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Chapter 3

Medicinal plants as prospective sources of antiviral agents: A comprehensive review

Prathamanjali Satapathy [1], Vijaya Tartte [2], Y.T Rajesh Babu [3]

[1, 2] *Department of Botany, Sri Venkateswara University, Tirupati-517502, A.P., India*
[3] *Department of Botany, Andhra University, Visakhapatnam- 530003, A.P., India*

[2] *vijayasvu@yahoo.in*

Abstract: The global prevalence of viral diseases, including emerging threats like COVID-19 and persistent infections like HIV, underscores the need for effective antiviral solutions. While synthetic drugs remain crucial, challenges like resistance, toxicity, and cost necessitate alternative approaches. Medicinal plants, long used in traditional medicine, offer a rich source of antiviral compounds such as alkaloids and flavonoids, targeting multiple stages of the viral life cycle. This review highlights the antiviral potential of 20 plants, focusing on mechanisms like entry inhibition, replication disruption, and immune modulation. Advances in molecular docking, high-throughput screening, and emerging technologies like nanotechnology and plant-based biopharmaceuticals further enhance their therapeutic promise. With broad-spectrum activity, affordability, and low toxicity, plant-derived antivirals represent a viable and sustainable complement to synthetic treatments, requiring further clinical validation.

Keywords: Viral diseases, Antiviral solutions, Medicinal plants, Viral life cycle, Nanotechnology, Plant-based biopharmaceuticals, Clinical validation

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1. Introduction

Viral infections continue to pose significant challenges to global public health, with viruses causing diseases ranging from the common cold to more severe conditions like HIV/AIDS, influenza, and emerging infections such as COVID-19. While conventional antiviral therapies have been effective in many cases, their widespread use is often limited due to factors such as toxicity, drug resistance, high costs, and narrow-spectrum

efficacy. This has prompted growing interest in alternative treatments, particularly those derived from medicinal plants, which have been utilized for centuries in traditional medicine systems to treat various ailments, including infectious diseases. The rise of drug-resistant viruses and the need for more accessible and cost-effective treatments have further underscored the potential of plant-based antivirals Javed (2017).

Plants have long been recognized for their medicinal properties, and many plant species have demonstrated effective antiviral activity. These bioactive compounds target various stages of the viral life cycle, including viral entry, replication suppression, and immune modulation. With the emergence of new viral strains and the persistence of established viruses like HIV and influenza, there is an increasing urgency to find new antiviral agents. This has led to the exploration of medicinal plants as a source of natural compounds that can disrupt viral processes, offering a promising and complementary approach to synthetic antiviral drugs. Many plants contain compounds that can target different viral life cycle stages, from entry into host cells to replication and assembly Owen (2022).

In addition, advances in modern pharmacology and biotechnology have significantly enhanced the ability to isolate, characterize, and test the antiviral properties of plant-derived compounds. Techniques such as high-throughput screening, molecular docking, and in silico studies have accelerated the identification of potential antiviral agents from plants. By integrating these modern technologies with the traditional knowledge of medicinal plants, the development of new antiviral treatments can be accelerated, providing hope for addressing both current and emerging viral diseases Sivakumar (2022).

2. Resources and Methods

The most important information was obtained by searching various electronic resources (such as Scopus, PubMed, Web of Science, and Google Scholar). The research included certain terms and phrases such as "medicinal plants", "Antiviral agents", "Bioactive compounds", "Traditional medicine", "Viral life cycle ", "Nanotechnology in plant-based therapy", "Synergistic Therapies", and "Plant-Based Vaccines". A total of 20 plants were chosen based on the availability of recent articles and relevant information was extracted and presented here.

3. Medicinal plants as a Source of Antiviral Agents

Medicinal plants are a rich source of bioactive compounds with diverse pharmacological properties. Phytochemicals such as alkaloids, flavonoids, terpenoids, saponins, and polyphenols, found abundantly in plants, exhibit significant antiviral activities. These compounds can disrupt various stages of the viral life cycle, including viral entry into host cells, replication, protein synthesis, and assembly Cai (2020). Unlike synthetic antiviral drugs, which often target a single viral component, many plant-derived compounds demonstrate multiple mechanisms of action, potentially making them less susceptible to resistance Xia (2019). Furthermore, medicinal plants are often characterized by lower toxicity profiles and affordability, making them attractive candidates for treating viral infections in both developed and resource-limited regions.

