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MINI REVIEW

Antifungal properties of *Andrographis paniculata* extracts as potential biofungicides: a review

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Abstract

Andrographis paniculata, commonly known as the king of bitters, has been studied for its potential as a natural fungicide due to its several bioactive compounds, including andrographolides. The primary objective of this study was to demonstrate the possible efficacy of *A. paniculata* against a wide range of fungal diseases in terms of the properties of *A. paniculata* extracts that could potentially be used as a bio-fungicide. The presence of alkaloids, flavonoids, phenols, terpene derivatives compounds, and other phytochemical constituents makes the *A. paniculata* extract more precise in its mode of action against the variety of phytopathogenic fungi. Various physiological and biochemical changes in crops result in unintended physiological issues, degradation, and subsequent financial losses during storage. Synthetic fungicides have been applied to control plant diseases caused by phytopathogenic fungi. However, their application has drawn criticism because of adverse effects. Therefore, a possible solution would be to apply botanical fungicides, which have been proven to be generally non-phytotoxic, systemic, and rapidly disposable in nature. Botanical fungicides are endowed with benefits such as resistance inhibition, being eco-friendly, effective, elective, and more affordable than synthetic fungicides. Therefore, the medicinal herb, *A. paniculata* has been proven to be effective in controlling pathogens of agricultural crops and increased their shelf-life when used as a substitute for synthetic chemicals. Due to their antimicrobial capabilities against fungal, bacterial, and viral infections, various medicinal herbs have been investigated and employed for crude extraction globally. *Andrographis paniculata* extracts have broad-spectrum antifungal activity, indicating potential efficacy against a diverse variety of fungal infections.

1. Introduction

Almost all crops have been vulnerable to a variety of pests and diseases, the majority of which are fungal pathogenic infections. Fungi are a varied collection of microorganisms that include plant pathogenic species that cause significant output losses in crop production systems across the world (Rodriguez-Moreno *et al.,* 2018). Abiotic factors such as pH, water activity, solute concentration, temperature, environment, time, and others make vegetable and fruit crops extremely susceptible to fungus spoilage. These elements also cause a variety of plant infections and significant financial losses in the field and before harvest (Choudhury *et al.,* 2018). Therefore, many researchers have attempted to develop a successful treatment technique for this issue to reduce the risk of disease transmission.

Pathogens, especially fungi, are commonly responsible for plant disease. Fungus, for example, may rapidly transfer disease infestations to other plants. Fungi have developed several ways for colonising plants, and these interactions have a wide range of implications, from positive interactions to host death. Under favourable conditions, the infection cycle of plant

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pathogenic fungus begins with spore germination and filamentous germ tube development, which need complete cell reprogramming and specific regulatory networks. After spore germination, runner hyphae produce polarised cells and grow along the host plant surface, which is based on the recognition of distinct physical (surface hardness and hydrophobicity) and chemical (cutin monomers and leaf waxes) signals (Doehlemann *et al.,* 2017).

Controlling fungal infections is challenging due to their constantly changing behaviour and development, which relates to significant genetic variety and quick growth periods, allowing them to defeat the most recent highly impactful disease. The proportions of increased fungicides are employed to represent the lowered competence with the economic return of applied fungicides against fungal diseases (Jain *et al.,* 2019). Many countries have strict regulations and restrictions on the use of chemical fungicides. Natural biofungicides can provide alternatives that are easier to register and comply with regulatory standards. Fungicides might be employed in a regime that controls the timing, frequency, and application amount, regardless of resistance status or ecological context. The safe and immobile approach to fungicide application not only reduces management efficacy and increases costs but also has negative environmental implications, such as livestock poisoning.

Furthermore, biofungicides are formulations produced from naturally occurring compounds that control fungi through non-toxic methods that are also environmentally benign. Biofungicides promote sustainable agriculture by reducing the reliance on synthetic chemicals, which can lead to soil degradation, resistance development in pests and diseases, and negative impacts on non-target organisms. Similarly, Musa *et al.* (2011) have stated that chemical compounds from plants are increasingly being used in medicinal applications due to their lower environmental effect. They could be obtained from medicinal plants such as *A. paniculata*, their derivatives, or by-products that can be employed for fungal treatment. The global impact of biofungicides on agricultural production and food security cannot be overstated. Biofungicides have been receiving much attention in the recent decade, especially with the increased purchase intention of organic foods (Najmi *et al.,* 2022). Suharti *et al*. (2020) reported that many Asian farmers use plant extracts like ginger, garlic, turmeric, and onion to prevent fungal infections. Therefore, bio fungicide is significantly used in the agriculture sector since they are compatible with integrated pest management (IPM) strategies, which emphasise a holistic approach to pest and disease control, including cultural, biological, and chemical methods. Natural biofungicides fit well into such integrated approaches.

