

Pharmaceutical Perspectives of Spices and Condiments as Alternative Antimicrobial Remedy

Savita P. D'Souza, PhD¹, Suvarna V. Chavannavar, PhD¹,
Kanchanashri B., PhD¹, and Niveditha S. B., MSc¹

Abstract

Medicinal values of spices and condiments are being revived by biologists through *in vitro* and *in vivo* trials providing evidence for its antimicrobial activities. The essential oils and extracts of spices like black pepper, cloves, cinnamon, and nutmeg contain active compounds like piperine, eugenol, cinnamaldehyde, and lignans. Similarly, condiments like coriander, black cumin, turmeric, garlic, and ginger are recognized for constituents like linalool, thymoquinones, curcumin, allicin, and geranial respectively. These act as natural preventive components of several diseases and represent as antioxidants in body cells. Scientists have to investigate the biochemical nature, mode of action, and minimum concentration of administering active ingredients effectively. This review reports findings of recent research carried out across South Asia and Middle East countries where spices and condiments form chief flavoring components of traditional foods. It narrates the history, myths, and facts people believe in these regions. There may not be scientific explanation but has evidence of cure for centuries.

Keywords

spices, condiments, antimicrobial agents

Received July 16, 2016. Accepted for publication March 4, 2017.

Spices and condiments have been consumed since the prehistoric times to enhance the flavor and taste of the cooked food. Spices are aromatic, pungent, seasoning agents generally used in small quantities. Condiments are the herbs used for complementing foods and usually added in more quantities compared to spices. Unlike spices, they have no toxic effect on the human body. Herbs were recognized to be of medicinal value since ancient times and were recorded by the earliest writers as elixirs of life. Though scientific reasons of diseases were not known, spices and condiments were traditionally utilized as curative and preventive agents. Several metabolic diseases and developmental or age-related degenerative disorders are known to be associated with oxidative processes within the body. As stated by scientists these herbs can combat oxidative damages and prevent the occurrence of a number of diseases by developing innate immunity if consumed appropriately.^{1,2} Tea (green or black leaves) and flax seeds are known to contain potent phytochemicals, like carotenoids or catechins, that are demonstrated as good anticancer agents.³ The most exceptional condiment "turmeric," which is known to contain curcumin, is evidenced to have numerous therapeutic properties and has already been exploited for skin treatments and general health

purposes. Turmeric is a must use ingredient in all *Ayurveda* systems (unprocessed plant origin medicines) for its enormous benefits. Herbs have a traditional history of use in the countries like India, China and South-East Asia, with strong roles in cultural heritage. Understanding and demonstrating the application of herb and spice extracts by scientific means remains a challenge, particularly when compared to the standards applied for assessing other pharmaceutical agents. The pharmacological potential of the essential oils and concentrated extracts obtained from these elements have given in strong bioactive compounds, exhibiting potential antimicrobial activities. The existing challenge lies in defining their benefits, concentration for administration, and methods of application through scientific research. Overcooking and consuming inadequately or in excess quantities will have no positive effect on human health.

¹ University of Agricultural Sciences, Bangalore, Karnataka, India

Corresponding Author:

Savita P. D'Souza, New faculty housing, Indian Institute of Sciences, Bangalore 560012, Karnataka, India.
Email: savitapd02@yahoo.com



Table 1. List of Condiments of Potential Use as Antimicrobial Agents.