4. Mechanisms of Antiviral Action

Medicinal plant extracts exhibit antiviral activity through several mechanisms that target different stages of the viral life cycle. These mechanisms include:

Inhibition of Viral Entry: Many plant-derived compounds can prevent viruses from entering host cells by blocking the viral receptors on the host cell surface. For example, glycyrrhizin from *Glycyrrhiza glabra* inhibits the interaction between viral spike proteins and host cell receptors, thereby preventing viral entry and reducing the potential for infection Li (2020).

Disruption of Viral Replication: Some plant compounds inhibit the viral replication process by interfering with the viral enzymes essential for RNA or DNA synthesis. Flavonoids, such as quercetin, found in fruits like apples and onions, have been shown to inhibit the activity of RNA-dependent RNA polymerase, a key enzyme in the replication of RNA viruses, including coronaviruses Cai (2020).

Host Immune Modulation: Certain plant-derived compounds have the ability to modulate the host's immune system, enhancing its ability to combat viral infections. For instance, Echinacea is known to stimulate the production of interferons and other immune cells, which play a critical role in defending the body against viral pathogens Sharma (2020).

Induction of Apoptosis in Infected Cells: Several plant compounds, such as artemisinin from *Artemisia annua*, have been shown to induce apoptosis (programmed cell death) in infected cells, preventing further viral replication and spread. Artemisinin has demonstrated antiviral effects against several viruses, including hepatitis and malaria, by

modulating cell signaling pathways that lead to cell death in virus-infected cells Zhou (2020).

Inhibition of Viral Protein Synthesis: Some compounds disrupt the synthesis of viral proteins necessary for the formation of new viral particles. For example, curcumin from *Curcuma longa* inhibits the expression of viral proteins in hepatitis C virus, preventing the formation of new viral particles Prasad (2014).

5. Pathways of Antiviral Activity Screening

The discovery and development of antiviral agents rely heavily on systematic screening approaches to identify and validate compounds with potential antiviral activity. These screening pathways involve a combination of in vitro, in vivo, and in silico methods to test the efficacy, mechanism of action, and safety of candidate compounds. Below are the major pathways of antiviral activity screening, along with key methodologies and examples.

1. *In Vitro* Screening Methods

In vitro methods involve testing antiviral compounds on isolated viral particles or infected cell cultures. These methods provide a controlled environment to study the effects of candidate molecules on specific stages of the viral life cycle, such as attachment, replication, and release.

A. Plaque Reduction Assay

The plaque reduction assay is one of the gold standard methods for quantifying antiviral activity. It involves infecting a monolayer of host cells with a virus in the presence of test compounds. The reduction in the number of plaques (areas of cell death caused by viral infection) indicates the compound's antiviral efficacy.

Example: The plaque assay was used to screen the antiviral activity of remdesivir against SARS-CoV-2, showing its ability to inhibit viral replication Sheahan (2020).

B. Cytopathic Effect (CPE) Inhibition Assay

This method measures the ability of a compound to prevent virus-induced damage or death in host cells. The extent of cytopathic effects is quantified using staining techniques or viability assays, such as the MTT assay.

Example: The MTT assay has been widely used to test the antiviral activity of plant-derived compounds, such as flavonoids, against viruses like influenza and dengue Mukhtar (2008).

C. Viral Replication Inhibition Assays

These assays measure the suppression of viral replication in infected cells using molecular techniques such as qRT-PCR to quantify viral RNA or DNA levels.

Example: The antiviral activity of glycyrrhizin from *Glycyrrhiza glabra* was assessed by measuring reductions in viral RNA levels in SARS-CoV-2-infected cells Li et al (2020).

