Review Article

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Antimicrobial activity of saponin-containing plants: review

Abstract

The resistance of pathogenic microorganisms to antibiotics has become a "scourge" of the medical field in recent decades. In this regard, the vector of medical research rightly changed in favor of the search for natural mechanisms to fight pathogens. Nature has produced mechanisms for maintaining balance for millions of years, so it is reasonable to investigate and, in the future, use such mechanisms. This current study reviews and analyzes the last five years of research on the effects of saponin-containing plants on the most common pathogens. The analysis of literary data confirms the growing interest in natural antimicrobial drugs that are currently used in folk medicine or have the prospect of use in humane medicine in different countries of the world. Wide interest of the scientific community in the search for alternative antimicrobial agents, which would make it possible to overcome antibiotic resistance in the treatment of various types of diseases, has been revealed. Current scientific research has confirmed or disproved the effectiveness of only a thousandth part of all possible plants. Undoubtedly, the use of natural plant components will make it possible to make the treatment process cheaper and more effective, so this direction of research is currently very promising from all points of view.

Keywords: pathogenic microorganisms, saponin-containing plants, antibiotic resistance

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Introduction

The growing problem of antibiotic resistance has attracted attention in recent decades. Bacterial resistance to antibiotics is considered the number one public health problem in the 21st century. Due to insensitivity to the action of antibiotics, 700,000 people die every year in the world and if this problem is not solved World Health Organization (WHO) predicts that this number could rise to 10 million by 2050.[1]

The issue of research, development and implementation of new antimicrobial drugs remains relevant despite the 258 existing ones.[2] Relatively rapid acquisition of bacterial resistance to synthetic and semi-synthetic antimicrobial drugs through various mutational mechanisms,[3] makes one think about the development of drugs with «more natural» mechanisms of effect on pathogens.

Because of the high resistance of infectious agents to antibiotics, especially in developing countries, the World Health Organization supports the development of research based on medicinal plants to identify new compounds that will help treat infectious diseases.[4]

An important source of «inspiration» in this case is nature itself, which for millions of years produced mechanisms to balance the coexistence of plants, microorganisms and animals. Biologically active components of secondary synthesis of plant origin, such as glycosides, alkaloids, flavonoids, phenolic compounds, essential oils, tannins and pectin substances, coumarins, saponins, organic acids, mineral elements, resins, phytoncides have direct and indirect effects on living cells.[5]

Plants turned out to be interesting sources of new drugs to overcome antimicrobial resistance. It is reported that about 80,000 flowering plants are used in medicine around the world.[6] Plant extracts with a high content of biochemically active substances are widely used not only in cosmetology, but also in traditional herbal medicine of many peoples of the world due to their significant therapeutic effect.[7] They are used for the prevention and treatment of various metabolic disorders, diseases of viral and bacterial origin.[8]

Saponins

Of the entire large list of natural biochemically active components of plants, it is saponins and their effect on microbial cells that are the subject of this review.

Saponins are biologically active nitrogen-free glycosides of plant origin. Depending on the chemical structure of the aglycon, saponins are divided into triterpene (C30) and steroid (C27). Saponins are widespread among higher plants. The most of them are in the families — Caryophylaceae, Polemoniaceae, Araliaceae, Fabaceae, Asparagaceae and others. Saponins accumulate mainly in underground organs (rhizomes, roots, tubers), fruits, much less often in the bark and above-ground part.[9]

Microorganisms of the environment consider the plant as a potential source of energy, attacking every part of it at all stages of growth. It is for the purpose of protection against pests, plants produce various biologically active components that are toxic to insects, fungi and bacteria. It is known that saponins are compounds of the secondary metabolism of healthy plants and play the role of a chemical barrier between the plant and the pathogen. In addition to medicinal and wild plants, saponins are found in many agricultural plants — legumes (for example, soybeans), quinoa, millet, sorghum, oats, onions, spinach, etc.[10]

Saponins in the composition of plants show various pharmaceutical and medicinal properties, such as antimicrobial, insecticidal and molluscicidal effects, but a negative factor is their hemolytic activity and cytotoxicity. It has been proven that the molecular structure of saponin plays a decisive role in these processes.[11] Böttger et al.[12] were unable to demonstrate a general correlation between hemolytic activity and cytotoxic potential for steroidal saponins, indicating that these characteristics are performed by different mechanisms.