Typically, the plant generates a wide range of secondary metabolites employed directly as lead chemicals in the pharmaceutical sector or as a precursor (Zain *et al.,* 2021). Zain *et al*. (2018) also stated that phytochemical constituents such as secondary metabolites and bioactive compounds generated by plants are abundant in medicinal plants. Metabolites are typically thought to be tiny molecules that serve numerous functions in the organism's physiology and biochemistry. Many plants have been recognised as therapeutic plants due to the presence of secondary metabolites that serve as natural antimicrobial agents. In this review, we have summarised the phytochemical compounds found in the different solvents of extraction that affected their effectiveness as antifungal properties, and thus, led them to be made as a potential bio fungicide to control plant pathogenic fungi. Beyond its potential for human fungal infections, *A. paniculata* extracts have also been explored for their ability to control fungal pathogens that affect plant yield and quality. Therefore, they can be used as a natural fungicide in agriculture to protect crops from fungal infections.

2. *Andrographis paniculata* plant and uses

Andrographis paniculata, commonly known as *hempedu bumi* is an annual herbaceous plant that belongs to the Acanthaceae family and is widely cultivated in southern Asia, China, and some parts of Europe (Battu *et al.,* 2018). *Andrographis paniculata* has been identified as an annual and branched plant attached with lanceolate green leaves, and it could attain heights of 60-70 cm (Battu *et al.,* 2018). This medicinal herb is known as the king of bitters due to its exceptionally bitter flavour in all parts of the plant (Battu *et al.,* 2018). The bitter principle of andrographolide is mostly derived from the plant *A. paniculata*. Figure 1 shows the morphology of *A. paniculata* plant.

Andrographis paniculata is a medicinal plant that has been used for generations due to its various pharmacological effects. It contains bioactive compounds such as andrographolide, which is mainly found in the leaves. Andrographolide has been shown to have immunostimulant, antibiotic diuretic, antipyretic, anti-inflammatory, hepatoprotective, hypotensive, hypoglycaemic, and antibacterial properties (Septiani *et al.,* 2021). Research has been conducted to isolate and purify andrographolide from *A. panicula* leaves, and the results showed a yield of 0.47% using purification and crystallisation methods (Pandey and Rao, 2018). Additionally, a quantitative analysis method using high-

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performance liquid chromatography (HPLC) has been developed to determine the content of isolated andrographolide, which showed good precision and accuracy (Syukri *et al.,* 2015). The plant has been widely cultivated and its importance as a medicinal plant is growing, with reports supporting its various therapeutic uses (Joselin and Jeeva, 2014). Overall, *A. paniculata* and its bioactive compound andrographolide have shown promising pharmacological properties and potential as a multipurpose medicinal agent.

Figure 1. Morphology of *A. paniculata*: (a) plant, (b) flower, (c) root and (d) seed.

According to Gupta *et al*. (2022), *A. paniculata* was found to be an effective antibiotic, antiviral, anti-parasitic, and immune system stimulant. *Andrographis paniculata* has long been utilised for clinical pharmaceutical purposes in China and India to cure snake bites, deadly insect stings, fevers (such as malaria and dengue), diarrhoea, flu, skin illnesses, and upper respiratory infections (Kumar *et al.,* 2021). According to the literature, the primary groups of chemicals include terpenoid lactones and flavonoids, with many additional classes of compounds such as diterpenoids, phenolic acids, xanthones, and volatile compounds reported in various parts of this plant (Kalaivani *et al.,* 2012). Antimicrobial compounds derived from herbaceous plants can inhibit the development of fungi, bacteria, viruses, and protozoa through processes distinct from those of currently used antimicrobials, and they can impose therapeutic value for the control of resistant pathogenic strains (Keita *et al*., 2022).