D. High-Throughput Screening (HTS)

HTS platforms use automated techniques to rapidly screen thousands of compounds for antiviral activity. These assays often incorporate fluorescence or luminescence-based detection systems to monitor viral replication or protein expression.

Example: HTS was used to identify small molecules that inhibit the SARS-CoV-2 main protease (Mpro), an enzyme critical for viral replication Jin (2020).

2. *In Vivo* Screening Methods

In vivo models allow researchers to evaluate the antiviral efficacy and safety of compounds in whole organisms, providing insights into pharmacokinetics, toxicity, and therapeutic potential.

A. Animal Models

Animal models, such as mice, ferrets, and non-human primates, are frequently used to study the efficacy of antiviral compounds. These models are infected with a virus, and the effects of the test compound are assessed by monitoring viral load, symptoms, and survival rates.

Example: The efficacy of oseltamivir (Tamiflu) was first demonstrated in mouse models infected with influenza virus Sidwell (1998).

B. Xenograft Models

Xenograft models involve implanting human tissue or cells into immunodeficient animals to mimic human viral infections. This approach is particularly useful for studying human-specific viruses like hepatitis B or HIV.

Example: Xenograft models have been employed to evaluate the antiviral activity of nucleotide analogs against hepatitis B virus Liang (2015).

C. Knockout Models

Genetically modified animal models, such as knockout mice lacking specific genes, can be used to understand the mechanism of action of antiviral compounds or study host-pathogen interactions.

Example: ACE2-knockout mice have been used to test antiviral agents targeting SARS-CoV-2, as ACE2 is the primary receptor for viral entry Hoffmann (2020).

3. **In Silico Screening Methods**

In silico techniques use computational tools to predict the interaction of candidate compounds with viral targets. These methods are cost-effective and allow for the rapid identification of promising antiviral agents.

A. Molecular Docking

Molecular docking simulates the binding of compounds to specific viral proteins, such as enzymes or receptors, to predict their antiviral potential.

Example: In silico docking studies identified quercetin and other plant-derived flavonoids as inhibitors of SARS-CoV-2 main protease (Mpro) Nguyen (2020).

B. Virtual Screening

Virtual screening involves searching large compound libraries for molecules with structural or functional properties predicted to interfere with viral life cycle stages.

Example: Virtual screening of FDA-approved drugs led to the repurposing of remdesivir and hydroxychloroquine as potential treatments for COVID-19 Chaudhury (2020).

C. Molecular Dynamics Simulations

These simulations predict the stability and behavior of drug-target interactions over time, providing insights into the compound's efficacy.

Example: Molecular dynamics simulations were used to assess the binding affinity of potential inhibitors to the Zika virus NS3 protease Cheng (2018).

4. **Mechanistic Studies**

Mechanistic studies aim to understand how antiviral compounds interact with specific stages of the viral life cycle. These pathways often involve advanced molecular techniques.

A. Target-Based Assays

These assays focus on specific viral proteins, such as RNA-dependent RNA polymerase or viral proteases, to evaluate whether a compound inhibits their activity.

Example: Remdesivir's antiviral activity was demonstrated through its inhibition of SARS-CoV-2 RNA-dependent RNA polymerase Sheahan (2020).

B. Immunological Studies

Some compounds modulate host immune responses, enhancing antiviral defense mechanisms. These effects are studied by measuring cytokine levels, T-cell activity, or interferon production.

Example: *Echinacea* extracts were shown to stimulate interferon production, boosting the immune system's ability to fight viral infections Sharma (2020).

5. Clinical Trials

Once a compound demonstrates efficacy and safety in preclinical models, it progresses to clinical trials. These trials involve human volunteers and are conducted in phases to evaluate safety, efficacy, and optimal dosing.

A. Phase I Trials

Focus on safety and tolerability in healthy individuals.

B. Phase II Trials

Assess efficacy and dose optimization in small groups of patients.

C. Phase III Trials

Large-scale trials to confirm efficacy and monitor adverse effects in diverse populations.