Sen et al.[13] believe that saponins are able to modulate microbial growth in natural and artificial fermenters. Saponins are able to show a synergistic effect with antibiotics, such as tetracycline, erythromycine and ciprofloxacine, which were considered ineffective due to the resistance of pathogens to them. Monte et al.[14] demonstrated the potential of saponins to control *Escherichia coli* and *Streptococcus aureus* in both plankton and biofilm conditions.

According to many researchers, saponins, which are similar to detergents, show not only antibacterial, antiprotozoal, insecticidal, but also anticancer potential.[15] Wei et al.[16] found that after exposure to saponins (sapindosides A and B from the *Sapindus mukorossi* tree) cells of *Cutibacterium acnes* increased the hydrophobicity of the cell surface and decreased the fluidity of the cell membrane by changing the composition of membrane fatty acids.

Arabski et al.[17] suggested that saponins bind to lipids, which may lead to an increase in the permeability of the outer membrane of the bacterial cell wall and thereby facilitate the penetration of antibiotics into bacterial cells.

Effect of different saponin-containing plants on pathogens

In addition to researching the properties of medicinal plants, it is important to determine the antimicrobial potential of saponin-containing plants that are used for food by humans and animals. The medicinal value of plants is determined by their chemical components, which have a certain physiological effect on the human and animal body for the prevention of diseases.

Edible plants

Plants used in the cuisines of different nations can have versatile properties, ranging from improving the organoleptic and taste qualities of dishes to medicinal ones.

According to Azzah,[18] green tea extracts (based on aqueous, ethanol, and methanol), rich in flavonoids, saponins, and tannins, have shown effective antimicrobial activity against various types of G^+ and G^- bacterial strains, as they have good inhibitory and bactericidal effects.

When studying the antibacterial activity of isolated saponin fractions from green tea seeds against *E. coli*, *S. aureus* and six *Salmonella* serovars *in vitro* and *in vivo*, Khan et al.[19] came to the conclusion about the strong antibacterial effect of saponins of green tea seeds. In their opinion, the antibacterial mechanism of saponins was related to damage to the cell wall and membrane by saponins.

When studying the antimicrobial properties of the methanol extract of tea (*Camellia sinensis*), its inhibitory effect on *E. coli*, *C. albicans*, *K. pneumoniae*, *S. aureus*, *S. typhi*, *L. monocytogene* was revealeds. Phytochemical analysis of the tea extract revealed the content of alkaloids, flavonoids, carbohydrates, saponins, tannins, steroids, terpenoids and cardiac glycosides.[20]

Similar results were obtained by Shixia et al.[21] They found that quinoa (*Chenopodium quinoa* Willd.) saponins caused severe damage to *S. aureus*, *S. epidermidis*, *B. cereus*, *S. enteritidis*, *P. aeruginosa*, and *L. ivanovii* through cell wall degradation with subsequent disruption of the cytoplasmic membrane and membrane proteins, leading to leakage cell contents.

Pumpkin seeds (*Cucurbita pepo* L.) are a nutritious food and known for their medicinal properties. Sadiq and Yahya[22] performed a chemical analysis of pumpkin seed extract, and confirmed the presence of alkaloids, flavonoids, phenol, saponin, tannin, terpenoid, and steroid. *S. aureus* was found to be sensitive to the ethanol extract of pumpkin seeds with an MIC of 0.625 mg/ml.

The results of phytochemical tests conducted by Kamilawati et al.[23] showed that onion-shallot (*Allium ascalonicum* L) and garlic (*Allium sativum*) containe alkaloids, tannins, saponins, terpenoids and flavonoids, and antibacterial test results showed that garlic was more effective in inhibiting the growth of *S. aureus* than onion-shallot.

