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Phytochemical Composition and Antimicrobial Activities of Edible Fruits from Assam, India: A Review of Bioactive Constituents and Experimental Evidence

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Abstract

In today's world, antimicrobial resistance has emerged as a critical health concern that is fueling the hunt for natural alternative medicinal agents. Wild edible fruits contain a variety of phytochemicals and have promising antibacterial properties that could slow the emergence of resistance. This review compiles the most recent information on the phytochemical composition and antibacterial qualities of edible fruits that are indigenous to or frequently found in Assam, India. According to recent studies, bioactive phytochemicals such as flavonoids, phenolic acids, tannins, alkaloids, terpenoids, and organic acids can be found in fruits, including *Citrus limon, Citrus jambhiri, Mangifera indica, Psidium guajava, Musa paradisiaca,* and *Punica granatum*. By interfering with the production of biofilms, disrupting cell membranes, and inhibiting enzyme systems, these components demonstrate broad-spectrum antibacterial efficacy against harmful bacteria and fungi. *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa,* and *Candida albicans* are all significantly inhibited by a number of *in vitro* investigations on fruit extracts, juices, and peel fractions. Overall, the edible fruits of Assam are a significant source of natural antimicrobial compounds, highlighting their potential for use in creating sustainable, cost-effective, and safe methods of battling antibiotic resistance.

Major Findings: Assam wild fruits contain various bioactive phytochemicals such as flavonoids, phenolics, and tannins with notable antimicrobial activities. The extracts of the edible fruits of Assam exhibit bacteriostatic properties against selected pathogenic bacteria and fungi, showing their potential as natural alternatives for antimicrobial agents and functional food applications.

Keywords: Antimicrobial Activities, Antimicrobial Resistance, Edible Fruits, Phytoconstituents

Abbreviations: AMR - Antimicrobial Resistance; CDC - Centers for Disease Control and Prevention; DNA - Deoxyribonucleic Acid; DIZ - Diameter of Inhibition Zone; EAEC - Enteroaggregative *Escherichia coli*; MIC - Minimum Inhibitory Concentration; MRSA - Methicillin-resistant *Staphylococcus aureus*; MW - Water-Methanol Mixture; N.C. Hills - North Cachar Hills; PLs - Papaya Leaves; ROS - Reactive Oxygen Species; WHO - World Health Organization; ZOI - Zone of Inhibition.

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1. Introduction

In recent years, antimicrobial resistance (AMR) has become a severe health issue for the global population. The treatment of specific infections becomes more difficult and, in some cases, impossible when drugs lose their potency due to drug resistance. Researchers from the Centres for Disease Control and Prevention (CDC), World Health Organisation (WHO), and International Public Health Institutes maintain that global remedial measures are required to battle the growth of antimicrobial resistance (AMR)[1-3]. In the twenty-first century, antibiotic resistance is one of the biggest concerns facing global public health[4]. When microorganisms, including bacteria, fungi, parasites, and viruses, go through evolutionary processes that make them resistant to antimicrobial medication such as antibiotics, AMR is regularly used to treat similar infection[2]. The widespread issue is mostly attributable to the ramifications of antibiotic overuse or irresponsible usage across varied contexts, predominantly in clinical treatment, agriculture practices, animal healthcare, military crisis, and the food chain[5]. Antimicrobial agent such as antibiotics, antifungals, antivirals, disinfectants, and food preservatives, kill or inhibit the growth and proliferation of microorganisms. Antibiotics are a class of medications that are specifically intended to combat bacterial infections and antibiotic resistance. They are the most commonly used type of antimicrobial. All species show AMR, an unavoidable evolutionary phenomenon caused by the establishment of guard against lethal selection pressure. Bacteria try to develop resistance to antibacterial medicines so they can survive in harsh environmental conditions. Because of this, the medicines may stop working effectively[6]. Prominent experts have said that the era of antibiotics is coming to an end, and that this trend may jeopardise the foundation of much of modern public health and medicine. Since antibiotics were first employed in medicine over 80 years ago, microbes have evolved defences against them; nonetheless, the issue of antimicrobial resistance (AMR) has rapidly worsened. Reliable estimates of the number of cases worldwide are lacking, mostly due to inadequate surveillance; nonetheless, there is conflicting information that shows the issue is significantly worse in many developing nation[7,8]. These ailments influence nearly every medical environment. Pathogens that have gained resistance to one or more antibiotics to which they were previously sensitive cause a large number of children's ear infections, community-acquired pneumonias, sexually transmitted infections, and wound and skin infections. For example, half of the WHO regions have countries where the rate of gonorrhoea resistance to third-generation cephalosporins exceeds 50%, whereas other WHO regions have nations with rates of penicillin resistance above 50% in community-acquired pneumococcal infections[9]. Historically, medicinal plants have been utilised for a range of therapeutic purposes, such as the treatment of microbial infections, all over the world[10,11]. In fact, current research has focused on plant extracts' ability to inhibit the growth of dangerous bacteria, particularly in light of their potential to change bacterial antibiotic resistance. These results may be a useful guide for future research on reversing microbial resistance[12,13]. Traditional knowledge highlights the fruit's use in medicine, where it is valued for its anti-inflammatory, antimicrobial, and wound-healing properties. While these claims are supported by anecdotal evidence, detailed scientific investigations are still in their infancy. Expanding research into its phytochemical composition, pharmacological activities, and potential health benefits will provide the foundation for its integration into mainstream functional foods and nutraceuticals[14]. Traditional medicines have a very long history. It is the sum of total practices based on theories, beliefs and experiences of different cultures and times[15].

The northeastern region of India, particularly Assam, is recognised for its rich biodiversity and unique agro-climatic conditions that support the growth of a wide variety of edible fruits with potential medicinal value. Many indigenous fruits cultivated or naturally available in this region—such as *C. limon*, *P. guajava*, *P. granatum*, *M. paradisiaca*, and *P. emblica*—have long been utilised in traditional practices for the treatment of infections and other health conditions[16]. Despite their ethnomedicinal importance, scientific documentation and systematic evaluation of the antimicrobial phytochemicals present in these fruits are still limited and fragmented across different studies.

Therefore, the novelty of this review lies in compiling and critically analysing the available experimental evidence on the phytochemical constituents and

antimicrobial activities of edible fruits commonly found in Assam. By integrating traditional knowledge with modern scientific findings, this review aims to highlight the potential of these fruits as natural sources of antimicrobial compounds and to emphasise the importance of the region's biodiversity in the discovery of novel therapeutic agents. Furthermore, this work seeks to identify existing research gaps and encourage future investigations focused on bioactive compound isolation, mechanism-of-action studies, and the development of plant-based antimicrobial formulations.

2. Phytochemistry of Some Edible Fruits Cultivated in Assam

For human consumption, fruits are a significant source of phytochemicals. Bioactive compounds called phytochemicals are extracted from plants and offer significant health benefits[17]. They are found in plants as secondary metabolites. The main phytochemicals are phenolic compounds, carotenoids, and glucosinolates[18]. Fruits contain various types of phytochemicals such as flavonoids, alkaloids, tannins, catechins, esquiterpenes, phenylpropanes, polyacetylenes, polyketides, etc[19]. According to studies, apple and berry juice help lower hypercholesterolemia, and the polyphenols in grape juice can protect individuals from heart disease[20]. Additionally, the juice of oranges, pineapples, and grapefruits has significant amounts of folic acid derivatives, which are involved in the prevention of diseases of the nervous system[21]. Custard apple includes antioxidants, such as ascorbic acid, which aid in the fight against free radicals in our bodies. It is high in potassium and magnesium, which protect our hearts from cardiac disease and regulate blood pressure. It is important to include this fruit in the daily diet, as the copper content helps to cure constipation, and helps to treat diarrhoea and dysentery[22].

Table 1. Details of edible fruits and their mechanism of action against microorganisms

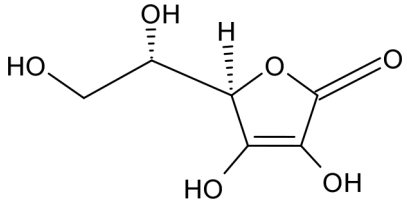
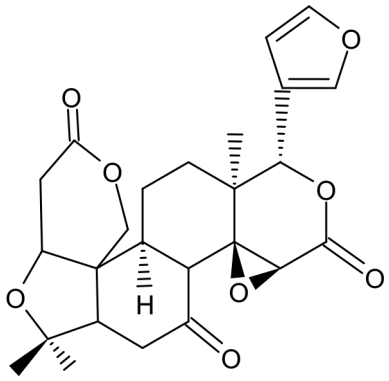
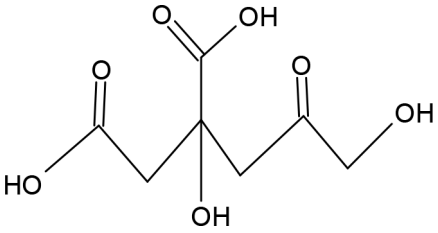
Class of Phytochemical	Sources	Structure	Relation with Antimicrobial Activity	References
Ascorbic acid	Lemon, Orange, Grapes, Star fruits, Guava, Papaya		Because of the presence of the ionisation hydroxyl group, it shows good antioxidant activity and reducing agent that can have antibacterial activity.	23
Limonin	Lemon, Orange, Grapes		Interferes with the production of biofilms and quorum sensing in bacteria; the limonoid backbone damages membranes.	24
Citric acid	Lemon, Orange, Grapes		Destabilises membranes, lowers pH, and chelates metal ions to inhibit bacterial growth.	25

Table 1. Continued...

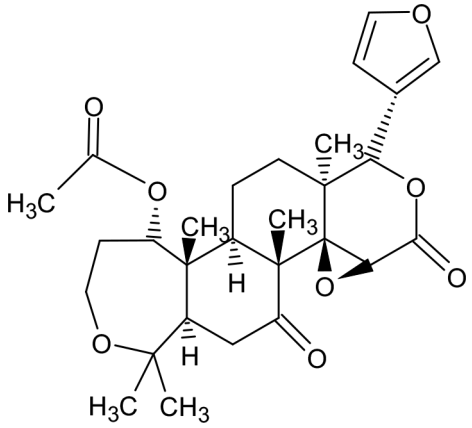
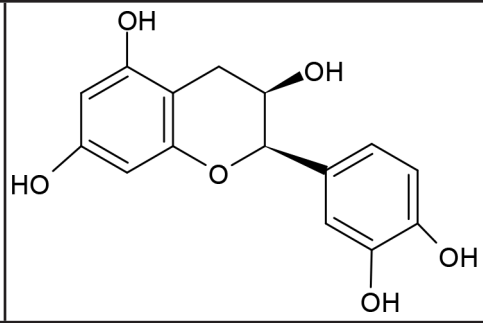
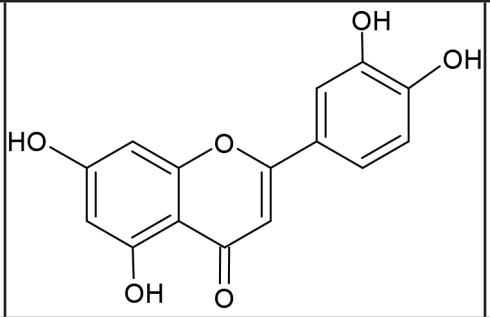
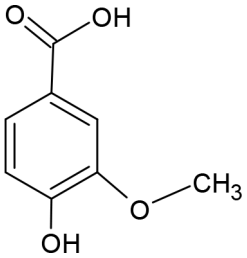
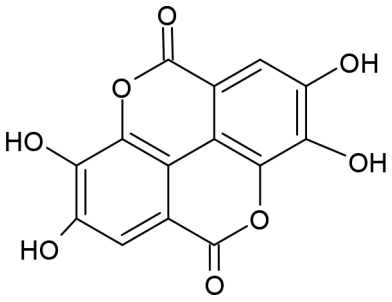
Class of Phytochemical	Sources	Structure	Relation with Antimicrobial Activity	References
Nomilin	Lemon, Orange, Grapes		Demonstrates antibacterial and antifungal action through membrane disruption; structurally related to limonin	26
Epicatechin	Pomegranate		Works in concert with antibiotics to bind bacterial proteins, destabilise membranes, and inhibit enzymes.	27
Luteolin	Pomegranate		Reduces bacterial biofilm and motility; it also inhibits enzymes and raises ROS.	28
Vanillic acid	Amla		Disrupts bacterial membranes; is more effective against Gram-positive bacteria.	29
Ellagic acid	Amla, Guava, Strawberry, Pomegranate		Binds bacterial DNA and proteins; inhibits Fats (cell division protein) and biofilm formation	30

Table 1. Continued...