Condiments	Active Ingredients	Sensitive Organisms
Black cumin (seeds)	Nigellone, thymoquinones, hydrothymoquinones	<i>Escherichia coli</i> , <i>Staphylococcus aureus</i> , <i>Proteus mirabilis</i> , <i>Enterococcus faecalis</i> , <i>Streptococcus thermophiles</i> , and <i>Pseudomonas aeruginosa</i>
Coriander (seeds/leaves)	Linalool	<i>Escherichia coli</i> , <i>Salmonella typhi</i> , <i>Pseudomonas aeruginosa</i> , <i>Bacillus cereus</i> , and <i>Bacillus subtilis</i>
Cumin (seeds)	Cuminaldehyde	<i>Bacillus pumilus</i> , <i>Pseudomonas aeruginosa</i> , and <i>Staphylococcus aureus</i>
Garlic (bulb)	Allicin, allyl-alcohols	<i>Candida albicans</i> , <i>Escherichia coli</i> , <i>Entamoeba histolytica</i> , <i>Giardia lamblia</i> , and viruses
Ginger (rhizome)	Zingiberene, geranial	<i>Bacillus subtilis</i> , <i>Staphylococcus aureus</i> , <i>Listeria monocytogens</i> , and <i>Klebsiella pneumoniae</i>
Mustard (seeds)	Sinapic acid and sinapoyl conjugates	<i>Staphylococcus aureus</i> and <i>Listeria monocytogens</i>
Turmeric (rhizome and leaves)	Curcumin (diferuloylmethane)	<i>Bacillus macerans</i> , <i>Bacillus licheniformis</i> , <i>Escherichia coli</i> , and <i>Helicobacter pylori</i>

Table 2. List of Spices of Potential Use as Antimicrobial Agents.

Spices	Active Ingredients	Sensitive Organisms
Black pepper (seeds)	Piper amides (piperine)	<i>Staphylococcus aureus</i> , <i>Escherichia coli</i> , <i>Salmonella</i> sp, <i>Bacillus subtilis</i> , and <i>Fusarium oxysporum</i>
Cinnamon (bark)	Cinnamaldehyde, cinnamic acid	<i>Staphylococcus aureus</i> , <i>Enterococcus faecalis</i> , <i>Bacillus cereus</i> , <i>Escherichia coli</i> , <i>Klebsiella pneumoniae</i> , and <i>Rhizomucor</i> sp
Cloves (buds)	Eugenol	<i>Listeria monocytogens</i> , <i>Aeromonas hydrophila</i> , <i>Escherichia coli</i> O157: H7, <i>Candida albicans</i> , <i>Staphylococcus aureus</i> , and other oral pathogens
Nutmeg (seeds)	Argenteane (lignans)	<i>Bacillus subtilis</i> , <i>Staphylococcus aureus</i> , and <i>Shigella dysenteriae</i>
Star-anise (fruit)	Anethole	<i>Aeromonas hydrophila</i> , <i>Aeromonas salmonicida</i> , <i>Edwardsiella tarda</i> , <i>Enterobacter</i> (fish pathogen), <i>Aspergillus</i> , <i>Rhodotorula</i> and <i>Geotrichum</i>

Pharmaceuticals, however are consumed in purified and concentrated form and thus have an effective use in treating various diseases. Similar strategy needs to be practiced for spices and condiments.

The review emphasizes mainly on the antibacterial, antifungal, and anthelmintic nature of the active ingredients and essential oils of spices and condiments, which can be of excellent therapeutic use in the near future.

The essential oils or extracts of spices and condiments are prepared by either steam distillation or using organic solvents and alcohols.⁴ On extraction the solvent evaporates leaving the active component in the concentrated form. The composition of the extracts or essential oils obtained from spices and condiments depends on the method of extraction or protocol used. The antimicrobial activities of these extracts and oils are typically tested by agar well diffusion method. The test organism is inoculated into the molten medium (45°C to 50°C) and poured in a sterile plate immediately. After solidification of agar, a well is created in the center of the agar plate with sterile cork borer and the antimicrobial agent is added into this well. The sensitiveness of an organism is determined by measuring the minimum inhibition concentration (MIC). The MIC is defined as the lowest concentration of antimicrobial component for which no growth is visible as compared with the control (without antimicrobial component) after a defined period of incubation at a definite temperature, normally at 37°C (body temperature). MICs of the essential oils have been determined by some researchers according to the method demonstrated by Valgas et al.⁵ Distinct pathogens exhibit MICs at different

dilution of the extracts. Tables 1 and 2 display the main possible active ingredient obtained and the sensitive organisms. In most of the studies, the sensitivity of the pathogens to essential oils and extracts are found to be increasing with increasing concentration of the extracts. However, it is important that the concentrations used are below toxic level to a human body. Antimicrobial activity is understood as the ability of the tested agents to eliminate pathogens by inhibiting their growth. Following are descriptions of a few spices and condiments that have been studied by several researchers for their potential in controlling human and animal pathogens.

