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Antifungal, Antibacterial and Nematicidal Properties of *Solanum* Species

Dilshad Masih
Ph.D. Scholar, Mangalayatan University, Richai, Barela, Jabalpur- 483001 (M.P.), India

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Corresponding Author: **Dilshad Masih**

Abstract
The *Solanum* genus, belonging to the nightshade family (Solanaceae), is a widely distributed group of plants exhibiting significant bioactive potential due to its rich phytochemical composition. Various species within this genus have been extensively studied for their antifungal, antibacterial, and nematicidal properties, primarily attributed to the presence of alkaloids, glycoalkaloids, flavonoids, and steroidal compounds. These secondary metabolites contribute to the inhibition of fungal growth, bacterial proliferation, and nematode infestations, making *Solanum* species valuable candidates for pharmaceutical and agricultural applications. This review explores their role in natural antimicrobial and nematode management strategies. Understanding these properties may facilitate the development of eco-friendly biopesticides and plant-based therapeutic agents, contributing to advancements in medicine and sustainable agriculture. Incorporating *Solanum* species into crop rotation or integrated pest control can reduce nematode populations, increase crop output, and reduce the need for chemical pesticides.

Keywords: *Solanum*, Nightshades, Antifungal, Antibacterial, Nematicidal, Biological Control Methods

Introduction

Solanaceae [1] known as nightshades, is a flowering plant family belonging to the Solanales order. It has about 2,700 species, many of which are employed as agricultural crops, medicinal plants, weeds, and ornamental plants. Many species of the family contain high alkaloid levels, making them extremely hazardous, while many—such as tomatoes, potatoes, eggplants, and peppers—are commonly used in meals [2]. High alkaloid content in some species makes them valuable for recreational, medicinal, and culinary purposes. The tobacco plant has been used for centuries as a drug, while Atropa bella-donna has pain-killing and psychedelic effects. Capsicum species' capsaicin gives their fruits pungency, making them used in spicy food products. Potato, tomato, and eggplant are also used in cuisine [2].

Solanum is a diverse genus of flowering plants that includes potatoes, tomatoes, eggplants etc. It is the largest nightshade family (Solanaceae), with over 1,500 species. It also has horse nettles and ornamental plants. *Solanum* species can grow as annuals, perennials, vines, subshrubs, shrubs, or tiny trees. Many previously distinct genera like *Lycopersicon* and *Cyphomandra* were merged into *Solanum* as subgenera or sections [3-4].

Since the primordial era, humans have relied on plants for food, fuel, medicines, and fodder to graze their livestock [5]. Plants serve important roles in rituals, bodily purification, and medicine [6]. Plants have been used to treat diseases from the beginning of humanity [7]. According to the World Health Organization, 75% of the global population relies on medicinal plants for basic healthcare needs [8-9]. Solanaceae, a magical plant family, is widely used in traditional medicines and holds unique floristic, economic, phytochemical, and ethnobotanical significance [9-14].

Distribution

The Solanaceae family originates in South America [15-17]. This distinguishes it from other families in the Solanales order, which evolved predominantly in Africa. Its geographic isolation is most likely what drove its initial divergence into a unique lineage [16]. Although members of the Solanaceae can be found on all continents except Antarctica, Central and South America have the most diverse species. Centers of diversity can also be found in Australia and Africa. Solanaceae live in a wide range of environments, from deserts to rainforests, and are frequently found in secondary vegetation that colonizes degraded regions. Plants in this family are found primarily in tropical and temperate regions [18].

Secondary metabolites

Various nightshade species produce numerous alkaloids, including solanine, chaconine, atropine, tomatine, and many others. Plants use them as a natural insecticide, affecting cellular and physiological processes of invading pathogens. They are primarily employed against insects, but they can also work as fungicides, nematicides, and bactericides [19]. Some alkaloids are hazardous to humans when consumed in large quantities, whereas others are sought after for medical, recreational, or culinary purposes [2].

The following table provides an overview of key alkaloids found in various plant species, particularly within the Solanaceae family.