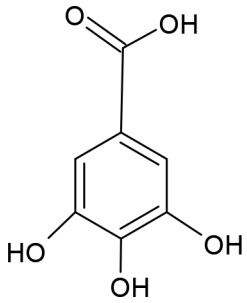
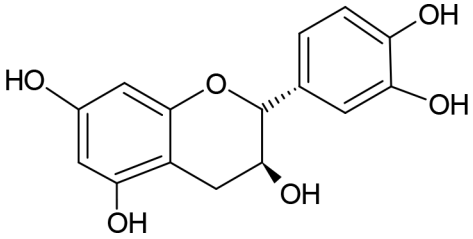
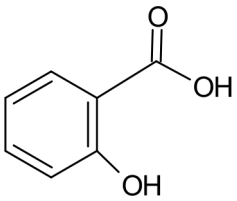
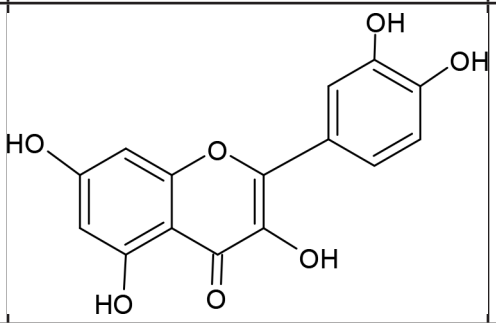
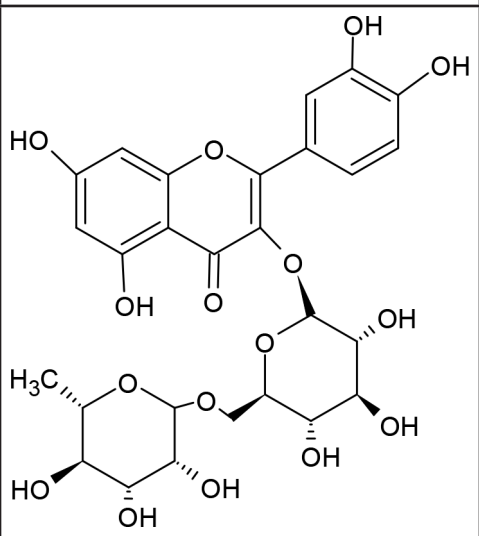
Class of Phytochemical	Sources	Structure	Relation with Antimicrobial Activity	References
Gallic acid	Star fruits, Amla, Banana, Guava, Pomegranate		Induces oxidative stress in bacteria; damages cell wall/membrane; inhibits efflux pumps	[25]
Catechins	Starfruits, Banana, Strawberry, Pomegranate		Intercalates in lipid bilayers, increases membrane permeability, inhibits virulence	[27]
Salicylic acid	Banana, Strawberry		Alters bacterial membrane permeability, acts synergistically with antibiotics	[25]
Quercetin	Guava, Strawberry, Papaya, Pomegranate		Inhibits nucleic acid synthesis, efflux pumps, and biofilm; synergistic with antibiotics	[31]
Rutin	Guava		Antibacterial and antibiofilm activity; sugar moiety improves solubility but reduces direct potency	[32]

Table 1. Continued...

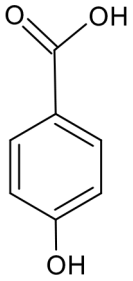
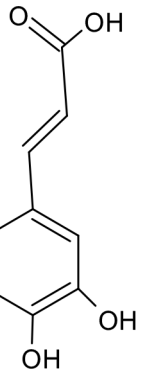
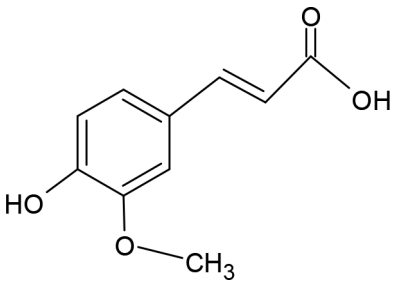
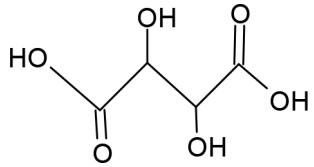
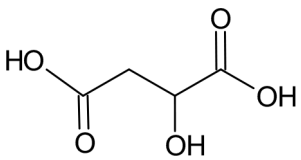
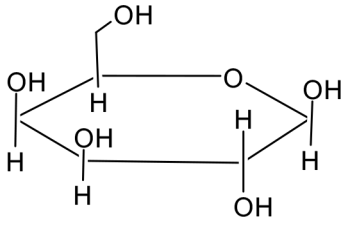
Class of Phytochemical	Sources	Structure	Relation with Antimicrobial Activity	References
Hydroxybenzoic acid	Strawberry		Disrupts membranes, interferes with enzymes, preservative role	33
Caffeic acid	Guava, Strawberry, Papaya		Suppresses the synthesis of DNA and proteins, damages membranes, and has antibiofilm properties.	34
Ferulic acid	Papaya		Alters membrane permeability; reduces biofilm; potentiates antibiotics	35
Tartaric acid	Tamarind		Lowers pH, chelates metals; preservative and antimicrobial activity	35
Mallic acid	Tamarind		Similar to tartaric acid; inhibits microbial growth by acidification and chelation.	25
Galactose	Tamarind		Not directly antibacterial; high osmotic concentration inhibits microbes (osmotic stress)	36

Table 1 summarises some important phytochemicals present in different edible fruits, their structure and possible structural activity relationship. As reported in the various literature, citric acid, epicatechin, vanillic acid, and nomilin show their antimicrobial activity by destabilising membranes or disrupting bacterial membranes and or other microorganisms[25-27]. Ellagic acid binds with the bacterial DNA and proteins, inhibiting or killing the microorganisms[30].

3. Antimicrobial Activity of Selected Fruits of Assam

3.1 Pomegranate (*Punica granatum*)

Pomegranate fruits, which are native to the Mediterranean area has historically been employed in the traditional medicine of India and many other countries. Pomegranate production worldwide approximately amounts to 1,500,000 tons[37]. The pomegranate peel is reported to have several health benefits due to the presence of different tannins, flavonoids, alkaloids and organic acids. Gallagyldilactone, gallic acid, and granatin B are phytochemicals that have been reported to exhibit notable anti-inflammatory activity[38-40]. Although pomegranate peels are generally considered agricultural waste, they are rich in bioactive compounds such as flavonoids and phenolic compounds, and they possess significant antioxidant, antibacterial, and antifungal properties[41]. Evaluation of antimicrobial efficacy: The antimicrobial properties of the pomegranate peel water extracts were assessed in this work using four bacterial strains and the agar well diffusion method. To evaluate the inhibitory effects of pomegranate peel extracts, agar cultures of *S. typhi*, *E. aerogenes*, *S. aureus*, and *K. Pneumonia* were produced. The existence of metabolic toxins or broad-spectrum antibacterial agents that combat both Gram-positive and Gram-negative bacteria may be the cause of the antimicrobial properties of *P. granatum* peels. The order *S. aureus*>*S. typhi*>*E. aerogenes*>*K. pneumonia* was discovered to possess the highest bactericidal effectiveness of different extracts against different types of bacterial strains. *P. granatum* has a high tannin content (25%) and antimicrobial properties, which may be a sign of secondary metabolites. Pomegranate peels' antimicrobial qualities have been investigated in the past, with varying findings from various investigators. Comparatively speaking, the diameter of the inhibition zone (DIZ) against *S. aureus* and *E. coli* was less than that of the other bacterial strains[42]. Several tropical plants from Puerto Rico were tested for their antibacterial qualities against *S. aureus* and *E. coli* using the disc diffusion method. As shown in Table 2, they demonstrated that pomegranate extract produced inhibitory zone widths of 20 and 11 mm for *S. aureus* and *E. coli*, respectively[43].

3.2 Citrus Fruits (Citrus Species)

Citrus is one of the largest plant species known to science, comprising forty (40) species that are found all across the world[44]. Orange, limes, lemons, and grapes are citrus fruits that are among the most frequently consumed in Nigeria. Fruit juice consumption is beneficial for the maintenance of good health and the prevention of diseases. The positive health benefits of juices have been ascribed in part to vitamin C (ascorbic acid), the major vitamin found in fruits[45]. Additionally, it is known that citrus fruits contain bioactive compounds include vitamins, flavonoids, phenolics, and essential oils, which are thought to provide several protective health benefits, including anticancer, anti-inflammatory, antioxidative, and antimicrobial activity[46,47]. As mentioned in Table 2, another study evaluated the citrus juice's antibacterial susceptibility test against a few Gram-positive and Gram-negative bacterial strains. The zones of inhibition that were detected differed between organisms and citrus juice concentrates. Comparing the Gram-positive and Gram-negative bacteria, the former displayed greater susceptibility levels. The zones of inhibition that *S. aureus* measured ranged from 10 to 20mm. From 8 mm for grape juice concentrate to 26 mm for tangerine juice concentrate, *E. faecalis* exhibited zones of inhibition. The juices under investigation showed the lowest zones of inhibition for *Salmonella* spp. (6–10 mm). Grape exhibited the lowest zones of inhibition for the bacterial strains under study, whereas tangerine produced the highest zones[45,48].

3.3 Banana (*Musa paradisiaca* L.)

The banana is a tropical fruit that is grown in many nations worldwide and belongs to the Musaceae family[49]. Every part of the banana plant, including

the pulp, leaves, stem, and flower, has a therapeutic use[50]. A banana's peel is a waste product, and research has indicated that it may potentially have therapeutic uses. Banana peels include bioactive substances like flavonoids, tannins, phlobatannins, alkaloids, glycosides, and terpenoids. It has been observed that this bioactive molecule has pharmacological effects, particularly as an antibacterial, antidiabetic, antioxidant, and anti-inflammatory[51]. Numerous studies have demonstrated banana peels' antibacterial properties[52]. Banana peel extract (*M. paradisiaca*) showed antibacterial activity against *P. mirabilis, E. coli*, and *S. aureus* when tested against human pathogenic microorganisms. Clinical isolates of four Gram-negative (*K. pneumoniae, E. coli, M. catarrhalis,* and *E. aerogenes*), two Gram-positive (*S. aureus* and *S. pyogenes*), and one yeast (*C. albicans*) were tested for antimicrobial activity by[53]. Banana extract displayed the highest antibacterial activity against *M. catarrhalis* and *S. aureus,* followed by *S. pyogenes, E. aerogenes,* and *K. pneumoniae. E. coli* and *C. albicans* were unaffected. They employed the serial broth dilution method and the well diffusion experiment to determine whether the alcoholic extract of banana peels was antibacterial. The well diffusion assay revealed that *P. gingivalis* and *A. actinomycetemcomitans* had inhibition zones of 15 mm and 12 mm, respectively, against the alcoholic extract of banana peel. In the serial broth dilution approach, both *P. gingivalis* and *A. actinomycetemcomitans* exhibited sensitivity up to 31.25 µg/ml against the same extract. Generally speaking, the antibacterial activity of plants has been attributed to their secondary metabolites[52]. Banana peel was shown to contain secondary metabolites, including terpenoids, alkaloids, glycosides, flavonoids, tannins, and phlobatannins[54]. The antibacterial properties of banana peel may be due to the presence of various phytochemicals and secondary metabolites.