According to Abbas and Al-Subaihawi[24] root extract of asparagus (*Asparagus officinalis* L.) contains various major phytochemical compounds such as flavonoids, phenols, alkaloids, glycosides, steroids, resins, saponins and tannins. They found that the alcoholic extract had a higher inhibitory effect on *E. coli* and *S. aureus* than the aqueous extract. Conversely, the aqueous extract was more effective against *A. niger* and *C. albicans*. Hamdi et al.[25] studied the phytochemical composition and antimicrobial activity of different parts of *Asparagus acutifolius* and came to the conclusion that the extract from the leaves of the plant was more effective.

Moni et al.[26] examined the content of biologically active components and antibacterial effectiveness the leaves of the well-known spicy herb *Petroselinum crispum*. They concluded, the plant contains carbohydrates, steroids and saponins and exhibits a low spectrum of antibacterial effects against *S. aureus*, *S. pyogenes*, *B. subtilis*, *K. pneumoniae*, *E. coli*, and *P. aeruginosa*.

Pimenta dioica (L.) (allspice) is a spice used in many cuisines around the world. Phytochemical screening of the aqueous extract revealed the presence of carbohydrates, alkaloids, flavonoids, steroids, saponins, tannins and terpenoids. According to researchers,[27] aqueous extract of *P. dioica* inhibited the growth of *K. pneumonia*, *S. aureus* and *S. mutans*.

Bay leaves and guava leaves contain essential oils, tannins, flavonoids and saponins. The ethanolic extract of the studied plants inhibited the growth of *E. coli*, while the guava leaf extract was more effective than the bay leaf extract.[28] A similar conclusion was reached by Hussein et al.[29] that crude alcoholic extract of *Laurus nobilis* inhibited the growth of *E. coli* (10.33 mm), but did not significantly affect the growth of *S. aureus* and *P. aeruginosa*. At the same time, the extract from *Laurus nobilis* showed greater effectiveness in combination with the extract from *Alhagi maurorumfo* against *E. coli*, *S. aureus* and *P. aeruginosa*.

Yucca (*Yucca Baccata*) is a plant widely known for its nutritional and pharmaceutical importance. In its composition, it contains a high concentration of steroid saponins, phenols, flavonoids. Morales-Figueroa et al.[30] they investigated the antioxidant and antibacterial capacity of extracts from *Y. baccata* and found that it had a greater effect on gram-negative bacteria than on gram-positive bacteria.

Alpinia nigra fruit extract contains saponins, glycosides, alkaloids, steroids and is rich in polyphenols. Silver nanoparticles coated with *A. nigra* showed good antimicrobial activity against *K. pneumoniae*, *S. aureus* and *C. albicans*.[31]

Wang et al.[32] investigated the effect of saponins from three different sources (*Gleditsia sinensis* shell, green tea and *Camellia oleifera* seeds) and found that all three saponins from different sources had antibacterial activity against four common foodborne pathogenic bacteria, namely *B. subtilis*, *S. aureus*, *Salmonella* spp. and *E. coli*. Among them, saponins from the shell of *Gleditsia sinensis* had the best antibacterial effect.

Averrhoa carambola L. (Oxalidaceae) is a tropical tree with tasty fruits containing pyrogallic tannins, steroids and saponins in the bark, fruit and, most importantly, in the leaves.[33] Alcoholic extracts of leaves, stem bark, ripe fruit bagasse and green fruit bagasse had

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MICs of 100 μg/ml against multidrug-resistant pathogenic bacteria and fungi. At the same time, crude leaf extract presented a broad spectrum of action against *S. aureus*, *E. faecalis*, *K. pneumoniae* and *A. baumannii*.

High activity against clinically resistant strains of *K. pneumoniae*, *S. aureus* and *P. aeruginosa* was shown by the extracts of the leaves and fruit peels of the *Annona muricata* Linn with a minimum inhibitory concentration of 25 and 6.25 mg/ml, respectively, while the phytochemical study established the presence of tannins, saponins, terpenoids, steroids, phenols, flavonoids, coumarin, alkaloids, anthocyanins and betacyanins.[34]

Its wastelessness is important for rational management of the economy. The fruit peel of pomegranate (*Punica granatum*), banana (*Musa acuminata*) and orange (*Citrus reticulata*) is rich in alkaloids, flavonoids, phlobatanins, saponins, terpenoids, glycosides, anthocyanosides, steroids, phenols, proteins and carbohydrates according to Gillani et al.[35] Ethanol extracts of pomegranate and banana peels showed the maximum inhibitory effect on *M. luteus*, and orange extracts on *K. pneumoniae*.

