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Review Article

Dual-Action Botanicals: Antiviral and Insecticidal Potential of Bangladeshi Medicinal Plants against Aedes-Borne Viruses

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ABSTRACT

Medicinal and aromatic plants (MAPs) have been utilized in the Indian subcontinent to combat viral infections and insect vectors since prehistoric times. This study examines the application of Bangladeshi MAPs for the treatment of Zika virus (ZIKV). It also provides a comprehensive review of prevention and management strategies for diseases transmitted by *Aedes* mosquitoes. A total of sixty-two Bangladeshi MAPs, belonging to 59 genera and 36 families, exhibit potential antiviral properties against ZIKV. Among these, four species, *viz*., *Erythroxylum* sp., *Chamaecrista* sp., *Scleromitrion diffusum*, and *Camellia sinensis*, demonstrated activity against chikungunya virus (CHIKV). Additionally, four species, *Allium sativum*, *Tridax procumbens*, *Trigonella foenum-graecum*, and *Punica granatum*, showed effectiveness against dengue virus (DENV). Nine other species, including *Andrographis paniculata*, *Azadirachta indica*, *Curcuma longa*, *Glycyrrhiza glabra*, *Ocimum tenuiflorum*, *Psidium guajava*, *Tinospora cordifolia*, *Vitex negundo*, and *Zingiber officinale*, were found to reduce viral loads of all three viruses, DENV, CHIKV, and ZIKV, transmitted by *Aedes* mosquitoes. Furthermore, at least sixteen species, including *Andrographis paniculata*, *Azadirachta indica*, *Bixa orellana*, *Blumea balsamifera*, *Camellia sinensis*, *Cannabis sativa*, *Cinnamomum verum*, *Curcuma longa*, *Momordica charantia*, *Psidium guajava*, *Rauvolfia serpentina*, *Tecoma stans*, *Tridax procumbens*, *Piper nigrum*, *Vitex negundo*, and *Zanthoxylum nitidum*, exhibited both antiviral and insecticidal properties against *Aedes* spp. Also, *Allium sativum*, *Kaempferia galanga*, *Lippia alba*, and *Zingiber officinale* were effective against both *Aedes* spp. and *Culex quinquefasciatus*. At the same time, *Punica granatum* showed efficacy against *A. aegypti*, *Anopheles stephensi*, and *C. quinquefasciatus*. This study underscores the significance of integrating traditional knowledge with contemporary scientific methods to develop innovative plant-based therapeutics and environmentally friendly insecticides.

Introduction

Each year, approximately 700,000 people die from arthropod-borne diseases, such as malaria, dengue, yellow fever, and Japanese encephalitis (<https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases>). Tropical and subtropical regions are disproportionately affected by diseases like dengue, malaria, chikungunya, yellow fever, and Zika, which have caused widespread health crises since 2014. Climate change significantly impacts pathogens, vectors, and reservoir hosts, ultimately affecting the transmission of vector-borne diseases.

The Zika virus (ZIKV) is a single-stranded positive-sense RNA virus, approximately 10.7 kb in length, closely related to the dengue virus (DENV). It was first identified in Uganda in 1947, initially detected in a rhesus macaque (*Macaca mulatta*) (Musso et al., 2019). Since 2007, outbreaks of ZIKV have been reported across Africa, the Americas, Asia, and the Pacific, indicating a global pandemic characterized by rapid transmission, with 80% of infections being asymptomatic. This situation has attracted significant international media attention as a major emerging pathogen (Sadeer et al., 2023). Many countries worldwide are at risk of ZIKV outbreaks due to the prevalence of *Aedes* mosquitoes. The World Health Organization declared ZIKV infection an emerging epidemic threat in 2016 (Haddad et al., 2019a). ZIKV infections were first detected in Bangladesh through a seroprevalence investigation in 2013, and another case was reported in the Chittagong district in 2014 (Hossain et al., 2019). As of December 2023, 92 countries and territories have reported local mosquito-borne ZIKV

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transmission (Rabe et al., 2025). Phylogenetic analysis identified three ZIKV lineages: two African and one Asian, with the Asian lineage associated with the most recent significant outbreaks and increased viral pathogenicity (Silva et al., 2020).