3.4 Amla (*Phyllanthus emblica* Linn)

Phyllanthus emblica Linn, a member of the Euphorbiaceae family, is widely distributed throughout tropical and subtropical regions. *Phyllanthus* is a relatively large genus with about 550-750 species and 10 to 11 subgenera[51]. Today, people all across the world recognise the importance of traditional medical systems and certain traditional medical practices. Selective medications with a botanical origin must now be evaluated using a logical and astute methodology. *P. emblica's* fruits, flowers, seeds, leaves, and bark are widely utilised in a range of traditional treatments. According to pharmacological research, *P. emblica* possesses antioxidant, antimicrobial, anticancer, antihypertensive, anti-diarrhoea activity etc[55,56]. Jahan and Akter researched the antibacterial activity of *P. emblica*. The disc diffusion technique was applied in this study. Using a standard Kanamycin disc, the methanolic extract of *P. emblica* was assessed against Gram-positive, Gram-negative, and multidrug-resistant organisms at a concentration of 500µg/disc[57]. The results showed that the ethanolic extract of PE had a substantial antibacterial impact on a number of pathogens, including *S. dysenteriae* (17 mm), *S. aureus* (20 mm), and *B. subtilis* (25 mm). The disc diffusion method revealed that both *P. emblica* aqueous and ethanolic extracts were efficient against *P. aeruginosa*[58]. The methanolic extract of *P. emblica* totally killed AMR (antimicrobial-resistant) *S. typhi* and *S. enteritidis* at doses of 50 mg/mL and 25 mg/mL, respectively[59].

3.5 Apple (*Malus domestic*)

Considering their high phenolic content, apples offer a number of health benefits to everyone[60]. One important class of phytochemicals with a range of biological properties, including astringent, antioxidant, anticancer, anti-inflammatory, and antibacterial action, are phenolic compounds[61,62]. Studies have demonstrated that fruit juices and apple cider include *S. serovars, L. monocytogenes, L. innocua,* and *E. coli* O157:H7[63]. *Malus domestica* Borkh is a kind of fruit that is consumed all over the world[64]. *M. domestica* extract's antimicrobial activity was assessed against a group of eleven bacteria, and whether they are present or not, inhibition zones, the associated zone widths, and MIC values were employed to assess the microorganisms' potencies both qualitatively and quantitatively[65]. In one investigation, ethanol extracts of apples provided a zone of inhibition against *Klebsiella* sp. (9.2 mm) and *Pseudomonas* sp. (16.3 mm) when made using the cold maceration procedure with petroleum ether, ethanol, and water as solvents[66]. In a separate study, apple methanol and ethanol extracts showed inhibitory efficacy against *S. aureus* (14.3 mm and 13 mm, respectively) and EAEC (16.3 mm and

14.7 mm, respectively). Nevertheless, *Klebsiella* species, *P. aeruginosa*, and *E. faecalis* were unaffected by the extracts[67].

3.6 Pineapple (*Ananas comosus* L. Merr.)

One of Indians' favorite fruits is the pineapple (*Ananas comosus* L. Merr.). In Assam, pineapples are mostly grown in the districts of Karbi-Anglong, Nagaon, Cachar, and North Cachar Hills (N.C. Hills), while other places like Darrang are also known for their growth. Pineapple is a plant with potential antibacterial properties. Phenolic compounds, such as phytochemical substances, operate as a natural antibiotic against harmful bacteria, such as *E. coli* and *S. viridans*. Flavonoids, saponins, tannins, and bromelain enzymes can suppress bacterial growth. Phytochemical compounds have the possible use as a natural antibacterial against pathogenic bacteria, for example, opposed to the bacterium *S. viridans* and *E. coli*[68]. The antibacterial research was conducted utilising the agar well diffusion technique to assess the antimicrobial qualities of the pineapple fruit pulp and peels[69]. The organisms under investigation were inoculated onto sterile nutrient agar and cultured for 24 hours at 37°C. After adding inoculums to five millilitres of nutritious broth, the mixture is incubated at 37°C for two hours. It functioned as a novel suspending inocula. Using a sterile cork borer and inocula comprising test bacteria dispersed on solid plates, five mm diameter wells were created. The pineapple peel's aqueous extract was poured into each well. The control treatment involved the use of sterile distilled water. The plates were incubated for 24 hours at 37°C, and any zones of inhibition were evaluated according to Girish and Satish[70].

3.7 Guava (*Psidium guajava*)

Guava (*Psidium guajava*) is a phytotherapeutic plant used in folk medicine that is thought to contain active ingredients that help treat and manage a variety of ailments. The plant's different parts have been used in traditional medicine to cure illnesses such as malaria, gastroenteritis, vomiting, diarrhoea, dysentery, wounds, ulcers, toothache, coughs, sore throat, swollen gums, and other conditions[71,72]. Guavas are small evergreen trees. Guava leaves measure 1 to 2 inches in width and 2 to 6 inches in length. They are dull-green in colour, rigid but coriaceous, with visible veins. When crushed, they give off a nice aroma[73]. Guava leaves contain bioactive substances that can regulate blood sugar levels, combat infections, and even help people lose weight. The essential oil found in guava leaves comprises a high quantity of cineol, tannins, triterpenes, flavonoids, resin, eugenol, malic acid, cellulose, chlorophyll, mineral salts, and other fixed compounds[74-76]. The disc diffusion method was employed to evaluate the essential oil, and three extracts, with each extract tested at four distinct concentrations. They discovered that the methanol extract had the greatest bacterial inhibition. Several studies have performed selective antibacterial screening utilising guava essential oil and solvent extract[77-80]. Antimicrobial action: According to the National Committee for Clinical Laboratory Standards, the well-diffusion method was utilized test for antibiotic susceptibility[81]. Antimicrobial properties: Just two of the extracts of crude solvents made from *P. guajava* leaves, methanol and ethanol, demonstrated inhibitory efficacy against bacteria, based on the results of the investigation. Only two Gram-positive bacteria, *S. aureus* and *B. cereus*, were suppressed by the two extracts; neither of the Gram-negative microorganisms was impacted. The methanol extract showed slightly higher antibacterial activity at 10 mg/50 μL than the ethanol extract, which had mean zones of inhibition of 6.11 and 11.0 mm against *B. cereus* and *S. aureus*, respectively, with mean zones of inhibition of 8.27 and 12.3 mm. Gram-negative bacteria may be resistant due to the structure of their cell walls. The thin lipopolysaccharide outer membrane of Gram-negative bacteria acts as an efficient permeability barrier, preventing the plant extract from passing through. Generally speaking, Gram-negative bacteria are more resilient to plant-based antibiotics and may even be useless against them, according to prior findings[82-84].

3.8 Papaya (*Carica papaya*)

The Carica plant grows primarily in the tropical and sub-tropical regions of India, North-east Assam, Malaysia, Australia, Brazil, and China. This plant, which belongs to the Caricacea family, is well known for its fruit, but its leaves also provide significant health advantages. Papaya leaves (PLs) have been utilised in medical formulations around the world to treat diseases like dengue, malaria, cancer, and diabetes because they contain bioactive chemicals such as catechins, flavonoids,

tocopherol, alkaloids, anthocyanins, tannins, saponins, and phenols[85,86]. By inhibiting bacterial protein synthesis, PLs show antibacterial properties against a variety of Gram-positive and Gram-negative bacterial species, including *B. cereus, K. pneumonia, M. luteus, E. coli, P. aeruginosa,* and *S. aureus*, highlighting their potential in a variety of applications[87]. The methanolic extract of PLs was tested for antibacterial activity using the well diffusion method, with minor alterations from Joshi *et al.,* antibacterial activity was assessed against Gram-positive *S. aureus* and *B. subtilis*, as well as Gram-negative *E. coli* and *K. pneumoniae*, using the zone of inhibition method. To ensure uniform bacterial growth on the Petri plate, bacterial inocula were swabbed across the nutritional agar medium surface with a sterile cotton swab. The wells were loaded with 100µL of PL extract and incubated at 37°C for 24 hours. Next, the inhibitory zone formed on the Petri plate was quantified[88]. Against all bacterial strains tested, the PL extract was as effective as ciprofloxacin in terms of antibacterial activity. Ciprofloxacin had a larger inhibition zone (27.38 ± 0.31), whereas methanolic PL extract inhibited Gram-positive *S. aureus* (25.15mm) and *B. subtilis* (25.00 mm) more than Gram-negative bacteria ($p < 0.05$). *E. coli* and *K. pneumoniae* showed zones of inhibition measuring 23.18 mm and 22.05 mm, respectively. These findings are consistent with those reported[89], whereas a 20 mm zone of inhibition for *E. coli* and a 24 mm zone of inhibition for *S. aureus* were demonstrated by a 100 µL concentration of methanolic PLs extract[90].

3.9 Star fruits (*Averrhoa carambola*)

Star fruit, *A. carambola* (Oxalidaceae), is found in various countries like India, America, Southern China, and others. The *A. carambola* tree has finely fissured light brown bark, leaves that are 15 to 20 cm long, and a typical height of 3 to 5 m with a maximum height of 10 m. It produces big, indehiscent, yellowish-green berries that are 5 to 8 cm long and have a distinctive five-pointed star form. Each fruit cell has five arillate seeds[91,92]. In traditional medicine, the fruit was used to cure conditions like malaria, food poisoning, sore throats, and coughs, etc[93]. This article covers the botanical and agricultural characteristics of *A. carambola*, as well as its traditional uses and pharmacological properties[94]. Mia *et al.*, extracted p-anisaldehyde and β-sitosterol from the bark of *A. carambola*. At 400 µg/disc, the petroleum ether, carbon tetrachloride, and chloroform fractions of *A. carambola's* methanol extract showed modest antibacterial activity. The soluble fractions of petroleum ether, carbon tetrachloride, and chloroform generated zones of inhibition that range from 8-12 mm to 8-15 mm on average. Petroleum ether extract moderately decreased the rate of *E. coli* growth and *S. dysenteriae*, with a 12 mm inhibition zone for each. Significantly, the chloroform-soluble fraction prevented *E. coli* growth, with a 15 mm zone of inhibition. All extractives showed mild inhibitory action against the fungus. The cytotoxicity study yielded LC_{50} values of 0.32, 0.70, 0.06, and 3.14 µg/mL for conventional vincristine tetrachloride. Sulfate and antitumor activity of petroleum ether, carbon chloroform soluble fractions, respectively[95].