Shojaemehr and Alamholo[36] confirmed the presence of phenols, flavonoids, saponins and tannins in the methanolic extract of white skin and the presence of an alkaloid in the methanolic extract of colored skin of *Citrus medica*. The methanol extract of the colored peel of *C. medica* was most effective against *B. cereus* and had no effect on *St. pyogenes*. Methanolic, ethanolic and aqueous extracts of colored and white peels were slightly effective or had no effect against *B. subtillis*, *S. aureus*, *S. pyogenes*, *M. luteus*, *S. typhi*, *Sh. boydi*, *P. aeruginosa*, *E. coli* and *En. aerogenes*.

Inedible plants

Stachytarpheta jamaicensis has some established pharmaceutical properties, but Anthoney[37] decided to investigate the antimicrobial properties of an ethanolic extract of the plant's leaves. He concluded that *B. cereus*, *S. typh*i, *P. vulgaris* and *S. pyogenes* are sensitive to the extract due to the presence of secondary metabolites in the leaves such as tannins, saponins, terpenoids, flavonoids, phenols, alkaloids, steroids and glycosides.

Mango (Mangifera indica) and guava (Psidium guajava) are delicious tropical fruits, in addition, they contain alkaloids, saponins, flavonoids and terpenoids. According to research by Okareh et al.[38] extracts and ointments from the leaves of these trees had a slight inhibitory effect on Staphylococcus aureus, while the extract and ointment from the mango kernel showed a sufficiently high antibacterial activity.

As Tagousop et al.[39] noted *S. aureus* was found to be more sensitive to saponins from Melanthera elliptica compared *E. coli* and *S. flexneri*. The findings of the present study showed that the antimicrobial activities varied with the bacterial and fungal strains and such variations may be due to genetic differences between the microorganisms.

According to Sulieman et al.[40] *Arnebia decumbens* plant extract is an effective source of antioxidants, saponins, terpenes, polyphenols and flavonoids and exhibits antibacterial activity against pathogenic bacteria including *S. epidermidis*, *E. cloacae*, *P. aeruginosa*, *E. coli* and *K. pneumoniae* and has strong antifungal activity against *C. albicans*. The antimicrobial activity of the plant extract increased depending on the concentration. A positive relationship between the content of saponin in the extract of *Calophyllum inophyllum* flowers and the zone of inhibition of *K. pneumoniae*, *S. tyhpi*, *B. cereus* was discovered by Vittaya et al.[41]

Due to the content of flavonoids, squalene, nimbidin, saponins, anthocyanins, tannins, myricetin, the extract of lakum (*Causonis trifolia* Linn.) leaves has an inhibitory effect on *S. aureus* biofilms.[42]

According to Hiberte et al.[43] *Tragia brevipes* may be a potential candidate in the treatment of bacterial infections as a source of new antimicrobial agents, as it showed high efficacy against *P. aeruginosa*, but did not inhibit the growth of *S. aureus* and *E. coli*. The results showed that the leaves and roots contain flavonoids, saponins, glycosides, phenols, tannins and resins.

As a result of the phytochemical screening of the *Kyllinga nemoralis* aqueous extract, the presence of saponin and a high concentration of steroid were found. Aqueous extract of *Kyllinga nemoralis* proved effective against *S. aureus*, methicillin-resistant *S. aureus* (MRSA), *S. epidermidis*, *St. pyogenes*, *B. thuringiensis*, *E. coli*, *Sh. sonnei*, *S. typhi* and *K. pneumoniae*.[44]

Punitha et al.[45] experimented with the peel of bitter orange (*Citrus aurantium*), lemon (*Citrus medica*) and tree apple (*Limonia acidissima*) fruits and found alkaloids, steroids, saponins, flavonoids, tannins, terpenes, phenolic substances and cardiac glycosides in their composition. The team of authors found that *C. aurantium* peel extract showed higher antimicrobial activity against *S. aureus*, *S. epidermis*, *P. aeruginosa*, *K. pneumoniae*, *C. albicans*, and *A. niger* with a different zone of growth inhibition. The minimum bactericidal/fungicidal concentration of these extracts ranged from 0.78 μg/ml to 12.5 μg/ml.