In tropical and subtropical regions, ZIKV is primarily transmitted through infected *Aedes aegypti* mosquitoes, which are active during the day and also transmit dengue, chikungunya, and urban yellow fever (<https://www.who.int/ news-room/fact-sheets/detail/zika-virus>). Additionally, ZIKV can be transmitted from mother to fetus during pregnancy, as well as through organ transplants, blood transfusions, saliva, urine, and sexual activity (Byler et al., 2016; Hossain et al., 2019). Since Zika shares symptoms with dengue and chikungunya, such as fever, rash, enlarged lymph nodes, and joint pain, its symptoms are non-specific. They may be mistaken for other flavivirus illnesses (Priya et al., 2018). Furthermore, multiple viral co-infections, including DENV and ZIKV, DENV and chikungunya virus (CHIKV), and ZIKV and CHIKV, add to the complexity (Silva et al., 2020; Hasan et al., 2025). ZIKV infection during pregnancy can result in miscarriage and stillbirth, microcephaly, congenital Zika syndrome, limb contractures, high muscle tone, eye abnormalities, and hearing loss in infants (Musso et al., 2019). In adults and older children, ZIKV infection can also lead to serious complications, including Guillain-Barré syndrome, multi-organ failure, thrombocytopenia, thrombocytopenic purpura, meningitis, encephalitis, neuropathy, and myelitis (Hossain et al., 2019).

Viral infections currently lack effective treatments due to the limited availability of antiviral drugs and the rise of drug-resistant virus strains, creating a genetically diverse environment (Atampugbire et al., 2024). The rapid spread of ZIKV has raised safety concerns for pregnant women since the virus can cause fetal microcephaly without known treatment. Wahab et al. (2025) recently reviewed the epidemiology, transmission patterns, oncolytic features, and control methods (vaccines, antivirals, and vector management) for ZIKV. They discussed molecular insights into neuro-immunopathogenesis and other neuropathies caused by ZIKV, along with a summary of in vitro and in vivo models for researching the cellular and molecular pathways underlying ZIKV pathogenesis. Currently, there is no specific treatment for ZIKV, DENV, or CHIKV infections. Thus, there is an urgent need for effective antivirals targeting arboviruses to reduce the infection burden on millions globally. This makes natural substances, such as nutraceuticals, promising options for prevention (Haddad et al., 2019a). Alternative therapies targeting key ZIKV enzymes, such as protease, helicase, and polymerase, are necessary to develop safe and effective drugs derived from natural compounds (Thirumoorthy et al., 2022). Plants have been used for centuries to treat and prevent diseases, and traditional herbal medicine remains common in Africa, Latin America, and China, while gaining popularity in Australia and the USA (Goh et al., 2020). Moreover, natural products generally exhibit lower toxicity and favorable physicochemical properties, making them an important source of drug candidates (Fong and Chu, 2021). Medicinal and aromatic plants (MAPs) of Bangladesh may provide promising antiviral compounds against emerging arboviruses (Sarwar, 2025; Sarwar et al., 2025).

As part of the ancient Indian subcontinent, Bangladesh has a rich history of using MAPs to treat various diseases within the Ayurvedic, Unani, and Tibetan systems of medicine (Ravishankar and Shukla, 2007; Sarwar, 2020). Despite their ignorance of viruses, several herbs have been utilised to treat viral-like fevers, skin eruptions, and respiratory ailments in the Vedic, Ayurvedic, Siddha, and Unani systems. In Bangladesh, over 1200 plant species are used for medicinal purposes (Uddin and Lee, 2020). This study investigates Bangladeshi MAPs, including their constituents and active chemicals that may be useful in treating ZIKV. Additionally, it provides a comprehensive overview of prevention and management strategies for diseases transmitted by *Aedes* mosquitoes, citing Sarwar (2025) and Sarwar et al. (2025).

Materials and Methods

This study aimed to review and synthesize the scientific literature on medicinal plants with anti-ZIKV properties, focusing on English-language publications from 2010 to 2025. It included research articles and clinical trials from reputable databases such as PubMed, Scopus, MDPI Link, ResearchGate, and Google Scholar, along with a comprehensive review of the use of medicinal plants as antiviral agents. Key search terms included Zika, antiviral, medicinal plants, mechanisms of antiviral action, phytochemicals, and others. Bangladeshi articles were searched in BanglaJol, a repository of papers published in Bangladeshi journals. Articles published in languages other than English, as well as editorials and comments without peer review, were excluded. Additionally, a manual search was conducted by reviewing the reference lists of eligible studies. Plants' current nomenclature and family classification were verified using Plants of the World Online (https://powo.science.kew.org/), the International Plant Names Index (https://www.ipni.org/), and World Flora Onlin(https://www.worldfloraonline.org/).