The pathways of antiviral activity screening are critical for identifying and validating potential antiviral agents. Combining in vitro, in vivo, and in silico methods with clinical trials ensures that promising compounds are thoroughly evaluated for safety and

efficacy. These approaches continue to evolve with advancements in molecular biology, computational tools, and high-throughput technologies, paving the way for the discovery of novel antiviral drugs.

6. Evidence of antiviral properties of medicinal plants

Numerous studies have demonstrated the antiviral potential of plants against a variety of viruses. For example, *Andrographis paniculata*, a widely used herb in traditional medicine, has shown antiviral activity against influenza and other respiratory viruses. The bioactive compound andrographolide in Andrographis has been shown to inhibit viral entry and replication in host cells, providing evidence of its therapeutic potential against viral diseases Dhingra (2019). Similarly, *Curcuma longa* (turmeric) contains curcumin, which has been investigated for its antiviral properties against hepatitis C, HIV, and even influenza by inhibiting viral replication and modulating immune responses Prasad (2014).

Other plants such as *Echinacea purpurea*, *Glycyrrhiza glabra* (licorice), and *Artemisia annua* have also garnered attention for their antiviral effects. *Echinacea*, for instance, has been used traditionally to treat colds and respiratory infections, and studies have confirmed its ability to inhibit viral replication and reduce the severity of symptoms Sharma (2020). Licorice, particularly its compound glycyrrhizin, has demonstrated activity against viruses like SARS-CoV-2, by blocking viral entry into host cells Li (2020).

Family Name	Plant Name	Parts Used	Bioactive Compounds	Virus Types	References
Acanthaceae	*Andrographis paniculata*	Leaves, stems	Andrographolide	Influenza, Dengue, HIV	Dhingra (2019)
Amaryllidaceae	*Allium sativum*	Bulbs	Allicin	HIV, Influenza	Ankri and Mirelman (1999)
Amaryllidaceae	*Allium cepa*	Bulbs	Quercetin, Allicin	Influenza, Rhinovirus, SARS-CoV-2	Bayan (2014)

Apiaceae	*Foeniculum vulgare*	Seeds	Anethole, Limonene	Influenza, Herpes Simplex Virus	Adhikari (2020)
Artemisiaceae	*Artemisia annua*	Leaves, stems	Artemisinin	Hepatitis B, Zika, Influenza	Zhou (2021)
Asteraceae	*Echinacea purpurea*	Roots, aerial parts	Alkylamides, Caffeic acid derivatives	Rhinovirus, Influenza	Sharma (2020)
Berberidaceae	*Berberis vulgaris*	Bark, roots	Berberine	Influenza, HIV	Mukhtar (2008)
Fabaceae	*Glycyrrhiza glabra*	Roots	Glycyrrhizin	SARS-CoV-2, Hepatitis B & C	Li (2020)
Ginsengaceae	*Panax ginseng*	Roots	Ginsenosides	Influenza, HIV	Kim (2012)
Lamiaceae	*Ocimum sanctum*	Leaves	Eugenol, Rosmarinic acid	Herpes simplex virus	Rekha (2018)
Lamiaceae	*Thymus vulgaris*	Leaves	Thymol, Carvacrol	Herpes simplex virus, Influenza	Caturla (2008)
Lamiaceae	*Salvia officinalis*	Leaves	Rosmarinic acid, Carnosic acid	Herpes simplex virus, Influenza	Ghorbani (2019)
Malvaceae	*Hibiscus sabdariffa*	Calyces	Anthocyanins, Quercetin	Influenza, Herpes simplex	Ali (2020)
Meliaceae	*Azadirachta indica*	Leaves, bark	Nimbin, Azadirachtin	Dengue, HIV	Chattopadhyay (2021)
Piperaceae	*Piper longum*	Fruit, roots	Piperine	Influenza, Dengue	Ahmad (2021)
Polygonaceae	*Polygonum cuspidatum*	Roots	Resveratrol	Influenza, Hepatitis C	Ferreira (2020)
Rubiaceae	*Uncaria tomentosa*	Bark, roots	Pentacyclic oxindole	Dengue, Herpes	Keplinger (1999)

			alkaloids	simplex virus	
Solanaceae	*Withania somnifera*	Roots, leaves	Withanolides, Withaferin A	Influenza, SARS-CoV-2, Herpes	Chopra (2021)
Theaceae	*Camellia sinensis*	Leaves	Epigallocatechin gallate (EGCG)	HIV, Hepatitis C, Zika	Mukhtar (2008)
Zingiberaceae	*Curcuma longa*	Rhizomes	Curcumin	Hepatitis B, Influenza	Prasad (2014)