Extracts (acetone, methanol, and water) of *Ficus capensis* leaves contain saponins, phenols, terpenoids, and tannins. The acetone-based extract had the highest activity against *S. aureus* and *S. typhi*, and the methanol-based extract had the highest activity against *E. coli*.[46]

Calotropis gigantea is a folkloric plant used in India with undisclosed therapeutic activity. According to Bankapalli et al.[47] alkaloids, glycosides, flavonoids, saponins, resins and phenols, etc. were found in methanol and petroleum ether extracts of *C. gigantea* leaves. Extracts showed activity against *S. aureus*, *E. coli*, *A. niger* and *Mucor*, which confirmed their antifungal and antibacterial activity.

Alkaloids, steroids, phenols, flavonoids, tannins, triterpenoids, and saponins were found in phytochemical screening evaluation of crude ethanol extract of milk thistle (*Cnicos benedictus Linneau*). In the study of antibacterial activity, an inhibitory effect on G^+ bacteria was found, while G^- bacteria did not respond to the extract.[48]

Burman and Chandra[49] identified alkaloids, saponins, steroids, terpenoids and a number of other functional groups in the mature green fruits of *Artocarpus chama* and established the inhibitory efficacy of the plant ethyl acetate extract against *E. coli*, *P. aeruginosa* and *S. aureus*.

Moringa oleifera seed oil extract, which is widely used in cosmetology and food industry, contains some secondary metabolites such as alkaloids, saponins, flavonoids, anthocyanins and betacyanins, quinones, tannins, terpenoids and acids. When studying the antimicrobial effect, greater effectiveness against fungi (*Rhizopus stolonifera* and *C. albicans*) and different degrees of inhibition of bacterial growth (*B. subtilis*, *K. pneumonia*, *S. aureus*, *E. coli* and *P. aeruginosa*) were found.[50]

Calamus (*Acorus calamus* L.) is a plant widely known throughout the world due to its wide use in folk medicine.[51] The methanol extract of *A. calamus* showed the presence of flavonoids, alkaloids, phenolic compounds, tannins, steroids, saponins, glycosides and terpenoids and was highly effective against *S. epidermis*, *P. vulgaris* and *B. cereus*.

Santana et al.[52] investigated the antimicrobial, insecticidal and antioxidant activity of *Myrcia oblongata* oil and its plant extracts. *M. oblongata* plant extract showed efficacy against *E. coli*, *S. enteritidis*, *P. aeruginosa, Proteus mirabilis*, *K. pneumoniae*, *S. epidermidis*, *S. aureus*, *E. faecalis*, *C. albicans*, *S. allinarum*, *B. subtillis* and ten serotypes of *Salmonella* spp.. The authors attribute this high antibacterial activity to the high content of saponins, steroids, triterpenoids, tannins and flavonoids.

Medicinal plant from India — *Aerva lanata* (L.) Juss. ex Schult. - has the maximum content of saponins, flavonoids, sterols, phenol. Ethyl acetate extract of the dried plant effectively inhibited the growth of *S. typhie, K. pneumoniae*, *C. glabrata*, *C. albicans* and *C. haemulonii*.[53]

Rachna et al.[54] evaluated the presence of phytochemicals and antimicrobial activity of the ethnomedicinal plant *Trillium govanianum*. They determined the presence of flavonoids, cardiac glycosides, alkaloids, reducing sugars and saponins in the plant, and also established the effectiveness of the rhizome extract against *S. aureus*, *E. coli*, *K. pneumoniae*, *S. typhimurium* and *P. aeruginosa*.