Black Cumin Seeds (*Nigella sativa*)

Popular among the ancient Egyptians, Arabs, and Persians, who first realized the significance of *Nigella* in treating many diseases such as common cold, infections of the trachea, bronchitis, urinary tract, and reproductive system. Some skin disorders such as warts and hair losses were also treated with *Nigella*. The Egyptians described it as a panacea of all diseases (cure for all problems) and used it for treating stomachaches, inflammations, intestinal worms, and migraines. In biblical times, these black seeds were often used to spice breads and cakes. It is believed to be a native of the Mediterranean region, which eventually spread over the years in the North African, East Asian, and South European continents. *Nigella* is now used in East Europe and North America in 6-grain breads. It has been reported to possess potent antioxidant, hepatoprotective, anticancer, antidiabetic, antimicrobial, antiparasitic,

analgesic, antiulcer, and antihistaminic properties.⁶ Research has been carried out in studying the phytochemical potency of the essential oils. Seeds are known to contain approximately 28% to 36% stable oil, proteins, alkaloids, saponins, and about 0.4 %to 2.5% of essential oils. The stable oil from its seed is mainly known to be composed of unsaturated fatty acids that include arachidonic, eicosadienoic, linoleic, and linolenic acids.⁷ It contains palmitic, stearic, and myristic acids. The crystalline active principle ingredient “nigellone” is the only constituent of carbonyl fraction in the volatile oil. The other constituents of the seed extracts are p-cymene carvacrol, *t*-anethole, 4-terpineol, and longifoline.⁶ The essential oil also consists of thymoquinone, dithymoquinone, thymol, and thymohydroquinone. The *in vitro* and *in vivo* anticancer effect of *Nigella sativa* L. seed extracts were studied by Mbarek et al.⁸ The administration of the essential oil into the induced tumor site inhibited the incidence of liver metastasis development and improved mouse survival. The antibacterial activity of extracts of *Nigella* in comparison with different antibiotics has been reported by several investigators. *Staphylococcus aureus*, a gram-positive bacterium, was highly susceptible to thymoquinone and thymohydroquinone extracts of black cumin seeds having MIC as low as 3 µg/mL.⁹ Gram-negative bacteria were less prone to both thymoquinone and thymohydroquinone with MIC ranging from 200 to 1600 µg/mL. The antimicrobial properties of *Nigella* oils have revealed an important growth inhibitory effect on pathogenic fungi and bacteria. Amina and Rachida detected an excellent activity of the essential oils against the gram-positive strains as compared to gram-negative strains.¹⁰ *Escherichia coli*, *Staphylococcus aureus*, and *Proteus mirabilis* were inhibited at 0.4% concentration, whereas *Enterococcus faecalis* SV, *Streptococcus thermophilus*, and *Pseudomonas aeruginosa* exhibited inhibition at 2% concentration. Gilani et al studied the antimicrobial activity of *Nigella* against *Klebsiella pneumoniae*, *Proteus vulgaris*, *Streptococcus pyogenes*, and *Pseudomonas aeruginosa*.¹¹ Methanol extracts and essential oils both showed strong positive correlation value, indicating increase in the diameter of the inhibition zone of pathogens with increasing concentration of the extract. Post-initiation administration of 1000 or 4000 ppm of *N sativa* volatile oil into the diet of male Wistar rats for 30 weeks significantly reduced malignant colon tumor size.¹² Ingredient isolated from seeds is usually evaluated as thymoquinone, but the beneficial effect of seeds is not limited to this compound. It appears that other compounds in the seeds probably act synergistically in the prevention of diseases.¹³ The active principle ingredient of black seed oil called “Nigellone” was injected for the first time in test animals and proved to have no toxic effect on the body organs. However, further study on animals is required to standardize concentration and determine its curing ability.