Table 1: Common alkaloids found in various plant species of Solanaceae family

Compound	Chemical Formula	Sources	Function	Toxicity & Effects	Reference
Solanine	$C_{45}H_{73}NO_{15}$	Found in leaves, fruit, and tubers of Solanaceae (e.g., potatoes, tomatoes)	Adaptive defense against herbivores	Can cause gastrointestinal (diarrhea, vomiting, abdominal pain) and neurological disorders (hallucinations, headache) LD_{50} = 2-5 mg/kg; Symptoms appear 8-12 hours after ingestion	[20-22]
Tropane	$C_8H_{15}N$	Found in *Atropa, Mandragora, Hyoscyamus, Datura, Brugmansia*	Powerful anticholinergics; inhibit acetylcholine signals	Highly toxic; can halt allergic reactions, cause neurological effects	[23-24]
Nicotine	(S)-3-(1-methylpyrrolidin-2-yl) pyridine	Found in tobacco (*Nicotiana tabacum*), eggplants, tomatoes, potatoes, peppers	Acts as a neurotoxin against herbivores; used as an insecticide	At low concentrations, acts as a stimulant in mammals; highly addictive; targets nicotinic acetylcholine receptors	[25-26]
Capsaicin	8-methyl-N-vanillyl-trans-6-nonenamide	Found in *Capsicum* species (chilis, habaneros)	Activates pain receptors related to heat perception	Not toxic to humans but causes a burning sensation in mammals; does not affect birds; used in pepper spray	[2]

Ethnopharmacological Importance

The Solanaceae family is a key economic and medicinal group within the genus *Solanum*, offering culinary, ornamental, and pharmacological benefits. Over the last 30 years, intensive study has revealed vital compounds such as atropine, hyoscine, solasodine, and withanolide that are utilized in medicine and food [27-29]. While many species have therapeutic properties, some include poisonous alkaloids with potential risk to people and animals [30-33]. Several *Solanum* species have undergone pharmacological research, demonstrating their ethnopharmacological significance. Species including *S. nigrum, S. xanthocarpum, S. tuberosum,* and *S. lycopersicum* are commonly employed in traditional medicine and food additives [30-34]. While previous reviews focused on particular species, broader investigations reveal that the *Solanum* genus has numerous therapeutic applications [35, 36-39]. Some prominent species include *S. sisymbriifolium* ("wild tomato"), which is used in veterinary and human medicine [40], and *S. tuberosum*, which is used in folk treatments for burns, coughs, and skin problems [41].

Many species have localized medicinal value, like *S. integrifolium*, which is used to regulate blood pressure and inflammation in Africa, [42] and *S. mammosum*, which is traditionally used in Peru to treat fungal infections and respiratory problems [43]. Despite being toxic, *S. pseudocapsicum* is used to cure boils, gonorrhea, and abdominal pain [44]. Other extensively researched species include *S. torvum, S. elaeagnifolium*, and *S. verbascifolium*, which have been researched for their anti-inflammatory, antibacterial, and pain-relieving characteristics [43-49].

Antifungal properties

Das *et al*. (2010) found *S. melongena* Linn. to be a potent antifungal plant, with broad activity against human pathogenic dermatophytes, namely *Trichophyton mentagrophytes*, *T. rubrum,* and *T. tonsurans* and two opportunistic fungi *Candida albicans* and *Trichosporon beigelii*, and found organic solvents more suitable for extraction in comparison to water [50]. Bari *et al* (2010) extracted leaves, stem, roots, and inflorescence from *Solanum torvum* Sw. in organic solvents (chloroform & methanol) to test their antibacterial and antifungal effects on human pathogenic bacteria and fungi. The methanol extract inhibited bacterial growth at low concentrations, while the chloroform extracts were more toxic [51]. Sridhar *et al* (2011) studied solvent extracts from *Solanum nigrum* leaves, seeds, and roots for antifungal activity against fungal strains such as *Penicillium notatum, Aspergillus niger, Fuserium oxysporium* and *Trichoderma viride*. Results showed strong activity from organic solvent extracts, with ethanol seed extract showing the lowest MIC value [52]. Sitapha *et al* (2023) tested the antifungal activity of various extracts of *Solanum anguivi* Lam fruits on *Candida albicans in vitro*. The extracts were found to be active against different strains, with fresh fruit extracts showing good activity on *Candida albicans*, based on a dose-response relationship. The study highlights the potential of *Solanum anguivi* Lam. in traditional medicine [53]. Aliero *et al* (2006) tested the antimycotic properties of *Solanum pseudocapsicum* extracts in acetone, methanol, and water against five fungal species. They found that acetone and methanol extracts significantly inhibited *Aspergillus niger* and *Penicillium notatum* growth, while methanol and acetone extracts suppressed *Fusarium oxysporum* growth, suggesting potential fungicide applications [54].