In vitro studies of the pharmacological properties of the methanol extract of *Micropus bombycinus* Lag., which is used mainly in dermatology, were conducted by Dekkiche et al.[55] The authors determined the content of secondary metabolites (tannins, polyphenols, favonoids, saponins, quinones, cyanogenic glycosides, alkaloids, steroids and terpenoids) in plant material. *M. bombycinus* extract demonstrated antibacterial activity against *S. aureus*, *St. pneumoniae*, *P. aeruginosa*, *M. morganii*, *E. coli*, *P. mirabilis*, *B. pumilus*, *R. aquatilis* and *Rahnella* spp.. Such a broad spectrum of efficacy may help in the treatment of diseases associated with oxidative stress.

Mudaliana[56] determined the content of flavonoids, alkaloids, saponins, and tannins in *Centella asiatica* extract and established its antimicrobial activity against *Mycobacterium tuberculosis* H37Rv strain, *E. coli*, *S. aureus*, and *S.*typhi, except *B. subtilis*.

The presence of secondary metabolites (steroids, saponins, alkaloids, flavonoids, terpenoids and tannins) of the leaves and other parts of the plant was established during the study of the methanolic extract of *Vitex trifolia* (Legundi). The researchers concluded that the methanol extract of *V. trifolia* is an effective antibacterial source, especially against *S. aureus*.[57]

Sowmya and Koteshwar[58] found significant inhibition of clinical strains of *S. aureus*, *P. vulgaris*, *S. typhi*, *P. aeroginosa*, and *B. subtilis* when studying acetone and methanol extracts of *Terminalia catappa*. The minimum inhibitory concentration for all tested bacteria was from 5000 μg/ml to 9 μg/ml. Phytochemical analysis of *T. catappa* leaf extracts revealed a predominance of polyphenols (terpenoids, steroids, flavonoids, flavones, saponins, and tannins).

There are many plants with unexplored medicinal potential, one of which is *Vernonia squarrosa* (D. Don) Less. Its phytochemical composition includes alkaloids, terpenoids, tannins, phenols, flavonoids, saponins, as well as cardiac glycosides. The hydromethanolic extract of V. squarrosa leaves showed an inhibitory effect on *S. aureus*, *P. aeruginosa*, *B. subtilis*, *E. coli*.[59]

Sage leaves have long been known for their medicinal properties and are successfully used all over the world. The phenolic complex, flavonoids, tannins, as well as various concentrations of saponins, alkaloids, and mucilage are the phytochemical components of *Salvia officinalis*. Aqueous extract of sage leaves showed an antibacterial effect against *E. coli*, *K. pneumoniae*, *P. aeruginosa*, *S. aureus* with a minimum inhibitory concentration of 0.25-0.125 mg/ml; and such antifungal activity against *S. sereveseae* and *C. albicans* (0.25 mg/ml).[60]

Alhajali and Ali-nizam[61] established the presence of saponins in aqueous extracts of *Pistacia atlantica* and *Pinus canariensis*. Aqueous extract of *P. canariensis* was most effective against *P. aeruginosa* at MIC from 5.468 to 43.75 mg/ml.

According to the results of phytochemical screening of extracts of *Pulicaria crispa* (Forsk.) Oliv. and *Pulicaria undulata* (L.) C.A.Mey. the content of saponins, komarins, tannins, sterols and triterpenes and the absence of alkaloids, anthraquinones and flavonoids was established. Mohamed et al.[62] proved the sensitivity of *B. subtilis*, *S. aureus*, *E. coli*, *P. aeruginosa*, *A. niger* and *C. albicans* to water extracts of the studied plants.

Quercus robur L. leaf extracts were found to be rich in alkaloids, anthraquinones, saponins, tannins and other components according to Benyagoub et al.[63] MIC for *E. coli*, *E. faecalis* and *S. aureus* was 10 mg/ml, and for *Salmonella* spp., *K. pneumoniae*, *P. aeruginosa* and *C. albican*s – 30 mg/ml.

When determining the phytochemical analysis of *Rhizophora apiculata* leaf extract, Syawal et al.[64] determined the content of saponins, tannins, flavonoids, steroids and terpenoids, and proved its small inhibitory effect on *S. aureus*, *A*. *hydrophila* and *P. aeruginosa*.