Furthermore, *A. paniculata* is believed to be a natural antibiotic with a variety of pharmacological properties, including antidiabetic, anti-inflammatory, hepatoprotective activity, antioxidant, and potential antiviral activity (Okhuarobo *et al.,* 2014). This is the most well-known and studied compound in *A. paniculata*. Andrographolide has been shown to have anti-inflammatory, immunomodulatory, and antioxidant properties. It is one of the primary bioactive compounds responsible for the plant's medicinal effects. Similarly, Nidiry *et al.* (2015) reported that *A. paniculata* is a plant that has antifungal properties by having andrographolide as a compound found in the plant with potential antifungal activity.

The therapeutically important active principle of *A. paniculata* found in aerial parts is andrographolide. It is colourless, crystalline, bitter in taste, and known as diterpene lactone. Other reported compounds include 14-deoxy-11, 12-didehydroandrographolide or andrographolide D; 14-deoxy andrographolide; non-bitter compound neoandrographolidehomo-andrographolide; andrographosterol; andro- graphane; andrographone; andrographosterin; andrograpanin; alpha -sterol; stigmasterol; apigenin-7,4’-di-O- methyl ether; 5 hydroxy 7, 8, 2’, 3’-tetramethoxyflavone; mono-hydroxy trimethyl flavones; andrographin; dihydroxy-di-methoxy flavones; panicolin; andrographoneo; andrographoside; andro- paniculosin, andropani-culoside A and number of compounds were identified by previous researchers (Sagadevan *et al.,* 2015).

Besides, according to Kalit *et al.* (2023), *A. paniculata* and its extract components have been extensively studied for their antifungal potential, along with the significant levels of antioxidants and other active compounds. The presence of 14-deoxyandrographolide, extracted from *A. paniculata*, was responsible for the detection of antioxidant activity in the plant (Sagadevan *al.,* 2015). Verma *et al.* (2008) conducted a study on lymphoma-bearing mice to investigate the impact of an aqueous extract of *A. paniculata* on the antioxidant system. The administration of various doses of the plant's aqueous extracts resulted in a significant increase in the activities of catalase, superoxide dismutase, and glutathione S transferase, indicating the antioxidant capabilities of *A. paniculata* and its potential to alleviate oxidative stress. In contrast, the hydroalcoholic extract of the medicinal plant enhanced the activity of antioxidant enzymes such as superoxide dismutase, catalase, and glutathione peroxidase (Ojha *et al.,* 2009). The bioactive constituents found in the samples could improve their antioxidant properties (Abdullah *et al.,* 2022).

3. Phytochemical constituents of *Andrographis paniculata*

Secondary metabolites are produced by plant species and are essential in plant defence against herbivores and other plant diseases. This secondary metabolite characteristic is being used as a natural treatment for a variety of ailments. Since the previous several decades, researchers' attention has been drawn to this topic, primarily due to the adverse effects of synthetic medications and the development of antibiotic resistance in microorganisms. The existence of hundreds of distinct physiologically active chemicals created by plants, known collectively as secondary metabolites, is linked to their healing potential. Organic acids, phenolic compounds, terpenes, saponins, and alkaloids are all examples of secondary metabolites. These secondary metabolites often serve vital ecological activities. A medicinal plant is one in which a plant or one of its constituents is used as medicine to treat a specific disease. Many plants are recognised as therapeutic plants due to the presence of secondary metabolites that serve as natural antimicrobial agents.

However, compounds in the extracts, which include alkaloids, flavonoids, saponins, tannins, and terpenoids, can exhibit antifungal activity (Kalit *et al.,* 2023). In a previous study, terpenoids were found to be the most abundant compounds in *A. paniculata* leaves. It was found in chloroform, ethyl acetate and methanol extracts. Terpenoid compounds were reported to have antibacterial, antiviral, antidiarrhoeal and antineoplastic effects (Jayashree, 2013). The terpenoid compounds exhibit antibacterial activity through the mechanism of membrane disruption by its lipophilic compounds (Tan, 2015). The most common terpenoid compounds that are isolated from *A. paniculata* are diterpenoid lactones. One of the examples of diterpenoids lactone is the andrographolide, which has a bitter taste, is colourless and in crystal form (Okhuarobo, *et al.,* 2014). The presence of secondary metabolites and bioactive compounds in *A. paniculata* plant extracts provide antifungal activity against plant diseases. These phytochemical constituents are first produced by plants to protect themselves from infections and predators (Tan, 2015).