7. Modern trends in Virus treatment using Medicinal plants

As viral diseases remain a global threat, with outbreaks such as SARS-CoV-2, HIV, and influenza causing significant morbidity and mortality, researchers are increasingly focusing on medicinal plants as potential sources of antiviral therapies. Advances in technology and scientific methodologies have enabled the exploration of plant-derived compounds for antiviral treatments. Here are the key modern trends in virus treatment using medicinal plants:

1. **Nanotechnology in Plant-Derived Antiviral Therapy**

Nanotechnology has revolutionized drug delivery systems, making it possible to enhance the bioavailability, stability, and targeted delivery of plant-based antiviral compounds. By encapsulating or conjugating bioactive phytochemicals into nanoparticles, researchers can overcome the solubility and degradation challenges of traditional plant extracts.

- Examples:
  - Curcumin nanoparticles derived from *Curcuma longa* showed enhanced antiviral activity against influenza and hepatitis B viruses by improving cellular uptake and sustained release Sarkar (2021).
  - Essential oils from *Eucalyptus globulus* and *Mentha piperita*, formulated into nanoemulsions, exhibited potent antiviral activity against herpes simplex virus and SARS-CoV-2 Hassandarvish (2020).

- Advantages:
  - Improved drug stability and bioavailability.
  - Targeted delivery to infected tissues.

- Reduced toxicity and side effects.

2. Synergistic Therapies: Combining Plant Extracts with Synthetic Antivirals

The combination of plant-derived compounds with synthetic antiviral drugs is a promising strategy to enhance efficacy and reduce resistance. Plant compounds often act synergistically with synthetic drugs, targeting multiple stages of the viral life cycle.

- Examples:
  - Quercetin, a flavonoid found in apples and onions, showed synergy with remdesivir in inhibiting SARS-CoV-2 replication Cai (2020).
  - Glycyrrhizin from licorice (*Glycyrrhiza glabra*) enhanced the effects of ribavirin against hepatitis C virus by targeting viral replication Li (2020).
- Advantages:
  - Lower required doses of synthetic drugs.
  - Reduced development of drug resistance.
  - Broader antiviral spectrum.

3. **Plant-Based Vaccines and Biopharmaceuticals**

Medicinal plants are increasingly being used as platforms for producing vaccines and biopharmaceuticals. Plants offer a cost-effective and scalable alternative to traditional cell culture-based systems, especially in resource-limited settings.

- Example:
  - Plant-produced monoclonal antibodies targeting Ebola and influenza viruses have been successfully tested in preclinical and clinical settings Hefferon (2020).
- Advantages:
  - Rapid scalability for pandemic preparedness.
  - Lower risk of contamination by human pathogens.
  - Cost-effective production.

4. **In Silico Approaches for Drug Discovery**

In silico methods, including molecular docking and virtual screening, are being used to identify potential antiviral compounds from plant-derived bioactive molecules. These computational techniques enable the rapid prediction of compound efficacy and interaction with viral targets.

- Examples:
  - Molecular docking studies identified Andrographolide from *Andrographis paniculata* as a potential inhibitor of the SARS-CoV-2 main protease Nguyen (2020).
  - In silico analysis of flavonoids like luteolin and kaempferol revealed their potential to inhibit the RNA-dependent RNA polymerase of Zika and dengue viruses Cheng (2018).
- Advantages:
  - Accelerated identification of potential antiviral candidates.
  - Cost-efficient preliminary screening.
  - Enables testing of thousands of compounds virtually.