3.10 *Bael* (*Aegle marmelos*)

Aegle marmelos, commonly known as *Bael*, is a spiny tree belonging to the family *Rutaceae*. It is an indigenous tree found in Iran, India, Myanmar, Pakistan, Bangladesh and most of Southeast Asian countries[96]. The leaves, roots, bark, seeds and fruits are edible and have medicinal values. The *Bael* tree is a medium-sized deciduous tree with unique branches, aromatic trifoliate leaves, and sweet-scented, greenish-white blooms[97]. Studies have shown that *Bael* fruit has 2.9% fiber, 0.3% fat, 1.8% protein, 61.5% moisture, 1.7% minerals, and 31.8% carbohydrates per 100 grams of edible portion. It has an estimated calorific value of 137[98]. Numerous researchers have previously assessed the medicinal value of various *A. marmelos* plant parts and discovered that the plant has anti-inflammatory, antipyretic, anti-diarrheal, anti-diabetic, analgesic, antimicrobial, radioprotective, anticancer, and antiviral qualities in addition to its natural ability to heal several different types of diseases[99,100]. Analysing the medicinal applications of the *Bael* plant, which include treating swollen joints, high blood pressure, asthma, fractures, dyspepsia, wound healing, stomach pain, vomiting, brain typhoid problems during pregnancy, diabetes, anaemia, jaundice, diarrhoea, and mental health, reveals its blessed nature[101]. The *Bael* fruit pulp includes active compounds such as alkaloids, coumarins, terpenoids, flavonoids, carotenoids, phenolics, and antioxidants, which can help prevent

chronic diseases[102]. Antimicrobial action reduces germ proliferation due to phytochemical activity. Antimicrobial compounds isolated from plant parts have a lot of medicinal potential since they may have fewer side effects than synthetic antimicrobial[103]. *Bael* fruit leaf and fruit extracts have been studied for their antibacterial effects against both Gram-positive and Gram-negative bacteria. The highest zone of inhibition against *R. plantikola* was discovered when employing fruit extract (9 mm). The plant extract has minimal effectiveness against *C. albican* and an 18 mm zone of inhibition against *P. chrysogenum*[104].

3.11 *Jamun* (*Syzygium cumini* L. Skeels)

The black plum, also known as *Jamun* (*Syzygium cumini* L. Skeels), is a significant minor fruit of Indian provenance that grows extensively in a variety of agroclimatic situations. According to Indian traditional medicine, the fruits have several medicinal properties. In addition to being used as a general liver tonic, the fruits are used to treat diarrhea[105]. This fruit is also related to a number of additional therapeutic benefits, including strengthening teeth and gums, enhancing blood, treating bilious diarrhoea, treating sore throats, treating ringworm, and more[106]. The plants have reportedly been found to have anti-oxidant and anti-free radical properties[107,108]. Antibacterial, antifungal, antidiabetic, anti-inflammatory, and antioxidant and free radical scavenging properties[71,72,109,110]. However, a study by Bagchi *et al.,* revealed that *S. cuminii* possesses strong antibacterial and antifungal properties against both Gram-positive and Gram-negative microorganisms[111]. Bhuiyan *et al.*, evaluated effective antibacterial activity against five Gram-positive and nine Gram-negative bacteria strains[112]. According to Ahmad and Beg, Gram-positive bacteria are more vulnerable than those that are Gram-negative due to changes in cell wall structure[113]. Shaikh *et al.,* found that extracts of ethanol from *Jamun* inhibit both Gram-positive and Gram-negative organisms[114].

3.12 Mango (*Mangifera indica* L.)

Mango is a major tropical fruit, and India is the world's top mango producer. Mango fruits belong to the *Anacardiaceae* family. Mango fruits are harvested at maturity, well before they are fully ripe. Mangos, a short-season fruit, are exceedingly perishable and cannot be kept cold. Mango pulp is thus kept by the majority of Pakistan's fruit processing sector, allowing mango products to be made year-round. Mango pulp is commonly used as a filler for pastries, jams, sauces, fruit juices and beverages, rather than being consumed raw[115]. Mangoes are popular because of their edible fruits, which possess flavouring and fragrance features. Traditional medicine has used several parts of the plant as a vermifuge, tonic, laxative, diuretic, astringent, diaphoretic, stomachic, dentifrice, and antiseptic. They are also used to treat or control rheumatism, toothache, haemorrhage, piles, diarrhoea, dysentery, anaemia, asthma, bronchitis, cough, hypertension, sleeplessness, etc[116,117]. It has been noted that certain plant morphological elements have antibacterial qualities against particular microbes. For example, against bacteria such as *C. albicans, P. aeruginosa, E. coli, B. subtilis,* and *S. aureus,* a number of solvent extracts of the plant's seeds have shown antibacterial activity[118,119]. Furthermore, preparations from the plant's leaves have shown antibacterial activity against *S. typhi*[120], *P. vulgaris, P. fluorescens, S. flexneri, K. pneumoniae, S. typhi*[121], *S. aureus, E. coli,* and *P. aeruginosa*[122]. Antimicrobial assay using the cup plate method, 0.1 ml of each microorganism's overnight broth culture—which contained roughly 106 cfu/mL—was added to the Nutrient Agar plate's surface and evenly spread using a sterile cotton swab. Using a cork borer number 3, five wells of roughly 6 mm in diameter and 5 mm in depth were created on the agar and labelled B, S, L, G, and MW to stand for bark, seed, leaves, gentamicin, and water-methanol, respectively[123,124].

4. Future Perspective

The global rise of antimicrobial resistance (AMR) underscores the urgent need for alternative strategies that go beyond conventional antibiotics. Medicinal plants and edible fruits, which contain a variety of phytochemicals such as flavonoids, tannins, alkaloids, terpenoids, and phenolic acid, offer a promising path for the development of novel antimicrobial agents. Future research should concentrate on systematically researching and standardizing plant drived bioactive chemicals, with a special emphasis on fruits indigenous to regions such as Assam, where traditional ethanomedical knowledge underlines their therapeutic

Table 2. Summary of findings of antimicrobial activity study of different edible fruits

Common Name	Botanical Name	Phytoconstituent	Microorganisms	Zone Inhibition	References
Pomegranate (peel extract)	*Punica granatum*	Punicalagin, ellagic acid, hydrolysable tannins	*S. aureus*, *E. coli*, *L. monocytogenes*, *S. enteritidis*	20 mm (*S. aureus*), 11 mm (*E. coli*)	43
Pomegranate (peel extract)	*Punica granatum*	Punicalagin, ellagic acid, tannins	*E. coli, P. aeruginosa*	22–25.5 mm (disc diffusion; extract and inoculum dependent)	125
Sweet orange (peel oil/extract)	*Citrus sinensis*	Limonene, myrcene, other monoterpenes; phenolics and flavonoids	*E. coli, S. agalactiae, S. aureus*, others	Study reported ZOI ≈ 14 mm *vs. E. coli* (disk diffusion)	126
Banana and Watermelon peels	*Musa paradisiaca* (banana), *Citrullus lanatus* (watermelon)	Phenolics, other bioactives	*B. cereus*, *E. coli*, *S. aureus*, *Salmonella,* etc.	~8–23 mm (varied by extract and organism)	127
Lime juice (100% extract)	*Citrus aurantifolia*	Flavonoids, saponins	*E. coli*	~19.9 mm (at 100%)	128
Citrus juice concentrates (grape, tangerine, etc.)	*Citrus* spp.	Flavonoids, phenolic acids, and ascorbic acid	*S. aureus*, *E. faecalis*, *Salmonella* spp.	*S. aureus*: 10–20 mm; *E. faecalis*: 8–26 mm; *Salmonella* spp.: 6–10 mm	126
Apple (peel)	*Malus domestica*	Phenolics (phloridzin, catechins), organic acids	*P. aeruginosa*, *E. coli*, *S. aureus*, *B. subtilis*	15–17 mm	129
Star fruit (*Kordoi*)	*Averrhoa carambola*	flavonoids, saponin, glycoside,	*S. typhi, S. aureus, E. coli, P. aeruginosa*		130
Amla	*(Phyllanthus emblica)*	Tannins, flavonoids (quercetin), phenols, ascorbic acid, emblicanin	*S. aureus*, *MRSA*, *E. coli*, *K. pneumoniae*	Up to ~15 mm	130
Lemon (peel extract)	*Citrus limon*	Flavonoids (hesperidin), limonene, limonoids	*S. aureus, E. colis*	*S. aureus and E. coli* at 100% concentration with a mean of 18.22 mm and 16.22 mm	131
Banana (peel extract)	*Musa paradisiaca*	Flavonoids, phenolics, saponins, glycosides, alkaloids, terpenoids	*P. gingivalis*, *A. actinomycetemcomitans*	~12–15 mm (alcoholic extract)	129
Guava (fruit peel extract)	*P. guajava*	flavonoid and alkaloids (*P. guajava, L. Myrtaceae*)	*S. aureus, E. coli*	11.0 mm against *S. aureus* and 8.4 mm against *E. coli*	132,133
Guava (leaf/fruit)	*Psidium guajava*	Flavonoids (quercetin), tannins, saponins, alkaloids	*S. aureus, Bacillus* spp., *E. coli,* clinical XDR, *A. baumannii*	methanol/ethanol leaf extracts ~6–12 mm; other studies report up to ~18 mm *vs*. some strains	134,135
Amla (leaf and fruit extract)	*Phyllanthus emblica*	Polyphenols, tannins, flavonoids	*S. moniliformis*	23–24 mm (fruit extract)	136

Table 2. Continued...

Common Name	Botanical Name	Phytoconstituent	Microorganisms	Zone Inhibition	References
Strawberry	*Fragaria ananassa*	Flavonoids, tannins, anthocyanins	*S. sanguinis, L. monocytogenes, E. coli*	16.3 mm (*S. sanguinis* – ethyl acetate extract); 20–24.5 mm (*L. monocytogenes*	[137]
Amla	*Phyllanthus emblica*	flavonoids, tannins, saponins, glycosides	*S. aureus, MRSA(Methicillin-resistant Staphylococcus aureus), E. coli, K. pneumoniae, Proteus* spp.	15–17.6 mm (leaf methanolic extract, 100 mg/mL)	[138]
Amla	*Phyllanthus emblica*	High in vitamin C, gallic acid, tannins, and flavonoids	*S. aureus, E. coli,*	15 mm on agar observed for *S. aureus*	[130]
Papaya	*Carica papaya*	catechins, flavonoids, tocopherol, alkaloids, anthocyanins, tannins, saponins, and phenols	*E. coli, Pseudomonas, S. aureus*	22.05–25.15 mm	[139]
Tamarind (fruit pulp)	*Tamarindus indica*	alkaloids, glycosides, terpenoids, saponins, steroids, flavonoids, tannins	*Staphylococcus aureus (S. aureus)* and *Klebsiella pneumoniae (K. pneumoniae)*	Ethanol extract (100–300 mg/mL): 13.33±0.88 → 16.00±1.00 mm (*S. aureus*); 13.67±0.33 → 17.67±0.33 mm (*K. pneumoniae*)	[140]
Pomegranate, Persimmon, Quince (leaf/peel extracts)	*Punica granatum, Diospyros kaki, Cydonia oblonga*	pomegranate juice and peel are rich in gallic acid and ellagic acid, the quince extract compound was caffeic acid	Gram-negative bacteria, including *E. coli, Pseudomonas, Salmonella, and K. pneumoniae*	peel extract was able to inhibit all *Staphylococcus,* with MICs mainly of 10 mg/mL	[141]
Pomegranate juice	*Punica granatum*	tannins, flavonoids, alkaloids, organic acids, triterpenes, and steroids	*E. coli, L. innocua*	(PJ at 10–50% showed inhibition/ decline *vs. L. innocua* and *E. coli*).	[142]
Lemon juice	*Citrus limon*	Citric acid, ascorbic acid, and flavonoids	*S. mutans, E. coli, S. aureus*	18.67 ± 0.33mm	[143]
Amla	*Phyllanthus emblica / Emblica officinalis*	Very high vitamin C, gallic acid, tannins, flavonoids, and alkaloids	*B. subtilis, S. aureus, S. dysenteriae, P. aeruginosa*	Shown to inhibit a range of Gram-positive and Gram-negative pathogens in juice	[144]
Papaya	*Carica papaya*	flavonoids, alkaloids	*E. coli, Pseudomonas, S. aureus,* clinical Gram-negatives	zone of inhibition against *P. aeruginosa* (17 mm), *E. coli* (12 mm), and *K. pneumoniae* (11 mm)	[145]
apple	*Malus domestica*	Phloridzin, phloretin, quercetin derivatives, catechins, chlorogenic acid	*S. aureus*, *S. mutans*, some Gram-negatives	12–19 mm	[146]

Table 2. Continued...