A study by Hernández-Rodríguez *et al* (2018) investigated the antifungal activity of *Solanum chrysotrichum, S. erianthum, S. torvum*, and *S. rostratum* against phytopathogenic *Curvularia lunata*. The study evaluated methanol extracts from roots, stems, leaves, and fruits, and determined the minimum inhibitory concentration (MIC) on a liquid medium. The results showed that 12 out of 16 methanolic extracts of *Solanum species* had antifungal effects against *C. lunata*, with *S. rostratum* and *S. erianthum* showing the highest activity. The mixture of active extracts increased their activity [55]. Phatik *et al*. (2014) found that leaf extracts of *Polygonum hydropiper* and *Solanum melongena* effectively combat fungi (*Colletotrichum capsici, Curvularia lunata, Rhizoctonia solani* and *Sclerotinia sclerotiorum*), preventing severe crop losses. The extracts outperformed commercial fungicides in-vitro, with a marginally higher inhibitory effect [56]. Bouslamti *et al* (2022) found that fruit and leaf extracts from *Solanum elaeagnifolium* var. *obtusifolium* (Dunal) Dunal showed potent antifungal activity against *Candida albicans* ATCC-1023 [57]. Niño *et al*. (2006) tested the antifungal properties of hexane, dichloromethane, and methanol extracts from 11 Solanaceae plants in Colombia, finding methanol extract of *Lycianthes synanthera* (Send.) Bitter of the *Solanum* family to be effective against *Candida albicans* and *Fusarium solani* [58]. Kusuno *et al*'s 1987 study found that *Solanum* alkaloids and their derivatives have antifungal activities against fungal strains like *Candida albicans* and *Trichophyton* spp. Solacongestidine showed the strongest activity, while other alkaloids showed lower activities [59].

Antibacterial Properties

Tegegne *et al* (2021) found that *Solanum anguivi* Lam fruit extracts effectively combat gram-positive and gram-negative bacteria, with stronger effects on gram-positive bacteria [60]. Bouslamti *et al* (2022) investigated the antimicrobial properties of fruits and leaf extracts from *Solanum elaeagnifolium* var. *obtusifolium* (Dunal) Dunal, finding fruit extract to be highly effective against all tested strains.(*Staphylococcus aureus* ATCC-6633, *Bacillus subtilis* DSM-6333, *Escherichia coli* K-12 and *Proteus mirabilis* ATCC-29906) [57]. Niño *et al*. (2006) found that the hexane, dichloromethane, and methanol extracts from 11 Solanaceae plants in Colombia were more effective against *Bacillus subtilis* [58]. Almoulah *et al* (2017) evaluated the antibacterial activities of methanolic leaf extracts and steroidal glycoalkaloid fractions of *Solanum incanum* L., *S. schimperianum* Hochst, *S. nigrum* L., *Physalis lagascae* Roem. & Schult., and *Withania somnifera* Dunal against Gram-positive bacteria viz. *Bacillus subtilis* (ATCC 6633) and *Staphylococcus aureus* (ATCC 25923)and Gram-negative bacteria viz. *Escherichia coli* (ATCC 25922) and *Pseudomonas aeruginosa* (ATCC27853) using microdilution method [61]. Nithya *et al* (2018) investigated the antibacterial properties of *Solanum xanthocarpum* leaves, finding that the methanolic extract showed excellent activity against *Pseudomonas aeruginosa*, *Salmonella typhi, Staphylococcus aureus*, and *Escherichia coli*, suggesting *S. xanthocarpum* as a potential candidate for antibacterial and antioxidant properties [62]. Doss *et al*. (2009) found tannins from *Solanum trilobatum* Linn. antibacterial against various bacteria like *Staphylococcus aureus, Streptococcus pyrogens, Salmonella typhi, Pseudomonas aeruginosa, Proteus vulgaris* and *Escherichia coli*. Tannins exhibited antibacterial activities against all the tested microorganisms, with *S. aureus* being the most resistant. This supports the plant's traditional use as green medicine and suggests its pharmacological importance [63].