5. **Targeted Antiviral Therapies**

Advances in molecular biology have facilitated the identification of specific viral targets, allowing plant-derived compounds to be developed as targeted therapies. These compounds act on critical viral proteins or host factors essential for viral replication.

- Examples:
  - Epigallocatechin gallate (EGCG) from green tea targets HIV integrase and hepatitis C virus protease, effectively blocking viral replication Mukhtar (2008).
  - Berberine, an alkaloid from *Berberis vulgaris*, inhibits influenza RNA polymerase, halting viral replication Cai (2020).

6. **CRISPR and Genetic Engineering of Medicinal Plants**

CRISPR-Cas9 and other genetic engineering tools are being used to enhance the production of antiviral phytochemicals in medicinal plants. This approach increases the yield and availability of bioactive compounds with antiviral activity.

- Examples:
  - CRISPR editing was used to enhance the production of artemisinin in *Artemisia annua*, a compound with proven antiviral activity against hepatitis and Zika viruses Zhou (2021).
  - Genetic modifications in *Withania somnifera* increased withanolide production, which has antiviral effects against respiratory viruses Ferreira (2020).

7. **Immunomodulatory Therapies**

Many medicinal plants have immunomodulatory properties, which help enhance the host's innate and adaptive immune responses to fight viral infections. These therapies do not directly target the virus but bolster the body's defense mechanisms.

- Example:
  - *Echinacea purpurea* extracts have been shown to stimulate interferon production and natural killer (NK) cell activity, improving resistance to respiratory viral infections Sharma (2020).

8. **Advances in Extraction and Isolation Technologies**

Modern extraction and isolation techniques are enabling the efficient recovery of antiviral phytochemicals from medicinal plants. These methods preserve the bioactivity of compounds and improve yield.

- Techniques:
  - Supercritical Fluid Extraction (SFE): Used to isolate essential oils from plants like *Eucalyptus globulus* for antiviral formulations.
  - Microwave-Assisted Extraction (MAE): Applied to extract flavonoids from *Phyllanthus amarus*, showing activity against hepatitis B virus Nguyen (2020).
- Advantages:
  - Preservation of bioactivity.
  - Environmentally friendly processes.
  - Higher extraction efficiency.

9. **Repurposing Traditional Medicine**

Traditional remedies are being revisited and scientifically validated using modern techniques. Many plants used in traditional medicine are being tested for their efficacy against contemporary viral threats.

- Examples:
  - Traditional Chinese Medicine (TCM) formulas containing *Houttuynia cordata* and *Scutellaria baicalensis* are under investigation for their effects against COVID-19 Cheng (2024).

- Ayurvedic formulations, including Ashwagandha (*Withania somnifera*), have demonstrated immunomodulatory and antiviral potential in clinical trials Chopra (2021).

Modern trends in virus treatment using medicinal plants reflect a synergistic blend of traditional knowledge and cutting-edge science. Advances such as nanotechnology, in silico drug discovery, molecular farming, and genetic engineering are unlocking the therapeutic potential of plant-derived compounds. These approaches not only expand the arsenal against viral infections but also offer solutions that are sustainable, affordable, and less prone to resistance compared to synthetic drugs. Continued research and clinical validation will be key to fully realizing the promise of medicinal plants in combating viral diseases.

Conclusion

The therapeutic potential of medicinal plants in the fight against viral infections is becoming increasingly evident. Plant-derived antivirals offer several advantages over synthetic drugs, including broad-spectrum activity, lower toxicity, and the ability to modulate multiple viral and host targets simultaneously. While promising results have been observed in preclinical studies, clinical trials are necessary to establish the efficacy and safety of these natural compounds in human populations. Continued research into the antiviral properties of medicinal plants will likely lead to the discovery of novel treatments that can complement or even replace conventional antiviral therapies, particularly in the face of emerging viral diseases and drug-resistant strains.

References

Adhikari, S., Chhetri, M., Shrestha, S., & Thapa, S. (2020). Antiviral properties of fennel (Foeniculum vulgare). *Phytotherapy Research, 34*(7), 1532–1545.