Figures/graphs were drawn from the data in Table 1.

Table 1: List of Bangladeshi medicinal and aromatic plants used against Zika virus.

Sl. No.	Bangla/Common Name	Scientific name	Family	Part used	Active constituents	Reference
1.	Kalomegh	*Andrographis paniculata* (Burm.f.) Wall. *ex* Nees*	Acanthaceae	Whole plant	Andrographolide	Thirumoorthy *et al*., 2022
2.	Palak-Jui/Snake jasmine	*Rhinacanthus nasutus* (L.) Kurz	Acanthaceae	Root, Leaf	Rhinacanthin D	Byler *et al*., 2016
3.	Garlic	*Allium sativum* L.**	Amaryllidaceae	Bulb	Allicin	Priya et al., 2018
4.	Spider Lily	*Crinum asiaticum* L.	Amaryllidaceae	Bulb	Lycorine	Wahaab et al. 2025
5.	Bhela/Marking Nut tree	*Semecarpus anacardium* L.f.	Anacardiaceae	Fruit, Leaf	Benzoic acid, 4-ethoxy ethyl ester	Sharma *et al*., 2023
6.	Aata/Custard apple	*Annona squamosa* L.	Annonaceae	Leaf	Isoquercitrin	Goh et al. 2020
7.	Kurchi/Indrajao	*Holarrhena pubescens* Wall. *ex* G.Don	Apocynaceae	Bark, Leaf, Seed	Conessine	Fong and Chu 2022
8.	Sarpagandha	*Rauvolfia serpentina* (L.) Benth. *ex* Kurz*	Apocynaceae	Root	Reserpine	Ahmed et al. 2020
9.		*Asarum* spp,	Aristolochiaceae	Root, Rhizome	(−)-Asarinin	Byler et al. 2016
10.	Alovera	*Aloe vera* (L.) Burm.f.	Asphodelaceae	Leaf	Emodin	Pereira *et al*., 2023
11.	Ayapan/Water hemp	*Ayapana triplinervis* (Vahl) R.M.King & H.Rob.	Asteraceae	Aerial part	Dimethylthiohydroquinone ether	Pereira *et al*., 2023
12.	Sambong	*Blumea balsamifera* (L.) DC.*	Asteraceae	Whole plant	Saponin, Terpenes and Terpenoids, Anthocyanin	Vista *et al*., 2020
13.	Chicory	*Cichorium intybus* L.	Asteraceae	Whole plant	Lactucopicrin, Chicoric acid	Byler et al., 2016
14.	Kukshim/Little Ironweed	*Cyanthillium cinereum* (L.) H.Rob.	Asteraceae	Root	Flavone glycosides	Sanju et al. 2017
15.	Lettuce	*Lactuca* spp.	Asteraceae	Root	Lactucopicrin	Byler et al., 2016
16.	Milk Thistle	*Silybum marianum* (L.) Gaertn.	Asteraceae	Whole plant	Neosilyhermin A	Byler et al. 2016
17.	Tridhara/Mexican Daisy	*Tridax procumbens* L.*	Asteraceae	Whole plant	Benzene propanoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy methyl ester	Sharma *et al*., 2023
18.	Asiatic/Indian Barberry	*Berberis asiatica* Roxb. *ex* DC.	Berberidaceae	Leaf	Berberine	Batista *et al*., 2019
19.	Yellow Bells	*Tecoma stans* (L.) Juss. *ex* Kunth*	Bignoniaceae	Leaf	Crenatoside	Reis et al. 2020
20.	Bixa/Annatto	*Bixa orellana* L.*	Bixaceae	Fruit/Seed	Bixin, Ethyl bixin	Sobrinho et al. 2022
21.	Hemp	*Cannabis sativa* L.*	Cannabaceae	Leaf	Cannflavin A	Byler et al., 2016
22.	Arjun	*Terminalia arjuna* (Roxb. *ex* DC.) Wight & Arn.	Combretaceae	Bark	Tannic acid	Priya et al., 2018
23.	Bitter gourd	*Momordica charantia* L.*	Cucurbitaceae	Leaf	Saponin, Terpenes and Terpenoids, Anthocyanin	Vista et al., 2020
24.	Coca	*Erythroxylum* sp.	Erythroxylaceae	Stem	-	Barbosa et al. 2022
25.	Badam/ Groundnut	*Arachis hypogaea* L.	Fabaceae	Fruit	Resveratrol	Fong and Chu 2022
26.	Sensitive pea	*Chamaecrista* sp.	Fabaceae	Stem, Fruit	Agarobiose, Leuhistin, Plumbagin	Barbosa et al. 2022
27.	Babachi/Scurfy Pea	*Cullen corylifolium* (L.) Medik.	Fabaceae	Fruit	Corylifol B	Byler et al., 2016
28.	Charchara/Erect Flemingia	*Flemingia stricta* Roxb.	Fabaceae	Roots, Leaf	Flemiflavanone D	Byler et al., 2016
29.	Licorice	*Glycyrrhiza glabra* L.	Fabaceae	Root	Glycyrrhetinic acid, Glycyrrhizin	Sanju et al. 2017
30.	Nil/Indigofera	*Indigofera tinctoria* L.	Fabaceae	Leaf	Ajoene	Priya et al., 2018
31.	Lupin	*Lupinus albus* L.	Fabaceae	Seed	Luteone	Ahmed et al. 2020
32.	Daad Mordon/ Candle bush	*Senna alata* (L.) Roxb.	Fabaceae	Leaf	Aloin	Priya et al., 2018
33.	Sickle pod	*Senna obtusifolia* (L.) H.S.Irwin & Barneby	Fabaceae	Seed	Anthraquinones, Emodin	Pereira *et al*., 2023
34.	Yellow cassia	*Senna siamea* (Lam.) H.S.Irwin & Barneby	Fabaceae	Flower	Cassiarin D	Byler et al., 2016
35.	Methi/Fenugreek	*Trigonella foenum-graecum* L.	Fabaceae	Seed	Trigoneoside I (aglycone)	Byler et al., 2016
36.	Head Leucas	*Leucas cephalotes* (Roth) Spreng.	Lamiaceae	Leaf, Fruit	Oleanolic acid, Flavonoids	Sanju et al. 2017
37.	Tulshi/Holy basil	*Ocimum basilicum* L.	Lamiaceae	Leaf	Apigenin	Priya et al., 2018

