:20 g:mL of the mixture of 43.3% propanone, 40.7% water, and 16% ethyl alcohol) inhibited *P. aeruginosa* IAL1853 (8.72 mm), *S. enteritidis* S 2887 (6.82 mm), *S. typhimurium* IAL2431 (6.42 mm), *B. cereus* ATCC14579 (9.04 mm), *Listeria monocytogenes* ATCC7644 (8.58 mm) (Fidelis *et al.*, 2020). However, Da Silva *et al.* (2021) studied the level at which *M. dubia* powder 0.0, 2.0, 3.5, or 5.0% (w/w), mixed with 200 g of ground meat and *Salmonella enterica* ser. *typhimurium* (5 log CFU g⁻¹). The concentration of CPP at 5% had an inhibition value of 5.089 log UFC g⁻¹ *S. enterica* compared to control without CPP (5.121 log UFC g⁻¹ *S. enterica*), indicating the rapid decrease in the concentration of *Salmonella* when increasing the concentration of CPP by interfering with the adaptability of the pathogens; however, it does not extend the shelf life of ground meat.

Furthermore, Willemann *et al.* (2020) showed that 2 mg of lyophilized aqueous extract of camu camu seed exocarp inhibited the growth of *L. monocytogenes* (11.9 mm), *P. aeruginosa* (8.9 mm), *S. typhimurium* (8.9 mm), *S. enteritidis* (10.5 mm) and *B. cereus* (8.8 mm).

CONCLUSIONS

Phenolic compounds of *M. dubia* (peel, pulp, seeds, and leaves) such as polyphenols, flavonoids, and anthocyanins have been studied and categorized as responsible for the inhibition of different Gram-positive bacteria (*L. monocytogenes*, *S. aureus*), Gram-negative bacteria (*E. coli*, *S. typhimurium*, *S. enteritidis*, *P. aeruginosa*, *S. tify*), yeasts (*S. cerevisiae*, *C. albicans*), protozoa (*P. falciparum*, *L. amazonensis*, *L. braziliensis*, *L. chagasi*) and other pathogenic microorganisms that could affect food, whose action could be due to functional interference of bacterial enzymes in their structures, bacteriostatic action on ribosomal function or protein synthesis and blocking of RNA or DNA synthesis by catalytic inhibition of DNA gyrase. The inhibition of protozoa is possibly due to the action of quercetin in causing mitochondrial dysfunction in these parasites.

The inhibitory capacity of *M. dubia* extracts might not affect beneficial probiotic bacteria and could be applied in foods after further studies on the subject.

Further fractionation and purification studies of compounds present in the different parts of *M. dubia* and evaluated against pathogenic and food spoilage microorganisms are required. It is also necessary to explain the mechanism of action of inhibition of the different compounds at the cellular level.

CONTRIBUTION OF THE REVIEW

Information regarding the antimicrobial capacity of *M. dubia*, an Amazonian fruit from countries such as Peru, Brazil, Colombia, and Venezuela, has been identified and organized, offering a possible alternative to be used as an antimicrobial additive in the food industry after further studies.

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