Dahibhate et al.[65] came to a similar conclusion when studying the antibacterial properties of the ethyl acetate extract of *Avicennia marina* and *Bruguiera gymnorhiza*. They found that the mangrove extract has strong antibacterial activity against *S. aureus*, S. *epidermidis*, *E. faecalis* and *P*. *aeruginosa*, while phytochemical analysis of the plant material revealed the presence of saponins, phenols, flavonoids, alkaloids, tannins and terpenoids.

A study of phytochemical analysis established the presence of flavonoids, alkaloids, saponins, tannins and phenols in the *Byrsocarpus coccineus* root bark extrac. *E. coli* and *S. pullorum* according to Sunday et al.[66] were susceptible to the extract with a minimum inhibitory concentration of 0.3125 mg/ml.

Mu'ad Al-zuabe et al.[67] investigated the antimicrobial properties of *Cyclamen persicum*, a wonderful indoor plant that is often used to decorate the home. They found that acetone, ethanol and methanol extracts of *C. persicum* tubers have antibacterial activity against *S. pyogenes*, *S. aureus*, *E. faecalis*, *P. mirabilis*, *K. pneumoniae*, *E. cloacae*, *P. aeruginosa* and *S. flexneri*; at the same time, acetone, ethanol and methanol extracts showed high efficacy against *Candida* spp.. Saponin was isolated from the methanolic extract of *C. persicum* tubers.

Some plants that are considered weeds can also have healing properties. Thus, *Lactuca serriole* L. contains alkaloids, glycosides, saponins and tannins. The plant extract showed good inhibitory activity against *S. aureus*, *P. vulgaris*, *E. coli* and *P. aeruginosa* in the range of 23-63 mg/ml.[68]

In addition to terrestrial plants, marine algae are also rich in saponins. According to Hamisi et al.[69] saponins, tannins, alkaloids, cardiac glycosides, diterpenes and flavonoids were found in algae from the Indian Ocean. The sea grasses *H. uninervis* and *C. rotundata* are of interest due to their strong antibacterial activity against *S. typhi* and low level of cytotoxicity.

The synergistic potential of saponins

Brahim et al.[70] showed that the combination of saponins extracts and fluconazole exhibited a total synergism against *C. albicans*, *C. parapsilosis*, *C. krusei* and C. *glabrata*. Saponin-rich extracts of *Paronychia argentea* and *Spergularia marginata* have been shown to be effective against most *Candida spp*. and gram-positive bacteria.

Horie et al.[71] they noted a synergistic effect on the antimicrobial activity of β-lactam antibiotics against β-lactamase-producing *S. aureus* strains of raw soy saponins and a significant reduction in the activity of β-lactamases obtained from *E. cloacae*, *E. coli* and *S. aureus* in the presence of raw soy saponins.

Conclusion

In the review, we collected the materials of the last five years of research into the possibilities of using plant raw materials with antimicrobial properties. This review shows that saponins are present in medicinal plants and many plants that do not have direct medicinal value. Together with other secondary metabolites, they play an important protective role for the plant itself, and can be very useful in medicine.

According to published data, extracts from saponin-containing plants have a high potential to inhibit both gram-positive and gram-negative bacteria, as well as fungi. The minimum inhibitory concentration of the saponin-containing plant extract depends on:

1. type of plant
2. plant parts (root, trunk, bark, leaves, shell or seeds)
3. the type of solvent used to extract secondary metabolites (ethanol, methanol or water)
4. the presence of other secondary metabolites in the extract
5. type of pathogenic microorganism.

According to scientific results from different countries of the world, depending on the species, saponin-containing plants, in addition to saponins, also contain a number of secondary metabolites (tannins, flavonoids, terpentoids, phenols, sterols, alkaloids, komarins, etc.), which directly or indirectly in a synergistic relationship linked to each other affect microbial cells, causing their death. Recent research also shows the effectiveness of saponin-containing plants in combination with antibiotics, which is an important direction in overcoming antibiotic resistance of the most common pathogens.

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Conflict of Interest

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