Besides, researchers have shown that phytochemical constituents generated by plants have biological actions such as antiperiodic, antibacterial, anticancer, antidiabetic, antithrombotic, anti-inflammatory, and antifungal. Alkaloids, sugars, flavonoids, tannins, terpenoids, and steroids are among the most important secondary metabolites (Akbar, *et al.,* 2020). According to Malahubban *et al*. (2013), andrographolide was an active compound found in the aerial part of the *A. paniculata* plant. Andrographolide, a diterpene lactone that is colourless, crystalline, and bitter, was presented in the aerial sections of *A. paniculata* (Okhuarobo *et al.,* 2014). Generally, andrographolide is the most abundant diterpene lactone in *A. paniculata*, accounting for 1.7% and 0.8% of the herb's dried leaves and stems, respectively (Pholphana *et al.,* 2004). The bitter principle of andrographolide is mostly derived from the plant *A. paniculata*.

Furthermore, Kalit *et al.* (2023) stated that the aerial plant part *A. paniculata* was used to extract the phytochemical constituents such as secondary metabolites and bioactive compounds. Consequently, plant extracts rich in organic compounds from *A. paniculata* have the potential to contain bioactive chemicals and were approved to provide efficient protection against plant diseases. However, the substantially increased fungal resistance to current fungicides used increases the requirement for discovering novel, prospective, and alternative active chemicals in plants to treat fungal infections caused by antibiotic-resistant fungi (Prasad, 2018). The antifungal and antibacterial properties of *A. paniculata* were studied by many researchers in India, Thailand, and other countries. Therefore, this review aimed to represent the antifungal activity of *A. paniculata* extracts as potential biofungicides against plant pathogens.

4. Antifungal activity of *Andrographis paniculata* extracts against plant pathogens

Antifungal activity of different plant extracts, including *A. paniculata* was reported to inhibit several plant pathogens, including *F. moniliforme* (Yasmin *et al.,* 2008). The findings indicated some potential use for *A. paniculata* plant extracts as antifungal agents in plant disease suppression. *Andrographis paniculata* also has antifungal properties of leaf extracts that resulted in 33.53% growth inhibition of *F. moniliforme* (Yasmin *et al.,* 2008). A study by Nidiry *et al*. (2015) found that antifungal activity assay of the methanol extract of the aerial parts of the plant *A. paniculata* could inhibit the mycelial growth of *Fusarium solani* and spore germination inhibition of *Alternaria solani*. Seed treatment with fungicides was a popular way to control seed-borne diseases. However, nowadays, the use of chemicals to manage crop diseases is discouraged due to health hazards and environmental pollution. Based on Table 1, several plant pathogens have been reported by the previous researcher where *A. paniculata* extracts had successively controlled them.

Successful prediction of bioactive compounds from plant material largely depends on the type of solvent used in the extraction procedure. In the previous study, three major parts, which are leaf, stem, and root, were used for extraction. The antifungal activity was significantly recorded in stem and root extracts. This might be due to the better solubility of the active components in the organic solvents (Rajalakshmi *et al.,*

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Table 1. Antifungal properties of *A. paniculata* against plant diseases