Turmeric (*Curcuma longa*)

The use of turmeric dates back nearly 4000 years, to the *Vedic* (ancient civilization) culture of India. It has been used

throughout the Indian history as food color agent, flavoring agent, and for preparation of traditional medicines and religious ceremonies. The rhizome portion (turmeric) of the plant is mainly used for consumption. Leaves are used to add flavors to medicinal drinks, decoctions, and as flavoring wrappers in the preparation of traditional sweets. The bright yellow color of turmeric comes mainly from fat-soluble, polyphenolic active pigmented flavonoid named “curcuminoids.” It is a mixture of curcumin (diferuloylmethane), monodex methoxy-curcumin, and bisdex methoxy-curcumin. Curcumin makes up approximately 90% of the Curcuminoids content in the rizome.¹⁴ It also contains various volatile oils, including tumerone, atlantone, and zingiberone. Other constituents include sugars, proteins, and resins. Oral consumption of turmeric powder is known to be healthy and its skin application as a natural antiseptic. It can be applied topically for the treatment of acne, wounds, boils, bruises, blisters, ulcers, eczema, insect bites, and skin diseases like herpes.¹⁴ It has been investigated that its contents can possibly prevent diabetes, cancers, and gastrointestinal and neurological diseases. It is found to counteract inflammation and irritation associated with skin allergies.¹⁴ Chinese and Indians (in *Ayurveda*) use turmeric, particularly for the treatment of jaundice, menstrual difficulties, colic conditions, and as an anti-inflammatory agent. Curcumin extracts have already been in use to reduce postoperative inflammation in some surgical treatments.¹⁵ Turmeric has potential in the development of modern medicines. Research on safety evaluation showed that administration of both turmeric and its purified content, curcumin, are well tolerated by the human body even at elevated doses.¹⁶ Curcumin, a dietary polyphenolic compound, was shown to have a potent antibacterial activity against a number of pathogenic bacteria like *Staphylococcus aureus* and *Streptococcus epidermidis*. The mode of action of curcumin on bacterial cells has been studied by many investigators. Recent evidence suggested that FtsZ (cell division protein) may be considered as an important antibacterial drug target, as curcumin was found to induce filamentation during cell division in *Bacillus subtilis*.¹⁷ The assembly and stability of FtsZ proto-filaments play critical roles in bacterial cytokinesis. Naz et al reported the antibacterial activity of curcuminoids against all tested organisms like *Bacillus subtilis*, *B macerans*, *B licheniformis*, and *Azotobacter* sp by agar well diffusion method with maximum inhibition zone (diameter 20.6 mm) against *Bacillus subtilis*.¹⁸ The hexane extract of turmeric separated at 60°C into 3 fractions using silica gel column chromatography were tested for its antibacterial activity by pour plate method against *Bacillus cereus*, *B coagulans*, *B subtilis*, *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa*.¹⁹ The major compounds present in these fractions along with other oxygenated compounds were found to be tumerone and curlone. It exhibited good antibacterial activity. A study conducted by Singh et al revealed significant antibacterial activity of essential oil fractions even at low concentration (20 µg/mL) on pathogenic drug-resistant clinical isolate of *Staphylococcus aureus* as compared to gentamycin (30 µg/mL).²⁰ The antimicrobial effect of curcumin in