Common Name	Botanical Name	Phytoconstituent	Microorganisms	Zone Inhibition	References
lemon	*citrus lemon*	flavonoids,	*P. aeruginosa, K. pneumoniae, Enterococcus* spp.	Methanolic extract showed the maximum antibacterial activity against *P. aeruginosa* (16.67 ± 1.53), while the highest antimicrobial activity against *P. aeruginosa* (ATCC: 27853) was demonstrated by lemon ethanolic extract (18.34 ± 0.58).	[145]
Pineapple (fruit/ peel; bromelain)	*Ananas comosus*	Bromelain (proteolytic enzyme), phenolics, flavonoids	*E. faecalis*, *S. aureus*, *E. coli*, *Candida* (varies)	**10–18 mm** reported	[147]
Guava juice	*Psidium guajava*	Flavonoids (quercetin derivatives), tannins, phenolics	*E. coli*	-	[148]
Strawberry(juice)	*Fragaria ananassa*	flavonoids, polyphenols, and tannins	*S. aureus* and *S. mutans*	-	[149]
Apple	*Pyrus malus* L.	alkaloids and quinones	*S. aureus* and *S. mutans*	-	[149]

potential. Advanced phytochemical profiling, along with high-throughput screening approaches, has the potential to find synergistic interactions between plant metabolites that improve antimicrobial activity and overcome microbial resistance. Standardised extraction procedures, dosage optimisation, and toxicity assessment will be crucial for the clinical application of fruit-based antimicrobials. Integrating traditional knowledge with current biotechnology, such as nanocarrier-based delivery methods, has the potential to improve phytochemical bioavailability, stability, and targeted delivery. Furthermore, given that many fruit extracts work as both antioxidants and antimicrobials, future research could look at their use in treating oxidative stress-related diseases like sepsis and chronic inflammatory disorders. Collaborative research between ethnobotanists, microbiologists, pharmacologists, and public health experts will be essential to bridge the gap between traditional medicine and evidence-based modern therapeutics. Given the increasing prevalence of multidrug-resistant pathogens, the valorisation of locally available fruits like pomegranate, citrus, banana, guava, papaya, and star fruit could contribute significantly to sustainable and affordable healthcare interventions. Ultimately, integrating plant-based antimicrobials into mainstream healthcare could not only combat AMR but also promote global health equity by providing cost-effective alternatives, particularly in resource-limited settings.

5. Conclusion

The effectiveness of current antimicrobial medications is in jeopardy, and contemporary medicine is at risk due to antimicrobial resistance (AMR), an unprecedented global health concern. The concerning rise of infections with resistance calls for the investigation of sustainable, affordable, and safe substitutes. The review emphasises the possible antibacterial properties of edible fruits and their phytochemicals. Various phytochemicals having antimicrobial activity, such as flavonoids, tannins, alkaloids, terpenoids, phenolic acids, and

organic acids is found to be present in fruits like pomegranates, citrus, bananas, guavas, papayas, amla, pineapple, apple, star fruit, *bael*, *jamun*, and mango. Numerous research findings show that fruit extracts and their secondary metabolites can effectively replace traditional antibiotics by inhibiting a wide range of harmful bacteria and fungi. Furthermore, these fruits' dual antioxidant and antibacterial properties highlight their importance in the prevention of chronic, oxidative stress-related ailments as well as in the treatment of infectious diseases. Significant gaps still exist, though, in the areas of clinical translation, dosage optimisation, safety assessment, and extraction process standardisation, notwithstanding their potential. Additional multidisciplinary investigation is required to examine the molecular mechanisms of action, synergistic interactions with already available antibiotics, and novel delivery methods such as nanoformulations to improve efficacy and bioavailability. In conclusion, edible fruits provide a widely available, environmentally friendly, and cost-effective source of natural antimicrobials that could supplement or replace synthetic medications in the fight against AMR. Integrating traditional knowledge with current pharmacological validation may pave the path for the development of innovative therapeutic medicines, which will help battle antimicrobial resistance while also supporting sustainable global healthcare. The findings emphasise the translational potential of these fruits as sustainable sources of natural antimicrobial agents that could be developed into functional foods, nutraceuticals, phytopharmaceuticals, and natural preservatives. In regions like Northeast India, where traditional knowledge and biodiversity are closely linked, integrating indigenous medicinal practices with modern scientific research may offer innovative and affordable solutions to combat antimicrobial resistance. Future research should focus on systematic phytochemical isolation, identification of active compounds, and detailed mechanistic studies to better understand their antimicrobial pathways. Additionally, standardised extraction methods, toxicity evaluation, and *in vivo* studies are required to validate safety and therapeutic efficacy. Clinical investigations and formulation development will further facilitate the translation of these natural products into practical healthcare applications. Strengthening interdisciplinary collaboration between ethnobotany, pharmacology, microbiology, and biotechnology will be crucial for harnessing the full medicinal potential of Assam's rich fruit biodiversity.

6. References

1. Mendelson M, Matsoso MP. The World Health Organization global action plan for antimicrobial resistance. S. Afr. Med. J. 2015; 105(5):325. https://doi.org/10.7196/SAMJ.9644 PMid: 2624264
2. Salam MA, Al-Amin MY, Salam MT, Pawar JS, Akhter N, Rabaan AA, Alqumber MA. Antimicrobial resistance: a growing serious threat for global public health. Healthcare. 2023; 11(13):1946. https://doi.org/10.3390/healthcare11131946 PMid: 37444780 PMCid: PMC10340576.
3. Price R. O'Neill report on antimicrobial resistance: funding for antimicrobial specialists should be improved. Eur J Hosp Pharm. 2016;23(4):245-247. doi: 10.1136/ejhpharm-2016-001013.
4. Prestinaci F, Pezzotti P, Pantosti A. Antimicrobial resistance: a global multifaceted phenomenon. Pathog Glob Health. 2015; 109(7):309–318. https://doi.org/10.1179/2047773215Y.0000000030 PMid: 26343252 PMCid: PMC4768623.
5. Asghar A, Khalid Z, Baqar Z, Hussain N, Saleem MZ, Sairash, Rizwan K. An insight into emerging trends to control the threats of antimicrobial resistance (AMR): an address to public health risks. Arch Microbiol. 2024; 206:72. https://doi.org/10.1007/s00203-023-03800-9 PMid: 38252323.
6. Centres for Disease Control and Prevention (CDC). How antimicrobial resistance happens. Atlanta (GA): CDC. Available from: https://www.cdc.gov/drugresistance/about/how-resistance-happens.html
7. Chhajer R, Ali N. Genetically modified organisms and visceral leishmaniasis. Front Immunol. 2014; 5:213. https://doi.org/10.3389/fimmu.2014.00213 PMid: 24860575 PMCid: PMC4030198.
8. Goedhart PW, van der Voet H, Baldacchino F, Arpaia S. A statistical simulation model for field testing of non-target organisms in environmental risk assessment of genetically modified plants. Ecol Evol. 2014; 4(8):1267–1283. https://doi.org/10.1002/ece3.1019 PMid: 24834325 PMCid: PMC4020688.
9. Liang C, van Dijk JP, Scholtens IM, *et al.* Detecting authorized and unauthorized genetically modified organisms containing vip3A by real-time PCR and next-generation sequencing. Anal Bioanal Chem. 2014; 406(11):2603–2611. https://doi.org/10.1007/s00216-014-7667-1 PMid: 24553665.
10. Safarzadeh S, Shirban F, Bagherniya M, Sathyapalan T, Sahebkar A. The effects of herbal medicines on cancer

therapy-induced oral mucositis: a literature review. Phytother Res. 2022; 36:243–265. https://doi.org/10.1002/ptr.7308 PMid: 34709682.
11. Alfuraydi AA, Aziz IM, Almajhdi FN. Assessment of antioxidant, anticancer, and antibacterial activities of the rhizome of ginger (*Zingiber officinale*). J King Saud Univ Sci. 2024; 36:103112. https://doi.org/10.1016/j.jksus.2024.103112
12. Yap PSX, Yiap BC, Ping HC, Lim SHE. Essential oils: a new horizon in combating bacterial antibiotic resistance. Open Microbiol J. 2014; 8:6–14. https://doi.org/10.2174/1874285801408010006 PMid: 24627729 PMCid: PMC3950955
13. Gang R, Matsabisa M, Okello D, Kang Y. Ethnomedicine and ethnopharmacology of medicinal plants used in the treatment of diabetes mellitus in Uganda. Appl Biol Chem. 2023; 66:39. https://doi.org/10.1186/s13765-023-00797-z
14. Mursu J, Virtanen JK, Tuomainen TP, Nurmi T, Voutilainen S. Intake of fruit, berries, and vegetables and risk of type 2 diabetes in Finnish men: the Kuopio Ischaemic Heart Disease Risk Factor Study. Am J Clin Nutr. 2014; 99(2):328–333. https://doi.org/10.3945/ajcn.113.069641 PMid: 24257723.
15. Mehdi S, Roohi TF, Srikanth MS, Krishna KL. Review on phytochemistry and pharmacological properties of *Momordica dioica* Roxb.: special emphasis on cardioprotective activity. In: Ancient and traditional foods, plants, herbs and spices used in cardiovascular health and disease. Boca Raton: CRC Press; 2023. pp. 313–329. https://doi.org/10.1201/9781003220329-22
16. Ramadan S, Ibrahim AAA. Fruits and vegetables as sources of functional phytochemicals for the prevention and management of obesity, diabetes, and cancer. In: Egbuna C, Hassan S, editors. Dietary phytochemicals: a source of novel bioactive compounds for the treatment of obesity, cancer and diabetes. Cham: Springer; 2021. pp. 147–167. https://doi.org/10.1007/978-3-030-72999-8_8
17. Buragohain J. Ethnomedicinal plants used by the ethnic communities of Tinsukia district of Assam, India. Recent Res Sci Technol. 2011; 3(9) 31-42.
18. Li H, Tsao R, Deng Z. Factors affecting the antioxidant potential and health benefits of plant foods. Can J Plant Sci. 2012; 92:1101–1111. https://doi.org/10.4141/cjps2011-239
19. Boyer J, Liu RH. Apple phytochemicals and their health benefits. Nutr J. 2004; 3:5. https://doi.org/10.1186/1475-2891-3-5 PMid: 15140261 PMCid: PMC442131
20. Habanova M, Saraiva JA, Holovicova M, Moreira SA, Fidalgo LG, Haban M, *et al*. Effect of berries/apple mixed juice consumption on the positive modulation of human lipid profile. J Funct Foods. 2019; 60:103417. https://doi.org/10.1016/j.jff.2019.103417
21. Starowicz M, Achrem-Achremowicz B, Piskuła MK, Zieliński H. Phenolic compounds from apples: reviewing their occurrence, absorption, bioavailability, processing, and antioxidant activity. Pol J Food Nutr Sci. 2020; 70(4):321–336. https://doi.org/10.31883/pjfns/127635
22. Sharma A, Chand T, Khardiya M, Yadav KC, Mangal R, Sharma KA. Antidiabetic and antihyperlipidemic activity of *Annona squamosa* fruit peel in streptozotocin-induced diabetic rats. Int J Toxicol Pharmacol Res. 2013; 5:15–21.
23. Majtan J, Sojka M, Palenikova H, Bucekova M, Majtan V. Vitamin C enhances the antibacterial activity of honey against planktonic and biofilm-embedded bacteria. Molecules. 2020; 25(4):992. https://doi.org/10.3390/molecules25040992 PMid: 32102181 PMCid: PMC7070301.
24. Lang SJ, Schmiech M, Hafner S, Paetz C, Steinborn C, Huber R, Simmet T. Antitumor activity of an *Artemisia* annua herbal preparation and identification of active ingredients. Phytomedicine. 2019; 62:152962. https://doi.org/10.1016/j.phymed.2019.152962 PMid: 31132755 PMCid: PMC6831675.
25. Albuquerque BR, Pereira C, Calhelha RC, Alves MJ, Abreu RMV, Barros L, *et al*. Jabuticaba residues (*Myrciaria jaboticaba* (Vell.) Berg) are rich sources of valuable compounds with bioactive properties. Food Chem. 2020; 309:125735. https://doi.org/10.1016/j.foodchem.2019.125735 PMid: 31704077.
26. Jismy B, Tikad A, Akssira M, Guillaumet G, Abarbri M. Efficient access to 3,5-disubstituted 7-(trifluoromethyl) pyrazolo[1,5-a]pyrimidines involving SNAr and Suzuki cross-coupling reactions. Molecules. 2020; 25(9):2062. https://doi.org/10.3390/molecules25092062 PMid: 32354132 PMCid: PMC7248703.
27. Silva A, Costa E, Freitas A, Almeida A. Revisiting the frequency and antimicrobial resistance patterns of bacteria implicated in community urinary tract infections. Antibiotics (Basel). 2022; 11(6):768. https://doi.org/10.3390/antibiotics11060768 PMid: 35740174 PMCid: PMC9220357.
28. Xi M, Hou Y, Wang R, Ji M, Cai Y, Ao J, *et al*. Potential application of luteolin as an active antibacterial composition in the development of hand sanitizer products. Molecules. 2022; 27(21):7342. https://doi.org/10.3390/molecules27217342 PMid: 36364167 PMCid: PMC9657794.
29. Morocho V, Hidalgo-Tapia M, Delgado-Loyola I, Cartuche L, Cumbicus N, Valarezo E. Chemical composition and biological activity of essential oil from leaves and fruits of limoncillo (*Siparuna muricata* (Ruiz and Pav.) A. DC.). Antibiotics (Basel). 2023; 12(1). https://doi.org/10.3390/antibiotics12010082 PMid: 36671283 PMCid: PMC9855075.
30. Narvaez-Bravo C, Taboada EN, Mutschall SK, Aslam M. Epidemiology of antimicrobial resistant *Campylobacter* spp. isolated from retail meats in Canada. Int J Food Microbiol. 2017; 253:43–47. https://doi.org/10.1016/j.ijfoodmicro.2017.04.019 PMid: 28477522.
31. Peri S, Ruzzolini J, Urciuoli S, Versienti G, Biagioni A, Andreucci E, *et al*. An oleocanthal-enriched EVO oil