Plant Part	Extracts	Phytochemical/ Phytocompound	Fungus	Plant Disease	Disease Symptom	References
Leaf	Hexane	Oleic acid, Octadecenoic acid, n-Hexadecanoic acid	*Colletotrichum capsici*	Chilli fruit rot pathogen	Circular sunken lesions on fruit	Priya *et al.* (2021)
Leaf	Ethanol Acetone Chloroform	Steroids, coumarin	*Fusarium oxysporum*	Fusarium wilt in tomato	Drooping and yellowing of leaves	Neela *et al.* (2014)
Leaf	Methanol	Flavanoids, alkaloids	*Alternaria alternata*	Alternaria fruit spot in papaya	Discoloration of the skin develop	Bobbarala *et al.* (2009)
Leaf Root stem	Methanol	Terpenoids, tannins, saponins, alkaloids	*Rhizoctonia solani*	Root disease in sweet basil	Wilting leaves and stunted growth	Bobbarala *et al.* (2009)
Leaf	Methanol Hexane	Saponins, tannins, terpenoids, alkaloids	*Rhizoctonia solani*	Black scurf in potato	Irregular-shaped sclerotia form	Mohanty *et al.* (2020)
Leaf	Methanol Hexane	Tannins, flavonoids, alkaloids	*Rhizopus stolonifera*	Rhizopus rot in tomato	Liquefies on the affected tissue and eventually collapse	Nasrin *et al.* (2018)
Leaf	Ethanol Methanol Hexane	Flavonoids, saponins, tannins, terpenoids, alkaloids	*Aspergillus niger*	Necrotic leaf spot in ginger	Infected tissue becomes cracks and papery	Robinson *et al.* (2020)
Leaf	Ethanol Methanol Hexane	Flavonoids, saponins, tannins, terpenoids, alkaloids	*Aspergillus flavus*	Yellow mold of seedling in peanuts	Main stem yellowing and wilting	Robinson *et al.* (2020)
Leaf	Ethyl acetate Methanol Hexane	Andrographolide, phenolic	*Alternaria solani*	Early blight of potato	Angular black spots appear on leaflets	Nidiry *et al.* (2015)
Leaf	Methanol Hexane	Tannins, flavonoids, alkaloids	*Alternaria tenuissima*	Nailhead spot of tomato	Blackish-brown spots on leaves	Nasrin *et al.* (2018)
Leaf	Methanol	Tannins, terpenoids, phenolic, polysaccharides	*Curvularia lunata*	Culvularia leaf spot of corn	Tan-colored lesions with brown margins surrounded by a yellow halo	Santra *et al.*, (2022)
Leaf	Methanol	Tannins, terpenoids, phenolic, polysaccharides	*Culcuvaria penniseti*	Leaf blight of elephant grass	Blighted appearance to the leaf surface	Santra *et al.* (2022)

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Table 1(Cont.). Antifungal properties of *A. paniculata* against plant diseases

Plant Part	Extracts	Phytochemical/ Phytocompound	Fungus	Plant Disease	Disease Symptom	References
Leaf	Aqueous	Alkaloids, flavonoids, terpenoids, tannins	*Drechslera oryzae*	Brown leaf spot disease of rice	Several spots coalesce and the leaf dries up	Singh *et al.* (2000)
Leaf	Aqueous	Alkaloids, flavonoids, terpenoids, tannins	*Drechslera turtica*	Leaf spot disease of elephant grass	Water-soaked lesions developed and appeared chlorotic	Singh *et al.* (2000)
Leaf	Aqueous	Alkaloids, flavonoids, terpenoids, tannins	*Fusarium udum*	Fusarium wilt of pigeon pea	Internal browning of xylem vessels	Singh *et al.* (2000)
Leaf	Aqueous	Alkaloids, flavonoids, terpenoids, tannins	*Alternaria brassicicola*	Black spot disease in cabbage	Sunken brown necrotic lesions on the leaf	Singh *et al.* (2000)
Stem	Chloroform	Saponins, tannins, terpenoids, phenolic, alkaloids	*Aspergillus niger*	Black rot of onions	Irregular yellow spots on the leaf	Radhika and Lakshmi (2010)
Leaf	Ethanol Aqueous	Andrographolide, isoandrographolide, neoandrographolide, 14-deoxy-11, 12-didehydroandrographolide, flavonoids, quinic acid derivatives, and xanthones	*Pyricularia oryzae*	Rice blast disease	Grayish green spot on the leaf	Wong *et al.* (2020)
Leaf	Ethanol Aqueous	Andrographolide, isoandrographolide, neoandrographolide, 14-deoxy-11, 12-didehydroandrographolide, flavonoids, quinic acid derivatives, and xanthones	*Exserohilum rostratum*	Rice brown spot	Purplish-brown spots on the leaf	Wong *et al.* (2020)
Leaf	Methanol Aqueous	Phenolis, flavonoids, phenolic glycosides	*Ganoderma boninense*	Basal stem rot of oil palm	Light-brown dry rot lesions of both the stem and bole	Wong *et al.* (2020)
Leaf	Methanol Ethanol	Alkaloids, flavonoids, terpenoids, phenolic	*Fusarium verticilliodes*	Ear rot of maize	Wilting	Wong *et al.* (2020)

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2012). In the previous study by Neela *et al*. (2014), ethanol, acetone, and chloroform extracts of *A. paniculata* leaves were tested for their antifungal activities assisted by its phytochemical constituents of steroids and coumarin to inhibit *Fusarium oxysporum*, the causal agent of *Fusarium* wilt in tomato. Table 1 shows the antifungal properties of *A. paniculata* extracts against plant pathogenic fungi.