38.	Tulsi/Holy Basil	*Ocimum tenuiflorum* L.	Lamiaceae	Leaf	Methyl eugenol, other terpenoids	Sanju et al. 2017
39.	Nishinda	*Vitex negundo* L.*	Lamiaceae	Leaf	Saponin, Terpenes and Terpenoids, Anthocyanin	Vista et al., 2020
40.	Daruchini/Ceylon cinnamon	*Cinnamomum verum* J.Presl*	Lauraceae	Bark	Cinnamic acid	Pereira *et al*., 2023
41.	Pomegranate/ Dalim	*Punica granatum* L.***	Lythraceae	Leaf	Ellagic acid	Pereira *et al*., 2023
42.	Cotton	*Gossypium* spp.	Malvaceae	Seed, Stem, Root	Gossypol	Fong and Chu 2022
43.	Neem	*Azadirachta indica* A. Juss.*	Meliaceae	Leaf	Azadirachtin, Nimbolide, Nimbin	Sanju et al. 2017
44.	Gulancha	*Tinospora cordifolia* (Willd.) Hook.f. & Thomson*	Menispermaceae	Leaf, Stem, Root	Magnoflorine, Berberine	Sanju et al. 2017
45.	Tut/White Mulberry	*Morus alba* L.	Moraceae	Fruit	Resveratrol	Goh et al. 2020
46.	Peyara/Guava	*Psidium guajava* L.*	Myrtaceae	Leaf	Saponin, Terpenes and Terpenoids, Anthocyanin	Vista et al., 2020
47.	Passion fruit	*Passiflora edulis* Sims	Passifloraceae	Seed	(iso-)vitexin, Apigenin, Quercetin	Pereira *et al*., 2023
48.	Black pepper	*Piper nigrum* L.*	Piperaceae	Fruit	Piperine	Sanju et al. 2017
49.		*Paulownia tomentosa* (Thunb.) Steud.	Paulowniaceae	Fruit	3-O-Methyldiplacone	Byler et al. 2016
50.	Nolkhagra/Tropical reed	*Phragmites karka* (Retz.) Trin. *ex* Steud.	Poaceae	Aerial parts	Polyphenols, Delphinidin, Epigallocatechin	Zainul et al. 2015
51.	Lal kakra/Burma Mangrove	*Bruguiera gymnorhiza* (L.) Lam. *ex* Savigny	Rhizophoraceae	Leaf, Bark	Cryptochlorogenic acid	da Silva et al. 2023
52.	Kelikodom	*Adina cordifolia* (Roxb.) Hook.f. & Benth.	Rubiaceae	Bark, Root	Flavonoids, Saponins, phenol, tannins, terpenoids, and cardiac glycosides	Sanju et al. 2017
53.	Spreading Diamond Flower	*Scleromitrion diffusum* (Willd.) R.J.Wang	Rubiaceae	Whole plant	Phenols, Flavonoids	Pereira *et al*., 2023
54.	Sour orange	*Citrus × aurantium* L.	Rutaceae	Fruit	Hesperidin, Hypericin	Priya et al., 2018
55.	Shiny-leaf prickly-ash	*Zanthoxylum nitidum* (Roxb.) DC.*	Rutaceae	Bark	Hibalactone	Byler et al., 2016
56.	Tea (green tea)	*Camellia sinensis* (L.) O.Kunze*	Theaceae	Leaf	Epigallocatechin gallate	Haddad *et al*., 2019a
57.	Bhui okra	*Lippia alba* (Mill.) N.E.Br. *ex* Britton & P.Wilson**	Verbanaceae	Whole plant	Essential oils	Pereira *et al*., 2023
58.	Grape	*Vitis vinifera* L.	Vitaceae	Fruit	Resveratrol	Goh et al. 2020
59.	Holud/Curcuma	*Curcuma longa* L.*	Zingiberaceae	Rhizomes, Leaf	Curcumin	Sanju et al. 2017
60.	Aromatic ginger	*Kaempferia galanga* L.**	Zingiberaceae	Rhizomes, Leaf	Kaempferide	Fong and Chu 2022
61.	Ada/Ginger	*Zingiber officinale* L.**	Zingiberaceae	Rhizomes, Leaf	[6]-Gingerol, Shogaol	Sanju et al. 2017
62.	Gokshur/Yellow Vine	*Tribulus terrestris* L.	Zygophyllaceae	Fruit	Terrestribisamide, Tribufuroside I	Byler et al., 2016