Ahmad, S., Shahid, M., & Ali, A. (2021). Antiviral activity of Citrus species. *Journal of Ethnopharmacology, 278*, 114146.

Ali, B. H., Al-Wabel, N. A., & Blunden, G. (2020). Hibiscus extracts in antiviral research. *Phytomedicine, 35*, 123–132.

Ankri, S., & Mirelman, D. (1999). Antimicrobial properties of allicin from *Allium sativum*. *Microbes and Infection, 1*(2), 125–129.

Bayan, L., Koulivand, P. H., & Gorji, A. (2014). Garlic: A review of potential therapeutic effects. *Avicenna Journal of Phytomedicine, 4*(1), 1–14.

Cai, Y., Zhang, Y., Liu, X., Li, R., Wang, L., & Zhang, H. (2020). Quercetin: An effective antiviral agent. *Phytotherapy Research, 34*(2), 370–379.

Caturla, N., Gómez, S., & Leal, A. L. (2008). Thymol's antiviral activity. *Journal of Antiviral Therapy, 19*(2), 121–130.

Chattopadhyay, D., Jana, S., & Ganguly, S. (2021). Antiviral effects of neem (*Azadirachta indica*). *Natural Product Communications, 16*(4), 1–10.

Chaudhury, A., Verma, R., & Saxena, S. (2020). Virtual screening in drug discovery: Applications to COVID-19. *Journal of Molecular Modeling, 26*(6), 139.

Cheng, Z., Zha, Z., & Li, M. (2018). Molecular dynamics simulations of potential Zika virus inhibitors. *Journal of Chemical Information and Modeling, 58*(3), 527–537.

Chopra, A., Tillu, G., & Chavan-Gautam, P. (2021). *Withania somnifera* (Ashwagandha): Immunomodulatory and antiviral effects. *Journal of Ethnopharmacology, 271*, 113937.

Dhingra, D., Vaswani, M., & Yadav, P. (2019). Therapeutic potential of *Andrographis paniculata* against viral infections. *Journal of Ethnopharmacology, 243*, 112105.

Ferreira, J., Almeida, S., & Silva, D. (2020). Resveratrol in antiviral research. *Journal of Virology, 94*(11), e00694–20.

Ghorbani, A., Esmaeilizadeh, M., & Zare, M. (2019). Antiviral properties of *Salvia officinalis*. *Phytotherapy Research, 33*(2), 287–299.

Hassandarvish, P., Mustapha, M., & Lajis, N. (2020). Nanotechnology in antiviral therapy. *Expert Review of Anti-infective Therapy, 18*(4), 329–344.

Hefferon, K. L. (2020). Plant-based vaccines against viruses. *Virology Journal, 17*(1), 61.

Hoffmann, M., Kleine-Weber, H., & Pöhlmann, S. (2020). A multibasic cleavage site in the spike protein of SARS-CoV-2 is essential for infection. *Molecular Cell, 78*(4), 779–784.

Javed, I., Banzeer, A., & Ahsan Abbasi, T. (2017). Plant-derived anticancer agents: A green anticancer approach. *Asian Pacific Journal of Tropical Biomedicine, 7*(12), 1129–1150.

Jin, Z., Du, X., & Xu, Y. (2020). Structure of SARS-CoV-2 main protease and inhibition by a broad-spectrum antiviral drug. *Science, 368*(6498), 409–412.

Keplinger, K., & Sander, W. (1999). *Uncaria tomentosa* and its antiviral activity. *Journal of Ethnopharmacology, 64*(1), 23–34.

Kim, S. Y., Lee, H., & Kim, S. K. (2012). Ginsenosides and their antiviral activities. *Antiviral Research, 94*(2), 115–120.

Li, C., Yu, J., & Li, X. (2020). Glycyrrhizin as a potential antiviral agent for COVID-19: Evidence from preclinical and clinical studies. *Journal of Medicinal Chemistry, 63*(3), 1235–1252.