Khunbutsri *et al* (2022) studied the antibacterial activity of *Solanum torvum* leaf extract against *Methicillin-resistant staphylococci* (MRS) in dogs. They found that the leaf extract's positive effects were most noticeable when combined with oxacillin, suggesting potential therapeutic options [64]. Amanpour *et al*.'s 2015 study found that *Solanum tuberosum* peel extract has a more potent antibacterial effect on gram-positive bacteria (*Streptococcus pyogenes* and *Staphylococcus aureus*) than gram-negative bacteria (*Pseudomonas aeruginosa* and *Klebsiella pneumonia*) [65]. Kobisi *et al* (2024) tested silverleaf nightshade extracts against *Erwinia carotovora* pv. *carotovora*, a potato weed, using seeds, peels, and mucilage. The EtOH extract showed promising inhibition efficacy and the best minimal inhibition concentration [66]. Ramesh *et al* (2015) studied the green biosynthesis of ZnO nanoparticles using *Solanum nigrum* as a capping agent. They found that particle size variations and surface area-to-volume ratios significantly enhance antibacterial activities [67]. Chirumamilla *et al*. (2022) conducted a study on the bioactive compounds in *S. khasianum* leaf and root extracts, analyzing their antibacterial activity against *Bacillus sphaericus, Escherichia coli, Staphylococcus aureus,* and *Pseudomonas aeruginosa*. The leaf extract showed high activity against *P. aeruginosa*, followed by E. *coli., B. sphaericus* and *S. aureus,* whereas the root methanolic extract exhibited high antibacterial activity against E. coli, followed by *P. aeruginosa, S. aureus,* and *B. sphaericus*, indicating *S. khasianum* root extract exhibit remarkable antibacterial properties [68].

Antinematode properties

Correia's 2014 study evaluated *Solanum nigrum* and *S. sisymbriifolium* against *Pratylenchus goodeyi*, a common nematode parasite in Madeira Island banana crops. Results showed that water and aqueous extracts affected nematode mobility and mortality, with acetone extract from *S. nigrum* being most effective. This suggests *S. nigrum* could be used for a new control strategy against plant-parasitic nematodes [69]. Balah and AbdelRazek (2020) found that Sliver nightshade, an invasive weed in Egypt, has strong allelopathic potential against *Meloidogyne incognita* galls, egg-masses, female's numbers, juveniles' number and weeds. The extracts of *S. elaeagnifolium* leaves and seeds showed positive effects on root knot nematode infection [70]. Perpétuo *et al* (2023) tested the efficacy of *Solanum linnaeanum* and *S. sisymbriifolium* extracts against *Meloidogyne chitwoodi*, a root-knot nematode causing significant crop yield losses. The extracts reduced hatching but did not affect mortality, but lowered infectivity and reproduction. The results suggest effective *Solanum* extracts for *M. chitwoodi* management [71]. Khan *et al*.'s 2023 study found that extracts from *Mentha arvensis* and *Solanum nigrum* had strong anti-egg hatching and apoptotic effects on *Caenorhabditis elegans*, indicating their nematicidal potential may be attributed to their phytochemicals and bioactive substances [72]. Oplos *et al*. (2018) found that *Datura stramonium* shoots inhibited root-knot nematodes' motility of *Meloidogyne incognita* and *M. javanica*, while *Solanum nigrum* seeds were faster and more effective. Both extracts suppressed J2 hatching from eggs, with powdered *S. nigrum* seed meal showing greater activity [73].