extract induces ROS production in gastric cancer cells and potentiates the effect of chemotherapy. Antioxidants (Basel). 2022; 11(9):1762. https://doi.org/10.3390/antiox11091762 PMid: 36139836 PMCid: PMC9495378.
32. Nguyen TLA, Bhattacharya D. Antimicrobial activity of quercetin: an approach to its mechanistic principle. Molecules. 2022; 27(8):2494. https://doi.org/10.3390/molecules27082494 PMid: 35458691 PMCid: PMC9029217.
33. Poudel DK, Rokaya A, Ojha PK, Timsina S, Satyal R, Dosoky NS, *et al*. Chemical profiling of essential oils from different tissues of *Cinnamomum camphora* L. and their antimicrobial activities. Molecules. 2021; 26(17):5132. https://doi.org/10.3390/molecules26175132 PMid: 34500567 PMCid: PMC8434199.
34. Tellers J, Vachon J, Soliman M, Dalcanale E, Pinalli R. Velcrand functionalized polyethylene. Molecules. 2019; 24(5):902. https://doi.org/10.3390/molecules24050902 PMid: 30841484 PMCid: PMC6429461.
35. Teixeira AM, Sousa C. A review on the application of vibrational spectroscopy to the chemistry of nuts. Food Chem. 2019; 277:713–724. https://doi.org/10.1016/j.foodchem.2018.11.030 PMid: 30502208.
36. Inui T, Okumura K, Matsui H, Hosoya T, Kumazawa S. Effect of harvest time on some *in vitro* functional properties of hop polyphenols. *Food Chem*. 2017; 225:69–76. https://doi.org/10.1016/j.foodchem.2017.01.002 PMid: 28193435.
37. Cozzolino A, Vergalito F, Tremonte P, Iorizzo M, Lombardi SJ, Sorrentino E, *et al*. Preliminary evaluation of the safety and probiotic potential of *Akkermansia muciniphila* DSM 22959 in comparison with *Lactobacillus rhamnosus* GG. *Microorganisms*. 2020; 8(2):189. https://doi.org/10.3390/microorganisms8020189 PMid: 32019075 PMCid: PMC7074805.
38. Food and Agriculture Organization of the United Nations (FAO). Statistical Database. Rome: FAO; 2012. Available from: http://www.fao.org
39. Tanaka T, Nonaka G, Nishioka I. Tannin and related compounds. C. Reaction of dehydrohexahydroxydiphenic acid esters with bases, and its structural application to the determination of pomegranate tannins, granatins A and B. *Chem Pharm Bull*. 1990; 38:2424–2428. https://doi.org/10.1248/cpb.38.2424
40. Satomi H, Umemura K, Ueno A, Hatano T, Okuda T, Noro T. Carbonic anhydrase inhibitors from the pericarps of *Punica granatum* L. *Biol Pharm Bull*. 1993; 16:787–790. https://doi.org/10.1248/bpb.16.787 PMid: 8220326.
41. Amakura Y, Okada M, Tsuji S, Tonogai Y. High-performance liquid chromatographic determination with photodiode array detection of ellagic acid in fresh and processed fruits. *J Chromatogr A*. 2000; 896:87–93. https://doi.org/10.1016/S0021-9673(00)00414-3 PMid: 11093643.
42. Lansky EP, Newman RA. *Punica granatum* (pomegranate) and its potential for prevention and treatment of inflammation and cancer. *J Ethnopharmacol*. 2007; 109:177–206. https://doi.org/10.1016/j.jep.2006.09.006 PMid: 17157465.
43. Khan AJ, Hanee S. Antibacterial properties of *Punica granatum* peels. *Int J Appl Biol Pharm Technol*. 2011; 2:23–27.
44. Al-Zoreky NS. Antimicrobial activity of pomegranate (*Punica granatum* L.) fruit peels. *Int J Food Microbiol*. 2009; 134:244–248. https://doi.org/10.1016/j.ijfoodmicro.2009.07.002 PMid: 19632734.
45. Karimi E, Oskoueian E, Hendra R, Oskoueian A, Jaafar HZE. Phenolic compounds characterization and biological activities of *Citrus aurantium* bloom. *Molecules*. 2012; 17:1203–1218. https://doi.org/10.3390/molecules17021203 PMid: 23442980 PMCid: PMC6268598.
46. Boudries H, Madani K, Touati N, Souagui S, Medouni S, Chibane M. Pulp antioxidant activities, mineral contents and juice nutritional properties of Algerian clementine cultivars and mandarin. Afr J Biotechnol. 2012; 11:4258–4267. https://doi.org/10.5897/AJB11.2943
47. Aruoma OI, Landes B, Ramful-Baboolall D, Bourdond E, Neergheen-Bhujune V, Wagner K, *et al*. Functional benefits of citrus fruits in the management of diabetes. Prev Med. 2012; 54:S12–S16. https://doi.org/10.1016/j.ypmed.2012.02.012 PMid: 22373887.
48. Holetz FB, Pessini GL, Sanches NR, Cortez DA, Nakamura CV, Filho BPD. Screening of some plants used in Brazilian folk medicine for the treatment of infectious diseases. Mem Inst Oswaldo Cruz. 2002; 97:1027–1031. https://doi.org/10.1590/S0074-02762002000700017 PMid: 12471432.
49. Cheruiyot KR, Olila D, Kateregga J. *In vitro* antibacterial activity of selected medicinal plants from Longisa region of Bomet district, Kenya. Afr Health Sci. 2009; 9(Suppl 1):42–46. https://doi.org/10.4314/ahs.v9i2.47811
50. Shadma A, Sundaram S, Rai GK. Nutraceutical application and value addition of banana peel: a review. Int J Pharm Pharm Sci. 2014; 6:81–85.
51. Imam MZ, Akter S. *Musa paradisiaca* L. and *Musa sapientum* L.: a phytochemical and pharmacological review. J Appl Pharm Sci. 2011; 1:14–20.
52. Chabuck ZAG, Al-Charrakh AH, Hindi NKK, Hindi SKK. Antimicrobial effect of aqueous banana peel extract. Res Gate Pharm Sci. 2013; 1:73–75
53. Ighodaro OM. Evaluation study on Nigerian species of *Musa paradisiaca* peels: phytochemical screening, proximate analysis, mineral composition and antimicrobial activities. Researcher. 2012; 4:17–20.
54. Nascimento GG, Locatelli J, Freitas PC, Silva GL. Antibacterial activity of plant extracts and phytochemicals on antibiotic-resistant bacteria. Braz J Microbiol. 2000; 31:247–256. https://doi.org/10.1590/S1517-83822000000400003
55. Summanen JO. A chemical and ethnopharmacological study on *Phyllanthus emblica* L. (Euphorbiaceae). Zhongguo Zhong Yao Za Zhi. 1999; 22:515–518.