5. Role of plant extract as biofungicide

The use of synthetic fungicides is mainly practised for the management of plant disease. This measure may cause adverse effects on the environment and human health. In addition, the residue of fungicides remaining in the fruit may decrease the quality of the product. The increased awareness of the environmental problems associated with fungicides has led to the search for non-conventional chemicals of biological origin to manage this disease. Some fungicides, notably organomercurials and benzimidazoles, have been observed to be successful in reducing fungal growth (Brauer *et al.,* 2019). According to Suprapta (2012), appropriate technological advancements towards more successful use of natural resources, such as the utilisation of microbial antagonists and plant extracts as biocontrol agents, are necessary for agriculture.

Plants and their derivatives have been extensively studied to control phytopathogenic fungi. Several studies have been carried out on the inhibitory potential of many botanical extracts against phytopathogenic fungi, including species of *Colletotrichum* (Priya *et al.,* 2021). The synergistic activity of diverse bioactive metabolites is responsible for the antimicrobial activity of medicinal plants (Priya *et al.,* 2021). The presence of ester compounds, such as eugenol, vanillin, ferulic acid, 1, 2-diphenylmethane, mono- and sesquiterpenes (oxidised or not), and triterpenes, has been available in the plant, which indicates its potential as a fungicide against plant pathogens (Priya *et al.,* 2021). Management of plant diseases with fungi and plant product-derived molecules has a special significance in the context of mitigating the problems of environmental pollution, accumulation of toxic substances in the produce, and development of resistance by plant pathogens. In this context, the bioactive compounds of plants can be used to formulate the efficacy of plant extracts of *A. paniculata* as biofungicides against fungal plant pathogens.

Fungicides used on plants on a regular and preventative basis are extremely poisonous to a wide range of organisms, resulting in a significant risk to freshwater ecosystems. As a result, eco-friendly management techniques against rice infections are required to ensure a healthy crop and a good yield. Plants produce a wide range of secondary metabolites as a natural product. These secondary metabolites found in plant extracts can potentially eliminate microbial infections through toxicity. It has been discovered that around 2000 higher plant species exhibit pesticidal capabilities against various plant diseases. Botanical extracts are being studied for their potential to suppress plant fungal infections. Natural antifungal compounds found in medicinal herbs have been recognised as one of the most significant alternatives to chemical-based fungicides (Kumar *et al.,* 2021).

In addition, secondary metabolites, including phenols, flavonoids, and phenolic glycosides, are prevalent in herbal plants, and many of them have antifungal properties. For numerous years, the antibacterial properties and activities of plant oils and extracts have been extensively studied. In their comprehensive review, Wong *et al.* (2020) have studied the bioactivities of various phytochemicals derived from *A. paniculata*, a medicinal plant belonging to the Acanthaceae family. These phytochemicals include andrographolide, isoandrographolide (a), neoandrographolide (b), 14-deoxy-11, 12-didehydroandrographolide (c), flavonoids (d), quinic acid derivatives (e), and xanthones (f), as depicted in Figure 2. Additionally, the fruit extract of *Phaleria macrocarpa*, a medicinal plant from the Thymelaceae family, has demonstrated a broad spectrum of antibacterial activity against test bacteria and fungi. This antibacterial action is attributed to the presence of

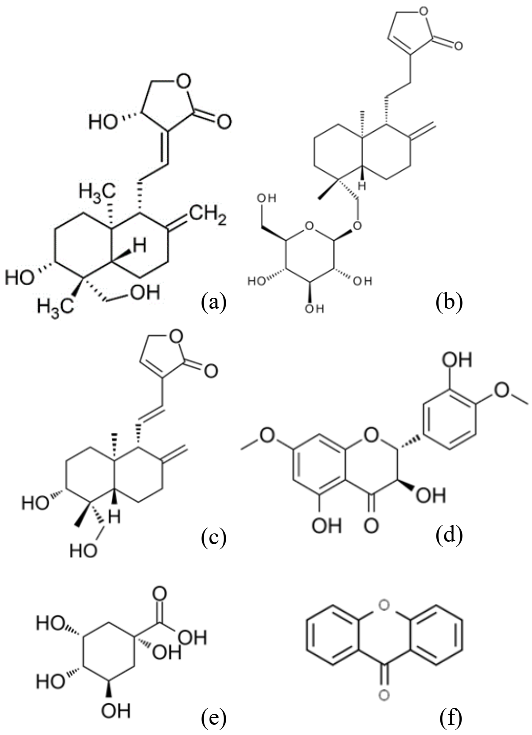

Figure 2. Phytochemicals present in *A. paniculata*: (a) Andrographolide, (b) Neoandrographolide, (c) 14-deoxy-11, 12-didehydroandropholide, (d) Flavonoids, (e) Quinic acid, (f) Xanthone.