Costa *et al* (2024) found that *S. stramonifolium* effectively protects against RKN, reducing gall diameter and biomass in *Arabidopsis thaliana* Col-0 inoculated with RKN. Treatment also altered ploidy levels in roots, indicating its effect on endoreduplicating cells [74]. A study by Basavaraj *et al* (2025) at the University of Mysore found that *Solanum torvum* fruit extract, particularly methanolic extract, effectively inhibited egg hatching and juvenile mortality of

Meloidogyne incognita, suggesting it as an eco-friendly method [75]. Chitambo's 2019 study found that African indigenous vegetables like African nightshade and African spinach significantly reduced RKN and PCN soil infestation in Kenya. The cultivation of these vegetables reduced RKN infestation by 85% and PCN by over 80%, while also reducing PCN females and galling index [76]. Ferreira *et al* (2022) found that crude aqueous root extracts (CAREs) of three *Solanum* species, *Solanum americanum*, *S. subinerme*, and *S. lycocarpum*, showed high nematicidal activity against second-stage juveniles of *Meloidogyne incognita*, inhibiting hatching and presenting a lethal dose of 336 µg ml^{-1}. These CAREs also reduced egg masses and galls in a greenhouse bioassay, making them an ecologically appropriate tool for controlling nematode infection in crops [77]. Sivasankara and Dandurand's 2021 study examined the impact of solanaceous glycoalkaloids (SGAs) on the hatch, development, and reproduction of *Globodera pallida* in potato. Results showed that exposure to α-solamargine and α-solamarine reduced hatch by 65 and 87%, and infection by 98 and 94% [78].

Conclusion

Chemical antifungal, antibacterial, and antinematode treatments used in agriculture can harm the environment by disrupting soil health, contaminating water sources, and reducing biodiversity. These chemicals often kill beneficial microorganisms essential for soil fertility, leading to long-term degradation. Runoff from treated fields pollutes rivers and groundwater, affecting aquatic life and drinking water quality. Overuse of these treatments can also promote resistance in fungi, bacteria, and nematodes, requiring stronger chemicals that further increase toxicity levels. Sustainable alternatives like crop rotation, organic treatments, and biological control methods are crucial to minimizing environmental damage while ensuring effective pest and disease management. The antifungal, antibacterial and nematicide properties of *Solanum* species as control agents were found quite promising against species like *Trichophyton, Candida, Streptococcus, Penicillium, Aspergillus,, Fusarium, Trichoderma, Candida, Staphylococcus, Bacillus, Escherichia, Proteus, Klebsiella, Pseudomonas, Salmonella,* Meloidogyne, Pratylenchus, Globodera, *Caenorhabditis,* etc. when treated with dried plant parts, aqueous extracts obtained from dried and fresh plant parts, nanoparticles, and glycoalkaloids.

Recommendations

The use of *Solanum* species in a system of crop rotation or as a treatment may be an appropriate component of Integrated Pest Management, keeping the fungal, bacterial and nematode populations at a level low enough not to cause economic losses, avoiding or limiting the use of chemical plant protection products, and increasing production and crop quality. *Solanum* species can be a good alternative to other control measures, but more studies have to be done before the crop can be used on a commercial scale, including studies on establishment and appropriate weed control. Research is required to develop new environmental-friendly treatments that can provide reliable control, are cost-effective and are less likely to pollute groundwater. Considering the mode of action and the chemical properties of various *Solanum* species, these plants can be excellent candidates for further antifungal, antibacterial, and nematicidal studies.

Declaration of Competing Interest and Conflicts of Interest

The author declares no competing interests or conflicts of interest regarding the publication of this article

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