56. Chaphalkar R, Apte KG, Talekar Y, Ojha SK, Nandave M. Antioxidants of *Phyllanthus emblica* L. bark extract provide hepatoprotection against ethanol-induced hepatic damage: a comparison with silymarin. Oxid Med Cell Longev. 2017; 2017:3876040. https://doi.org/10.1155/2017/3876040 PMid: 28168009 PMCid: PMC5267079.
57. Sheoran S, Nidhi P, Kumar V, Singh G, Lal UR, Sourirajan A, *et al*. Altitudinal variation in gallic acid content in fruits of *Phyllanthus emblica* L. and its correlation with antioxidant and antimicrobial activity. Vegetos. 2019; 32:387–396. https://doi.org/10.1007/s42535-019-00048-x
58. Jahan N, Akter S. Assessment of the antimicrobial activity of the ethanolic extract of *Phyllanthus emblica* in combination with different classes of antibiotics against single and multi-drug resistant strains. J Pharmacogn Phytochem. 2015; 4(4):142–155.
59. Farhana F, Mosaddek ASM, Joynal BJ, Sharmin H, Mosaddek N. Antibacterial effect of *amlaki* (*Phyllanthus emblica*) extract against *Pseudomonas aeruginosa*. J Clin Images Med Case Rep. 2022; 3:6. https://doi.org/10.52768/2766-7820/1886.
60. Nair A, Balasaravanan T, Jadhav S, Mohan V, Kumar C. Harnessing the antibacterial activity of *Quercus infectoria* and *Phyllanthus emblica* against antibiotic-resistant *Salmonella typhi* and *Salmonella enteritidis* of poultry origin. Vet World. 2020; 13(7):1388–1396. https://doi.org/10.14202/vetworld.2020.1388-1396 PMid: 32848315 PMCid: PMC7429395.
61. Alberto MR, Canavosio MAR, De Nadra MCM. Antimicrobial effect of polyphenols from apple skins on human bacterial pathogens. Electron J Biotechnol. 2006; 9(3). https://doi.org/10.2225/vol9-issue3-fulltext-1
62. Jeong MR, Kim HY, Jeong-Dan Cha JD. Antimicrobial activity of methanol extract from *Ficus carica* leaves against oral bacteria. J Bacteriol Virol. 2009; 39:97–102. https://doi.org/10.4167/jbv.2009.39.2.97
63. Rubnov S, Kashman Y, Rabinowitz R, Schlesinger M, Mechoulam R. Suppressors of cancer cell proliferation from fig (*Ficus carica*) resin: isolation and structure elucidation. J Nat Prod. 2001; 64:993–996. https://doi.org/10.1021/np000592z PMid: 11473446.
64. Raybaudi-Massilia R, Osqueda-Melgar J, Martin-Belloso O. Antimicrobial activity of malic acid against *Listeria monocytogenes*, *Salmonella Enteritidis* and *Escherichia coli* O157:H7 in apple, pear and melon juices. Food Control. 2009; 20:105–112. https://doi.org/10.1016/j.foodcont.2008.02.009
65. Shoji T, Akazome Y, Kanda T, Ikeda M. The toxicology and safety of apple polyphenolic extract. Food Chem Toxicol. 2004; 42:959–967. https://doi.org/10.1016/j.fct.2004.02.008 PMid: 15110105.
66. Jelodarian S, Ebrahimabadi AH, Kashi FJ. Evaluation of antimicrobial activity of *Malus domestica* fruit extract from Kashan area. Avicenna J Phytomed. 2013; 3(1):1.
67. Sunilson JAJ, Kumari AVAG, Khan A, Anandarajagopal K. Effects of *Malus domestica* fruit extracts against clinically isolated dental pathogens. Eur J Dent Med. 2016; 8:12–16. https://doi.org/10.3923/ejdm.2016.12.16
68. Kabir S, Jahan SM, Hossain MM, Siddique R. Apple, guava and pineapple fruit extracts as antimicrobial agents against pathogenic bacteria. Am J Microbiol Res. 2017; 5:101–106. https://doi.org/10.12691/ajmr-5-5-2
69. Pavan R, Jain S, Shraddha, Kumar A. Properties and therapeutic application of bromelain: a review. Biotechnol Res Int. 2012; 2012:976203. https://doi.org/10.1155/2012/976203 PMid: 23304525 PMCid: PMC3529416.
70. Cheesbrough M. Microbiological tests. In: Cheesbrough M. District laboratory practice in tropical countries. Part II. Cambridge: Cambridge University Press; 2000. pp. 105–130.
71. Girish HV, Satish S. Antibacterial activity of important medicinal plants on human pathogenic bacteria: a comparative analysis. World Appl Sci J. 2008; 5:267–271.
72. Abdelrahim SI, Almagboul AZ, Omer MEA, Elegami A. Antimicrobial activity of *Psidium guajava* L. Fitoterapia. 2002; 73(7–8):713–715. https://doi.org/10.1016/S0367-326X(02)00243-5 PMid: 12490238.
73. Jaiarj P, Khoohaswan P, Wongkrajang Y, *et al*. Anticough and antimicrobial activities of *Psidium guajava* Linn. leaf extract. J Ethnopharmacol. 1999; 67(2):203–212. https://doi.org/10.1016/S0378-8741(99)00022-7 PMid: 10619385.
74. Lutterodt GD. Inhibition of Microlax-induced experimental diarrhoea with narcotic-like extracts of *Psidium guajava* leaf in rats. J Ethnopharmacol. 1992; 37(2):151–157. https://doi.org/10.1016/0378-8741(92)90073-Z PMid: 1434689.
75. Morton JF. Fruits of warm climates. In: Guava. Miami (FL): JF Morton; 1987. pp. 356–363.
76. Burkill HM. The useful plants of West tropical Africa. 2nd ed. 1997.
77. Nadkarni KM, Nadkarni AK. Indian materia medica with *Ayurvedic, Unani-Tibbi, Siddha*, Allopathic, Homoeopathic, Naturopathic and home remedies. Mumbai: Popular Prakashan; 1999.
78. Ncube NS, Afolayan AJ, Okoh AI. Assessment techniques of antimicrobial properties of natural compounds of plant origin: current methods and future trends. Afr J Biotechnol. 2008; 7(12):1797–1806. https://doi.org/10.5897/AJB07.613
79. Kim S, Fung DYC. Antibacterial effect of crude water-soluble arrowroot (*Puerariae radix*) tea extracts on food-borne pathogens in liquid medium. Lett Appl Microbiol. 2004; 39(4):319–325. https://doi.org/10.1111/j.1472-765X.2004.01582.x PMid: 15355532.
80. Jaiarj P, Khoohaswan P, Wongkrajang Y, *et al*. Anticough and antimicrobial activities of *Psidium guajava* Linn. leaf extract. J Ethnopharmacol. 1999; 67(2):203–212. https://doi.org/10.1016/S0378-8741(99)00022-7 PMid: 10619385.
81. Ibrahim SA, Yang G, Song D, Tse TSF. Antimicrobial effect of guava on *Escherichia coli* O157:H7 and

Salmonella typhimurium in liquid medium. Int J Food Prop. 2011; 14(1):102–109. https://doi.org/10.1080/10942910903147833
82. Hoque MDM, Bari ML, Inatsu Y, Juneja VK, Kawamoto S. Antibacterial activity of guava (*Psidium guajava* L.) and neem (*Azadirachta indica* A. Juss.) extracts against foodborne pathogens and spoilage bacteria. Foodborne Pathog Dis. 2007; 4(4):481–488. https://doi.org/10.1089/fpd.2007.0040 PMid: 18041957.
83. Clinical and Laboratory Standards Institute (CLSI). Performance standards for antimicrobial susceptibility testing. 19th Informational Supplement M100-S19. Wayne (PA): CLSI; 2009.
84. Rameshkumar KB, George V, Shiburaj S. Chemical constituents and antibacterial activity of the leaf oil of *Cinnamomum chemungianum* Mohan et Henry. J Essent Oil Res. 2007; 19(1):98–100. https://doi.org/10.1080/10412905.2007.9699238
85. Stefanello MEA, Cervi AC, Ito IY, Salvador MJ, Wisniewski A Jr, Simionatto EL. Chemical composition and antimicrobial activity of essential oils of *Eugenia chlorophylla* (Myrtaceae). J Essent Oil Res. 2008; 20(1):75–78. https://doi.org/10.1080/10412905.2008.9699427
86. Tajkarimi MM, Ibrahim SA, Cliver DO. Antimicrobial herb and spice compounds in food. Food Control. 2010; 21(9):1199–1218. https://doi.org/10.1016/j.foodcont.2010.02.003
87. Sharma A, Sharma R, Sharma M, Kumar M, Barbhai MD, Lorenzo JM, *et al*. *Carica papaya* L. leaves: deciphering its antioxidant bioactives, biological activities, innovative products, and safety aspects. Oxid Med Cell Longev. 2022; 2022:2451733. https://doi.org/10.1155/2022/2451733 PMid: 35720184 PMCid: PMC9203216.
88. Munir A, Youssef FS, Ishtiaq S, Kamran SH, Sirwi A, Ahmed SA, *et al*. *Malva parviflora* leaves mucilage: an eco-friendly and sustainable biopolymer with antioxidant properties. Polymers (Basel). 2021; 13:4251. https://doi.org/10.3390/polym13234251 PMid: 34883753 PMCid: PMC8659702.
89. Koul B, Pudhuvai B, Sharma C, Kumar A, Sharma V, Yadav D, *et al*. *Carica papaya* L.: a tropical fruit with benefits beyond the tropics. Diversity (Basel). 2022; 14:683. https://doi.org/10.3390/d14080683
90. Joshi NC, Negi T, Gururani PJ. *Carica papaya* leaves extract-based synthesis, characterization and antimicrobial activities of CeO_2 nanoparticles. Inorg Nano-Met Chem. 2023; 53:795–802. https://doi.org/10.1080/24701556.2023.2166068
91. Callixte C, Baptiste NJ, Arwati H. Phytochemical screening and antimicrobial activities of methanolic and aqueous leaf extracts of *Carica papaya* grown in Rwanda. Mol Cell Biomed Sci. 2020; 4:39–44. https://doi.org/10.21705/mcbs.v4i1.74
92. Khadam S, Afzal U, Gul H, Hira S, Satti M, Yaqub A, *et al*. Phytochemical screening and bioactivity assessment of leaves and fruits extract of *Carica papaya*. Pak J Pharm Sci. 2019; 32:1941–1948.
93. Morton JF. *Fruits of warm climates*. Miami: Flair Books; 1987. pp. 125–128.
94. Margen S. *The wellness encyclopedia of food and nutrition*. New York: Health Letters Associates; 1992. pp. 271–272.
95. Mia MM, Rahman MS, Begum K, Begum B, Rashid MA. Phytochemical and biological studies of *Averrhoa carambola*. *Dhaka Univ J Pharm Sci*. 2007; 6:125–128. https://doi.org/10.3329/dujps.v6i2.688
96. Gheewala P, Kalaria P, Chakraborty M, Kamath JV. Phytochemical and pharmacological profile of *Averrhoa carambola* Linn: an overview. *Int Res J Pharm*. 2012; 3:88–92.
97. Sung CK, Kimura T, But PPH, Guo JX. *International collation of traditional and folk medicine: Northeast Asia*. Singapore: World Scientific Publishing; 1998. pp. 75–76. https://doi.org/10.1142/3938
98. Singh P, Kumar A, Dubey NK, Gupta R. Essential oil of *Aegle marmelos* as a safe plant-based antimicrobial against postharvest microbial infestations and aflatoxin contamination of food commodities. *J Food Sci*. 2009; 74:302–307. https://doi.org/10.1111/j.1750-3841.2009.01223.x
99. Morton JF. *Fruits of warm climates*. 1987. Available from: http://www.hort.purdue.edu/newcrop/morton/index.html
100. Panda H. Medicinal plants cultivation and their uses. Asia Pacific Business Press Inc; 2000.
101. Mhatre J, Nagaral S, Kulkarni S. Formulation and evaluation of herbal formulations. Int J Pharm Pharm Sci. 2014;6(2):575–579.
102. Gohil T, Pathak N, Jivani N, Devmurari V, Patel J. Treatment of diabetes mellitus using herbal drugs: a review. Afr J Pharm Pharmacol. 2010;4(5):270–275.
103. Sharma NG, Dubey KS, Sharma P, Sati N. Phytochemical screening and antimicrobial activity of some medicinal plants. Int J Curr Pharm Rev Res. 2011;2(1):12–22.
104. Charoensiddhi S, Anprung P. Bioactive compounds and antioxidant activities of edible flowers from Thailand. Int. Food Res. J. 2008;15(3):287–295
105. Nandedkar PH, Sonawane PA, Chavan VK. *In vitro* antimicrobial activity of fruit extract of *Aegle marmelos* (*Bael*). Int J Pure Appl Biosci. 2017; 5(5):595–599. https://doi.org/10.18782/2320-7051.5875
106. Meena RK, Pareek A, Meena RR. Antimicrobial activity of *Aegle marmelos* (Rutaceae) plant extracts. Int J MediPharm Res. 2016; 2(1):1–5.
107. Kirtikar KR, Basu BD. Indian medicinal plants. Vol. 2. Dehradun: International Book Distributors; 2006. pp. 1497.
108. Warrier PK, Nambiar VPK, Ramankutty C. Indian medicinal plants. Vol. 5. Hyderabad: Orient Longman Ltd.; 1996. pp. 225–228.