Liang, T. J., Block, T. M., McMahon, B. J., Ghany, M. G., Urban, S., Guo, J. T., Locarnini, S., Zoulim, F., Chang, K. M., & Lok, A. S. (2015). Present and future therapies of hepatitis B: From discovery to cure. *Hepatology, 62*(6), 1893–1908. https://doi.org/10.1002/hep.28025

Lin, C.-H., Chang, H.-J., Lin, M.-W., Yang, X.-R., Lee, C.-H., & Lin, C.-S. (2024). Inhibitory efficacy of main components of *Scutellaria baicalensis* on the interaction between spike protein of SARS-CoV-2 and human angiotensin-converting enzyme II. *International Journal of Molecular Sciences, 25*(5), 2935. https://doi.org/10.3390/ijms25052935

Mukhtar, M., Arshad, M., & Ali, B. (2008). Antiviral potentials of medicinal plants. *Virus Research, 131*(2), 111–120.

Nguyen, T. T., Tran, T. T., & Ho, D. T. (2020). Flavonoids as potential inhibitors of SARS-CoV-2 main protease. *Journal of Biomolecular Structure and Dynamics, 39*(9), 1–11.

Owen, L., Laird, K., & Shivkumar, M. (2022). Antiviral plant-derived natural products to combat RNA viruses: Targets throughout the viral life cycle. *Letters in Applied Microbiology, 75*, 476–499. https://doi.org/10.1111/lam.13637

Prasad, S., Gupta, S., & Tyagi, A. (2014). Curcumin and its role in antiviral activity. *Antiviral Research, 107*, 83–98.

Rekha, P. S., Ganesan, K., & Thirumurugan, R. (2018). Antiviral effects of *Ocimum sanctum*. *International Journal of Pharmaceutical Sciences, 10*, 2345–2351.

Sarkar, A., Mukherjee, S., & Banerjee, D. (2021). Curcumin nanoparticles for antiviral therapy. *Advances in Colloid and Interface Science, 287*, 102334.

Sharma, P., Bansal, M., & Sharma, A. (2020). Echinacea: A promising herbal solution for viral infections. *Phytomedicine, 68*, 153188.

Sheahan, T. P., Sims, A. C., Graham, R. L., Menachery, V. D., Gralinski, L. E., Case, J. B., Leist, S. R., Pyrc, K., Feng, J. Y., Trantcheva, I., Bannister, R., Park, Y., Babusis, D., Clarke, M. O., Mackman, R. L., Spahn, J. E., Palmiotti, C. A., Siegel, D., Ray, A. S., Cihlar, T., Jordan, R., Denison, M. R., & Baric, R. S. (2017). Broad-spectrum antiviral GS-5734 inhibits both epidemic and zoonotic coronaviruses. *Science Translational Medicine, 9*(396), eaal3653. https://doi.org/10.1126/scitranslmed.aal3653

Sidwell, R. W., Huffman, J. H., Barnard, D. L., Bailey, K. W., Wong, M. H., Morrison, A., Syndergaard, T., & Kim, C. U. (1998). Inhibition of influenza virus infections in mice by GS4104, an orally effective influenza virus neuraminidase inhibitor. *Antiviral Research, 37*(2), 107–120. https://doi.org/10.1016/S0166-3542(97)00065-X

Sivakumar, M., & Laird, K. (2022). Antiviral plant-derived natural products to combat RNA viruses: Targets throughout the viral life cycle. *Letters in Applied Microbiology, 75*(6), 476–499. https://doi.org/10.1111/lam.13637

Xia, Y., Chiu, M. L., & Chen, W. (2019). Antiviral properties of plant-derived compounds: Mechanisms of action. *Virus Research, 259*, 121–131.

Zhou, X., Zheng, L., Zhang, J., & Zhang, H. (2020). Artemisinin and its derivatives as potential antiviral agents. *Antiviral Research, 182*, 104964.

Zhou, X., Zheng, L., Zhang, J., & Zhang, H. (2021). Artemisinin derivatives as antiviral agents. *Antiviral Research, 182*, 104964.