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flavonoid compounds such as kaempferol, myricetin, naringin, quercetin, and rutin (Hendra *et al.,* 2011).

6. Mode of action of antifungal activity as biofungicides

Many plant extracts contain bioactive compounds that directly inhibit the growth or reproduction of fungal pathogens (Matrose *et al.,* 2021). Examples include alkaloids, phenols, flavonoids, and essential oils. These compounds may disrupt fungal cell membranes, interfere with cell wall synthesis, or disrupt cellular processes. The antifungal activity derived from plant-based sources can involve several different modes of action, which are often due to the presence of specific bioactive compounds in *A. paniculata* plant extracts. These modes of action include disruption of fungal cell membranes, inhibition of cell wall synthesis, and enzyme inhibition (Enyiukwu *et al.,* 2016). It is important to note that the specific mode of action of natural fungicides can vary depending on the plant extract or compound used and the target fungal pathogen. Additionally, many natural fungicides may have multiple modes of action, contributing to their effectiveness and reducing the risk of fungal resistance development.

Mainly, some plant-derived compounds, such as saponins, disrupt fungal cell membranes. They can alter the permeability of the cell membrane, leading to the leakage of essential cellular components and eventual cell death. In accordance, Sikarwar *et al.* (2023) have stated that saponins are a compound naturally present as a secondary metabolite with several forms and functions that are prevalent in plants. Saponins usually defend plants from illnesses and insects that feed on them. Besides, *A. paniculata* plant extracts contain compounds that interfere with the biosynthesis of fungal cell walls. These compounds can prevent the formation of essential cell wall components, weakening the fungal cell structure and making it more susceptible to damage. The fungal cell is composed primarily of fatty acid and protein polymers. The multifunctional *A. paniculata* bioactive molecule exhibits potential antifungal action and efficiently kills fungal growth (Kuppusamy *et al.,* 2016). In advance, plant-derived compounds can inhibit key enzymes necessary for fungal growth and metabolism. For example, phenolic compounds can interfere with enzymes involved in energy production and other cellular processes, hindering fungal development (Chhikara *et al.,* 2018). The specific mode of action of plant-based antifungal compounds can vary depending on the plant species, the bioactive compounds present, and the fungal pathogen targeted. Plant extracts offer a diverse and sustainable source of antifungal agents, and ongoing research in this area continues to uncover new compounds and mechanisms for combating fungal infections.

7. Conclusion

According to the research, *A. paniculata* has a wide spectrum of phytochemicals and antifungal properties. Traditionally, *A. paniculata* has been used for liver complaints and fever, and as an anti-inflammatory and immunostimulant. In clinical trials, Andrographis extract has been studied for use as an immunostimulant in upper respiratory tract infections and HIV infection. These plants showed the potential of andrographolide as an anticancer agent. Several products fortified with extract and isolated compounds have been in national and international markets for various diseases. Therefore, this review paper summarises various experimental and clinical pharmacological activities of *A. paniculata* since it is a valuable contribution to the field of herbal medicine and pharmacology. *Andrographis paniculata* is a medicinal plant that has been traditionally used in Ayurvedic and traditional Chinese medicines for potential health benefits. These plant extracts and isolated compounds showed good activity on antioxidant, anti-inflammatory, anticancer, antimicrobial, parasitic, hepatoprotective, antihyperglycemic, and anti-hypoglycaemic. Many studies have revealed plant extracts as a source of natural fungicides that make an excellent effort for new fungicide development. The added advantage includes that plant extracts are cheaper and non-toxic to humans if the appropriate concentrations are used. However, *A. paniculata* has been reported to have a wide range of antimicrobial agents like antibacterial and antifungal. The antifungal potential of *A. paniculata* is mainly attributed to the presence of secondary metabolites like alkaloids, flavonoids, terpenoids, saponins, tannins, and phenolic compounds. Therefore, *A. paniculata* has been found to be a valuable medicinal herb in many popular systems of plant disease management, including antifungal.

Conflict of interest

The authors declare no conflict of interest.

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