Helicobacter pylori-infected mice and its efficacy in reducing the gastric damage due to infection was examined histologically.²¹ Curcumin showed good therapeutic potential against different strains of *Helicobacter pylori*. It was highly effective in eliminating this organism from infected mice. It also helped in the restoration of *Helicobacter pylori*-induced gastric damage. The MIC of curcumin ranged from 5 to 50 µg/mL, showing its effectiveness in inhibiting *Helicobacter pylori* growth under *in vitro* conditions irrespective of the genetic makeup of the strains. Stabilizing curcumin with microencapsulation to obtain microcapsule curcumin was found to be very efficient against some foodborne pathogens and spoilage organisms such as *Escherichia coli*, *Yersinia enterocolitica*, *Staphylococcus aureus*, *Bacillus subtilis*, *B cereus*, *Aspergillus niger*, *Penicillium notatum*, and *Saccharomyces cerevisiae*.²² It exhibited a broad spectrum of inhibitory effect with MIC ranging from 15.70 to 250 µg/mL. Its antibacterial activity was found to be more pronounced against gram-positive bacteria than gram-negative bacteria. Turmeric oil is also examined to be active against *Aspergillus flavus*, *A parasiticus*, *Fusarium moniliforme*, and *Penicillium digitatum*.²³ Turmeric leaves have religious significance. They are added in food preparation as flavoring agent. It was also found to possess antimicrobial property. Gas chromatography (GC) and mass spectrometry (MS) of turmeric leaf oil extracts yielded α -phellandrene, p-cymene, and terpinolene as chief components.²⁴ Complete inhibition of *Aspergillus flavus* growth and aflatoxin production was observed when tested with leaf oil extracts at optimal doses of 1.5% (v/v) of leaf oil in *in vitro* conditions. The analysis of essential oils of the rhizome through GC/MS technique by Ferreira et al gave 3 major components, α -turmerone (23.5%), β -turmerone (22.7%), and ar-turmerone (33.2%). When tested against *Aspergillus flavus* it exhibited good antifungal properties, inhibiting spore germination even at 0.5% (v/v) concentration of essential oils.²⁵ When observed under scanning electron microscope, the leaf extracts showed damage to the hyphal membranes and conidiophores. An outstanding investigation done by Hergen-hahn et al revealed antiviral activity of curcumin against HIV where inhibition of HIV-1 integrase needed for viral replication was observed. It also inhibited UV light-induced HIV gene expression. Therefore, curcumin and its analogues may have a perspective for novel drug development against HIV.²⁶

Garlic (*Allium sativum* L)

The use of garlic dates back over 5000 years. It is assumed to be native to Central Asia and has been a staple additive in foods of the Mediterranean region. It is often used in seasoning foods by the Asians, Africans, and Europeans. The superstitious belief of ancient times holds that garlic repelled vampires and protected women and children against evil eyes. Fresh garlic clove pedant wrapped in a white cloth and hung around the neck of children was believed to maintain body temperature and reduce fever and stomach infections. It was said to give strength and

courage to athletes and warriors of the ancient Greek. Scientific research attempts to prove the old beliefs of benefits of garlic by defining the mechanism of action and exploring health potential for disease prevention. Garlic is forbidden by some casts and community in India for it is rumored to give unpleasant mouth and sweat odor. It has been investigated by several researchers with anticancer and antioxidant property,²⁷ control cholesterol and blood pressure,²⁸ prevent gastritis, and possess antibacterial activity.²⁹ Allicin is one of the active principle ingredients of freshly crushed garlic. Louis Pasteur described the antibacterial effects of juice of *Allium sativum* L for the first time, which eventually established that a component called allicin of garlic had significant antimicrobial activity.³⁰ Allicin in its pure form is known to exhibit antifungal and antiparasitic property. Gonzalez et al reported garlic extracts preventing production of *Staphylococcus enterotoxins* A, B, and C₁. It inhibited formation of thermonuclease, a heat-stable nuclease produced by *Staphylococcus aureus*.³¹ The main antimicrobial effect of allicin is due to its chemical reaction with thiol groups of various enzymes, for example, alcohol dehydrogenase, thioredoxin reductase, and RNA polymerase, which can affect essential metabolism of cysteine proteinase activity involved in the virulence of *Entamoeba histolytica*.³² The antibacterial effect of aqueous extracts of garlic was confirmed by testing all the strains of *Helicobacter pylori* clinical isolates.³³ The MIC of garlic extracts for all the isolates ranged between 25 and 400 mg/mL. According to Moghadam et al, these findings might help prevent the occurrence of peptic ulcers.³³ Jonkers et al reported synergistic effect of the combination of garlic juice extracts and omeprazole (pharmaceutical compound used in the treatment of stomach acidity) on *Helicobacter pylori* and stated that the efficacy of the ingredient depends on the concentration of the garlic juice.³⁴ In this study, 5 isolates of *Helicobacter pylori* showed resistance to more than one antibiotic, but were inhibited very well with the above combination. Yamada and Azuma reported pure allicin to be effective against species of *Candida*, *Cryptococcus*, *Trichophyton*, *Epidermophyton*, and *Microsporium* at low concentrations (MIC of allicin was between 1.57 and 6.25 µg/mL).³⁵ Inhibition of *Campylobacter jejuni* due to changes in the spectral features of proteins, lipids, and polysaccharides in the cell membranes was accurately investigated by complementary infrared Raman spectroscopy using a chemical-based, "whole-organism fingerprint."³⁶ It was shown that organosulfur compounds of garlic were responsible for the substantial antimicrobial activity and was much greater than other phenolic compounds of garlic.