* Plants with insecticidal properties against *Aedes* spp.; ** insecticidal properties against both *Aedes* spp. and *Culex quinquefasciatus*; *** insecticidal properties against *A. aegypti*, *Anopheles stephensi*, and *C. quinquefasciatus* (Baranitharan et al. 2018)

Results and Discussion

MAPs against ZIKV and other arboviruses

A total of 62 MAPs from various plant groups (i.e., 25 herbs, 20 shrubs, 12 trees, 3 vines, and 2 climbers) representing 59 genera and 36 families were documented for their ethnomedicinal uses against ZIKV (Table 1; Figure 1). Fabaceae, with 11 species, was the most represented family, followed by Asteraceae (7 species), Lamiaceae (4 species), and Zingiberaceae (3 species) (Figure 2). In contrast, four families, including Acanthaceae, Amaryllidaceae, Apocynaceae, Rubiaceae, and Rutaceae, were represented by two species each, while 27 families were represented by only one species each. Among the genera, *Senna* and *Ocimum* showed co-dominance with three and two species, respectively. All other genera were represented by a single species each (Table 1). This diversity aligns with previous ethnopharmacological surveys that highlight the region's rich history of plant-based treatments for infectious and vector-borne diseases (Mukherjee et al., 2010; Sarwar, 2025; Sarwar et al., 2025). It demonstrates their widespread availability and longstanding application in traditional medicine (Kirtikar and Basu, 2006). Among the MAPs, four species, *viz*. *Erythroxylum* sp., *Chamaecrista* sp., *Scleromitrion diffusum*, and *Camellia sinensis,* also showed activity against CHIKV; four species, *viz*. *Allium sativum*, *Tridax procumbens*, *Trigonella foenum-graecum*, and *Punica granatum,* against DENV; and nine species, *viz*. *Andrographis paniculata*, *Glycyrrhiza glabra*, *Ocimum tenuiflorum*, *Vitex negundo*, *Azadirachta indica*, *Tinospora cordifolia*, *Psidium guajava*, *Curcuma longa*, and *Zingiber officinale* can reduce viral loads of all three viruses, DENV, CHIKV, and ZIKV, transmitted by *Aedes* mosquitoes (Table 1; Sarwar, 2025; Sarwar et al., 2025). The MAPs, which have shown potential for controlling DENV, CHIKV, and ZIKV, may be a natural gift, as coinfection among these viruses is common and can lead to enhanced viral replication, antiviral suppression, and increased susceptibility and transmissibility (Hasan et al., 2025). Leaves are the most frequently used plant parts, followed by multiple plant parts and the whole plant (Figure 3). The following characteristics, which include being rich in antioxidants and other phytochemicals, being inexpensive, being easy to harvest, and having year-round availability, as well as being less prone to deterioration, might make leaves a unique source for medicinal use.