109. Rekha N, Balaji R, Deecaraman M. Effect of aqueous extract of *Syzygium cumini* pulp on antioxidant defense system in streptozotocin-induced diabetic rats. Iran J Pharm Ther. 2008; 7(2):137–145.
110. Zhang LL, Lin YM. Antioxidant tannins from *Syzygium cumini* fruit. Afr J Biotechnol. 2009; 8(10):2301–2309. https://doi.org/10.4314/ajb.v8i10.60578
111. Bhuiyan MSA, Mia MY, Rashid MA. Antibacterial principles of the seeds of *Eugenia jambolana.* Bangladesh J Bot. 1996; 25(2):239–241.
112. Chandrasekaran M, Venkatesalu V. Antibacterial and antifungal activity of *Syzygium jambolanum* seeds. J Ethnopharmacol. 2004; 91:105–108. https://doi.org/10.1016/j.jep.2003.12.012 PMid: 15036477.
113. Grover JK, Vats V, Rathi SS. Anti-hyperglycemic effect of *Eugenia jambolana* and *Tinospora cordifolia* in experimental diabetes and their effects on key metabolic enzymes involved in carbohydrate metabolism. J Ethnopharmacol. 2000; 73(3):461–470. https://doi.org/10.1016/S0378-8741(00)00319-6 PMid: 11091000.
114. Muruganandan S, Srinivasan K, Chandra S, Tandan SK, Lal J, Raviprakash V. Anti-inflammatory activity of *Syzygium cumini* bark. Fitoterapia. 2001; 72:369–375. https://doi.org/10.1016/S0367-326X(00)00325-7 PMid: 11395258.
115. Bagchi GD, Singh A, Khanuja SPS, Bansal RP, Singh SC, Kumar S. Wide spectrum antibacterial and antifungal activities in the seeds of some coprophilous plants of North Indian plains. J Ethnopharmacol. 1999; 64:69–77. https://doi.org/10.1016/S0378-8741(98)00094-4 PMid: 10075124.
116. Bhuiyan MSA, Mia MY, Rashid MA. Antibacterial principles of the seeds of *Eugenia jambolana.* Bangladesh J Bot. 1996; 25(2):239–241.
117. Ahmad L, Beg AZ. Antibacterial and phytochemical studies on 45 Indian medicinal plants against multidrug-resistant human pathogens. J Ethnopharmacol. 2001; 74:113–133. https://doi.org/10.1016/S0378-8741(00)00335-4 PMid: 11167029.
118. Shaikh MR, Baqir-Maleka FA, Naqvi S. Partial purification and antibacterial studies of extracts from *Eugenia jambolana* Linn and *Vinca rosea* Linn. Pak J Sci Ind Res. 1994; 37(6–7):279–280.
119. Hussain S, Rehman S, Randhawa MA, Iqbal M. tudies on the chemical composition and antioxidant activity of *Psidium guajava* leaves. J Res Sci (BZ Univ Multan). 2003; 14:1–9.
120. Adesegun SA, Coker HAB. Plants used in traditional medicine against malaria. Niger J Pharm. 2001; 32:50–62.
121. Shah KA, Patel MB, Patel RJ, Parmar PK. *Mangifera indica* (mango). Pharmacogn Rev. 2010; 4(7):42–48. https://doi.org/10.4103/0973-7847.65325 PMid: 22228940 PMCid: PMC3249901.
122. El-Gied AAA, Joseph MRP, Mahmoud IM, Abdelkareem AM, Al-Hakami AM, Hamid ME. Antimicrobial activities of seed extracts of mango (*Mangifera indica* L.). Adv Microbiol. 2012; 2:571–576.
123. Mirghani MES, Yosuf F, Kabbashi NA, Vegeyan J, Yosuf ZBM. Antimicrobial activity of mango kernel extracts. J Appl Sci. 2009; 9(17):3013–3019. https://doi.org/10.3923/jas.2009.3013.3019
124. Hannan A, Asghar S, Naeem T, Ullah MI, Ahmed I, Aneela S, Hussain S. Antibacterial effect of mango (*Mangifera indica* Linn.) leaf extract against antibiotic-sensitive and multidrug-resistant *Salmonella typhi*. Pak J Pharm Sci. 2013; 26(4):715–719.
125. Kupnik K, Primožič M, Vasić K, Knez Ž, Leitgeb M. A comprehensive study of the antibacterial activity of bioactive juice and extracts from pomegranate (*Punica granatum* L.) peels and seeds. Plants (Basel). 2021; 10(8):1554. https://doi.org/10.3390/plants10081554 PMid: 34451599 PMCid: PMC8402121.
126. Anwar T, Qureshi H, Fatima A, Sattar K, Albasher G, Kamal A, *et al. Citrus sinensis* peel oil extraction and evaluation as an antibacterial and antifungal agent. Microorganisms. 2023; 11(7):1662. https://doi.org/10.3390/microorganisms11071662 PMid: 37512835 PMCid: PMC10383466.
127. Toupal S, Coşansu S. Antioxidant and antimicrobial properties of freeze-dried banana and watermelon peel powders. Food Humanity. 2023; 1:607–613. https://doi.org/10.1016/j.foohum.2023.07.008
128. Nerdy N, Tarigan P, Elysa E, Lestari P, Nurmalisa S. Antibacterial activity test of lime juice extract against *Escherichia coli*. J Penelit Farm Herbal. 2020; 3(1):135–139. https://doi.org/10.36656/jpfh.v3i1.387
129. Sheoran S. Antimicrobial activity of some medicinal important plants. 2020. https://doi.org/10.5281/zenodo.3727377
130. Tiwana G, Cock IE, Cheesman MJ. *Phyllanthus emblica:* phytochemistry, antimicrobial potential with antibiotic enhancement, and toxicity insights. Microorganisms. 2025; 13(3):611. https://doi.org/10.3390/microorganisms13030611 PMid: 40142504 PMCid: PMC11945131.
131. Azali NAM, Bakar LM. Antibacterial activity of lemon (*Citrus limon)* against *Staphylococcus aureus* and *Escherichia coli*. J Academia. 2024; 12(2):127–131.
132. Prakruthi KN, Ahalyadevi KH, Krishna KR, Sindhu KB. Evaluation of antimicrobial activity of the peel extract of *Psidium guajava* fruit on selected bacterial strains. Asian J Pharm Health Sci. 2023; 13(1).
133. Mostafa AA, Al-Askar AA, Almaary KS, Dawoud TM, Sholkamy EN, Bakri MM. Antimicrobial activity of some plant extracts against bacterial strains causing food poisoning diseases. Saudi J Biol Sci. 2018; 25(2):361–366. https://doi.org/10.1016/j.sjbs.2017.02.004 PMid: 29472791 PMCid: PMC5815983.

134. Biswas B, Rogers K, McLaughlin F, Daniels D, Yadav A. Antimicrobial activities of leaf extracts of guava (*Psidium guajava* L.) on two Gram-negative and Gram-positive bacteria. Int J Microbiol. 2013; 2013:746165. https://doi.org/10.1155/2013/746165 PMid: 24223039 PMCid: PMC3817707.
135. Ratnakaran P, Barve AA, Patnekar KA, Patil NC, Udmale NM, Ramchandran S, Durve-Gupta A. Phytochemical and antimicrobial activities of leaf extract of guava (*Psidium guajava* L.). Int J Appl Res. 2020; 6:106–110.
136. Singh KK, Saini M, Prakash D. Screening of natural plant extracts for antimicrobial activity against *Streptobacillus moniliformis*. bioRxiv. 2025. https://doi.org/10.1101/2025.04.05.647341
137. Sójka M, Hejduk A, Piekarska-Radzik L, Ścieszka S, Grzelak-Błaszczyk K, Klewicka E. Antilisterial activity of tannin-rich preparations isolated from raspberry (*Rubus idaeus* L.) and strawberry (*Fragaria ananassa* Duch.) fruit. Sci Rep. 2025; 15(1):10196. https://doi.org/10.1038/s41598-025-94731-6 PMid: 40133376 PMCid: PMC11937420.
138. Sharma V, Heer A, Kour N, Sharma S. Antibacterial efficacy of *amla* leaves. Int J Pharm Chem Anal. 2023; 10(3):205–208. https://doi.org/10.18231/j.ijpca.2023.034
139. Choudhary R, Kaushik R, Akhtar A, Manna S, Sharma J, Bains A. Nutritional, phytochemical, and antimicrobial properties of *Carica papaya* leaves: implications for health benefits and food applications. Foods. 2025; 14(2):154. https://doi.org/10.3390/foods14020154 PMid: 39856820 PMCid: PMC11764965.
140. Goanar G, Tafesse G, Fereja WM. *In vitro* antibacterial activity of fruit pulp extracts of *Tamarindus indica* against *Staphylococcus aureus* and *Klebsiella pneumoniae*. BMC Complement Med Ther. 2024; 24(1):127. https://doi.org/10.1186/s12906-024-04404-6 PMid: 38504277 PMCid: PMC10949702.
141. Silva V, Silva A, Ribeiro J, Aires A, Carvalho R, Amaral JS, *et al*. Screening of chemical composition, antimicrobial and antioxidant activities in pomegranate, quince, and persimmon leaf, peel, and seed: valorization of autumn fruit by-products for a One Health perspective. Antibiotics (Basel). 2023; 12(7):1086. https://doi.org/10.3390/antibiotics12071086 PMid: 37508182 PMCid: PMC10376090.
142. Ban Z, Fan L, Song J, Fillmore S, Guan J. Antibacterial effect of pomegranate juice on *Listeria innocua* and *Escherichia coli* in different media. Foods. 2023; 12(17):3247. https://doi.org/10.3390/foods12173247 PMid: 37685180 PMCid: PMC10487088.
143. Katuromunda M, Ssekatawa K, Niwagaba S. A preliminary evaluation of the antibacterial activity of lemon fruit juice, *Mondia whitei* ethanolic extract, and their combination against *Streptococcus mutans*. Infect Drug Resist. 2024; 17:4291–4299. https://doi.org/10.2147/IDR.S474810 PMid: 39381078 PMCid: PMC11460347.
144. Prananda AT, Dalimunthe A, Harahap U, Simanjuntak Y, Peronika E, Karosekali NE, *et al*. *Phyllanthus emblica:* a comprehensive review of its phytochemical composition and pharmacological properties. Front Pharmacol. 2023; 14:1288618. https://doi.org/10.3389/fphar.2023.1288618 PMid: 37954853 PMCid: PMC10637531.
145. Liya SJ, Siddique R. Determination of antimicrobial activity of some commercial fruits (apple, papaya, lemon and strawberry) against bacteria causing urinary tract infection. Eur J Microbiol Immunol. 2018; 8(3):95–99. https://doi.org/10.1556/1886.2018.00014 PMid: 30345090 PMCid: PMC6186015.
146. Patocka J, Bhardwaj K, Klimova B, Nepovimova E, Wu Q, Landi M, *et al*. *Malus domestica*: a review on nutritional features, chemical composition, traditional and medicinal value. Plants (Basel). 2020; 9(11):1408. https://doi.org/10.3390/plants9111408 PMid: 33105724 PMCid: PMC7690411.
147. Abbas S, Shanbhag T, Kothare A. Applications of bromelain from pineapple waste towards acne. Saudi J Biol Sci. 2021; 28(1):1001–1009. https://doi.org/10.1016/j.sjbs.2020.11.032 PMid: 33424393 PMCid: PMC7785454.
148. Mitra S, Hodiwala AVB, Kar H. Susceptibility and synergistic effects of guava plant extract and antimicrobial drugs on *Escherichia coli*. Cureus. 2024; 16(1):e52345 https://doi.org/10.7759/cureus.52345
149. Kusuma SAF, Yulianto AN. Anticaries inhibition test of strawberry (*Fragaria ananassa*) and apple (*Pyrus malus* L.) fruit juices on *Staphylococcus aureus* and *Streptococcus mutans* clinical isolates. Drug Invent Today. 2020; 14(7):1225-1229.

Author Contribution

Samina Sultana contributed to the literature review and manuscript drafting; Himangshu Deka assisted in conceptualisation, data collection, organisation of tables, and editing of the manuscript; Ananta Choudhury and Kousik Mahanti contributed to critical revision and final approval of the manuscript; Debgopal Ganguly, Miss. Debasmita Ghosh and Arindam Chakraborty assisted in conceptualisation, data collection, and organisation of tables. All authors have read and agreed to the published version of the manuscript.