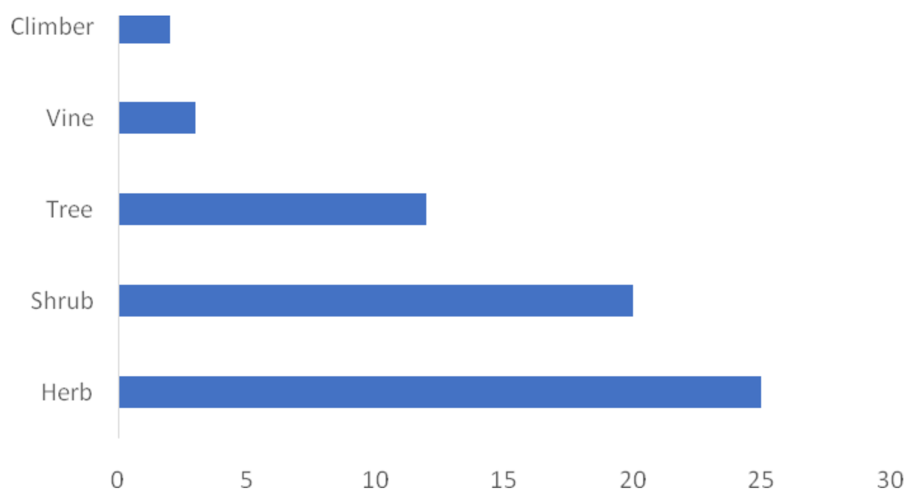

Figure 1. Life forms of plants against Zika virus with respect to number of species.

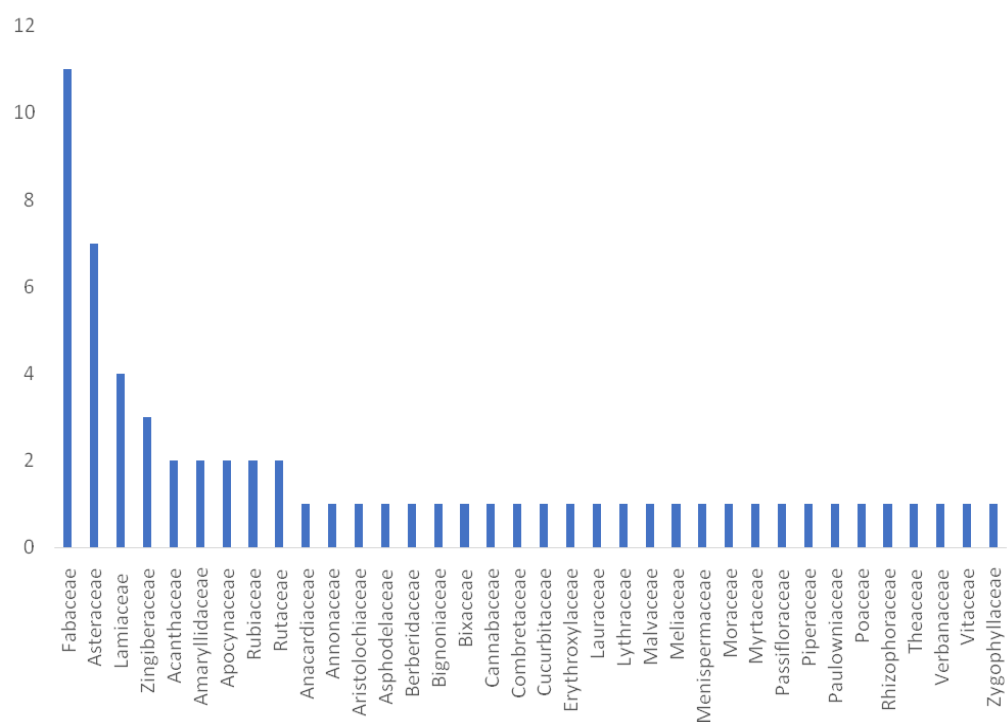

Figure 2. Family-wise distribution of medicinal and aromatic plants used against Zika virus.

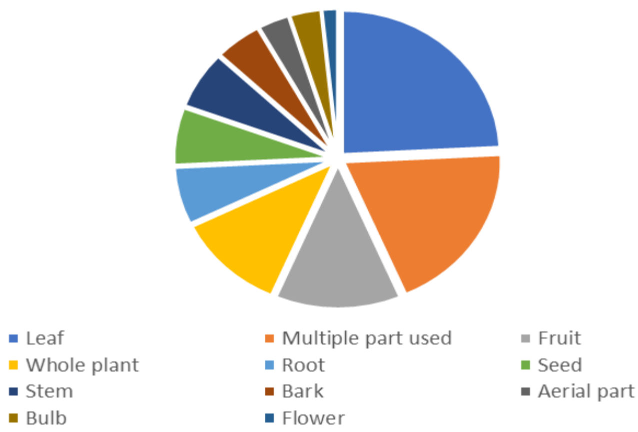

Figure 3. Medicinal and aromatic plant parts used against Zika virus.

Bioactive compounds and their action mechanism against ZIKV

A diverse array of bioactive compounds, including alkaloids, terpenoids, phenolics, flavonoids, anthraquinones, and related substances, is present in these MAPs (Table 1). Many enveloped RNA viruses, including ZIKV, are sensitive to a wide range of phytochemicals, such as alkaloids, coumarins, flavonoids, terpenoids, polyphenols, and saponins (Clain et al., 2018). These phytochemicals are important due to their antiviral and insecticidal properties, particularly against *Aedes* and *Culex* mosquito vectors. Plant antivirals target different stages of the viral life cycle, either by preventing the virus from attaching to host cells, stopping replication within host cells, or directly destroying the virus. Key mechanisms of antiviral action include breaking down the viral capsid, directly inhibiting viral replication, inducing apoptosis, modulating immune responses, and exerting antioxidant effects (Atampugbire et al., 2024). The effectiveness of medicinal plants is assessed through clinical studies that compare herbal medicines with established treatments or placebos. However, the diversity of active compounds in herbal medicines poses specific challenges for evaluating their overall antiviral potential. For instance, resveratrol (RES) has shown direct virucidal activity against ZIKV by inhibiting viral replication, highlighting the need for further research into RES as a potential antiviral agent (Mohd et al., 2019). Bixin and ethyl bixin inhibit the enzymatic activity of non-structural proteins, including NS2B, NS3, and NS5, suggesting their potential as effective anti-Zika compounds (Sobrinho et al., 2020). Berberine and emodin, which have multiple pharmacological properties, are highly effective in blocking the entry and replication of various viruses, including ZIKV (Batista et al., 2019). Additionally, combination therapies, such as gossypol combined with natural products like curcumin, have demonstrated a two- to threefold increase in inhibiting ZIKV infection in Vero cells, with minimal cytotoxicity (Fong and Chu, 2021). Both antiviral activity and cytotoxic effects should be considered when recommending or administering any MAPs (Vista et al., 2020).

The methods used for extraction and collection significantly influence the efficacy of different MAPs against viruses. For example, the nonvolatile extract from *A. triplinervis* showed no antiviral effect against ZIKV; however, the volatile extract, in the form of essential oil from the same species, was effective against ZIKV (Haddad et al., 2019b). Three natural compounds, curcumin, epigallocatechin gallate, and pinocembrin, are identified as common ingredients with antiviral properties against all three arboviruses (DENV, ZIKV, and CHIKV) (Goh et al., 2020). Furthermore, host lipids play a crucial role in the flavivirus infection process, including viral entry, innate immune responses, and viral egress, and affect specific host tissues. Consequently, FDA-approved cholesterol-lowering medications may be used to treat flaviviral infections (Goodman and Rasmussen, 2019). The effectiveness of a MAP's active constituents depends on their absorption capacity in the gastrointestinal tract. A molecule is considered well-absorbed if at least 90% enters the bloodstream; however, lipophilic molecules in excess can cross the blood-brain barrier, potentially affecting neurogenesis and contributing to neurodegenerative diseases (Valdiviezo-Campos et al., 2024). Generally, polyphenols have low toxicity risks, ranging from 1606 to 3927 mg/kg, according to OECD guidelines. The MAPs with anti-ZIKV potential discussed here have also demonstrated activity against several other viruses (Mohd et al., 2010; Ahmed et al., 2020; Goh et al., 2020; Reis et al., 2020; Vista et al., 2020; Atampugbire et al., 2024; Valdiviezo-Campos et al., 2024).

Anti-ZIKV MAPs and their mode of action against mosquito vectors

As a mosquito-borne disease, ZIKV requires immediate vector control measures to be effectively eradicated. Mosquitoes in Bangladesh are increasingly resistant to insecticides, leading to alarming outbreaks of dengue, Zika, and other mosquito-borne diseases (Hossain et al., 2019). Approximately 60% of the global population, or over 6.1 (4.7-6.9) billion people, will face dengue risk by 2080, increasing concern about vector control (Silvério et al., 2020). The lack of selectivity, environmental impacts, and insect resistance to synthetic insecticides has led to increased interest in botanical pesticides (Baranitharan et al., 2018). Integrated mosquito management (IMM) and integrated vector management (IVM) approaches may be more effective at controlling mosquitoes and disrupting transmission, as demonstrated worldwide. MAPs may be crucial for controlling vector mosquitoes. Almost one-third (16 species) of the MAPs identified in this study with anti-ZIKV properties, *viz*., *A. paniculata*, *A. indica*, *B. orellana*, *B. balsamifera*, *C. sinensis*, *C. sativa*, *C. verum*, *C. longa*, *M. charantia*, *P. guajava*, *R. serpentina*, *T. stans*, *T. procumbens*, *P. nigrum*, *V. negundo*, and *Z. nitidum*, showed insecticidal properties against *Aedes* spp., and *A. sativum*, *K. galanga*, *L. alba*, and *Z. officinale* against both *Aedes* spp. and *Culex quinquefasciatus* (Table 1). The documentation of *A. sativum* and *Z. officinale*, which exhibit activity against *C. quinquefasciatus*, further highlights the broader potential of culinary and medicinal plants in vector control. Among these MAPs, *P. granatum* was reported to possess insecticidal properties against *A. aegypti*, *Anopheles stephensi*, and *C. quinquefasciatus* (Baranitharan et al., 2018); some others are capable of controlling vectors of various mosquito-borne diseases (Baranitharan et al., 2018; Assemie and Gemeda, 2023). Essential oils of MAPs are promising insecticides due to their effective insecticidal properties and relative safety for mammals and the environment (Silvério et al., 2020). They exhibit high LC50 values and degrade easily in ecosystems. Key active compounds include terpenes (especially monoterpenes), phenylpropanoids, thiophenes, amides, and alkaloids, which show significant larvicidal and adulticidal activities (Silvério et al., 2020). The secondary metabolites (phytochemicals) of MAPs act as insect resistance compounds, including insecticides, repellents, oviposition deterrents, growth inhibitors, antifeedants, juvenile hormone mimics, and attractants. To prevent and control ZIKV and other arboviral infections, avoid (virus-infected) mosquito bites by taking measures such as wearing long-sleeved shirts, long pants, and socks; using mosquito nets; eliminating standing water; and other preventive measures (Vaziri et al., 2022).

Conclusion and Future Directions

The use of MAP extracts to prevent ZIKV replication demonstrates their potential as natural remedies. It also highlights rich biodiversity and deep-rooted traditional knowledge within local healthcare systems. The current investigation revealed at least nine Bangladeshi MAP extracts with anti-Zika, anti-dengue, and anti-chikungunya properties, which can be further studied to develop effective phytopharmaceuticals for these diseases. Additionally, the future of these plants as antiviral agents is complex. Safety concerns are significant, requiring extensive research and clinical trials to evaluate potential risks and toxicity. Balancing the proven effectiveness of MAPs with thorough safety assessments is crucial for their future use. Initiatives to combine ethnopharmacology with modern scientific validation could lead to new phytomedicines and environmentally friendly vector control strategies, benefiting biodiversity, preserving traditional knowledge, and enhancing public health.

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