Ginger (*Zingiber officinale*)

One of the world's most widely cultivated herb and a warming spice is ginger. It comes from the same family as turmeric. It has a great history as a spiritual beverage. Its history resembles both medicinal and economic importance and has been recorded back since 200 BC in the Greek literature. Its value

as an aphrodisiac is undoubtedly connected to its widespread use as a systemic tonic to balance hormones, enhance energy, as a digestive aid, and as an agent for improving appetite and blood circulation. Traditional Chinese and Indian medicines viewed ginger as a healing gift from God. Gingerols isolated from the rhizome are the active constituents that are structurally related to polyphenol compounds. Barman and Jha characterized essential oils and compounds of ginger by GC and GC/MS. It demonstrated the important active ingredient as zingiberene (nearly 28%).³⁷ Other compounds were geranial, ar-curcumene, and β -bisabolene. The oils were tested for antimicrobial activity against *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, *Candida albicans*, *Aspergillus niger*, and *Fusarium oxysporum*. It showed varying inhibitory nature with MIC values ranging from 1 to 20 $\mu\text{g/mL}$ and inhibition diameter ranged from 6 to 12 mm.³⁷ It is generally assumed that the antimicrobial activity of essential oil and extracts of any spice and condiments depends on the chemical nature and composition of each component in the extract. The methanol extracts of the rhizome was found to inhibit the growth of all the strains of *Helicobacter pylori* with MIC range of 6.25 to 50 $\mu\text{g/mL}$.³⁸ *Helicobacter pylori* is the main reason for peptic ulcer, dyspepsia, and gastric/stomach cancer; hence, administration of ginger in a purified form at standardized concentration would be one remedy to eliminate *Helicobacter pylori* from the digestive tract. Park et al experimented with ethanol and *n*-hexane extracts of ginger, which presented excellent antibacterial activity against 3 anaerobic gram-negative bacteria (ie, *Porphyromonas gingivalis* ATCC53978, *Porphyromonas endodontalis* ATCC35406, and *Prevotella intermedia* ATCC 25611) that cause periodontal disease.³⁹ The 2 highly purified alkylated gingerols effectively inhibited the growth of these oral pathogens at MIC ranging from 6 to 30 $\mu\text{g/mL}$ and minimum bactericidal concentration (MBC) ranged over 4 to 20 $\mu\text{g/mL}$. Good antimicrobial results were reported by Sunilson et al on common food-borne pathogens like *Escherichia coli*, *Salmonella enteritidis*, *Clostridium perfringens*, *Staphylococcus aureus*, *Campylobacter jejuni*, *Bacillus cereus*, and fungi like *Mucor mucedo* and *Candida albicans* with zone of inhibition varying from 8 to 18 mm with concentration of 100 $\mu\text{g/mL}$ of solvent extracts.⁴⁰

Nutmeg (*Myristica fragrans*)

Used as food spice, flavoring agent, and medicines for headaches, bad breath, and fever. Nutmeg is a tropical tree, probably native to the Banda islands of Moluccas in Indonesia. Nutmeg is the seed covered with reddish-brown skin called mace, which is also an important spice. Arabs used them as a good cure for stomach ailments. Nutmeg is now commercially produced in countries like Malaysia, Caribbean Islands, Guinea, Sri Lanka, and India. The antimicrobial activity of nutmeg and mace has been tested by a number of investigators. When Ibrahim et al tested ethanol and acetone extracts of nutmeg crust, it produced good antibacterial activity against gram-positive bacteria like

Staphylococcus aureus.⁴¹ Similarly, acetone extracts of nutmeg seed showed a strong antioxidant activity and antimicrobial activity against all tested organisms, mainly *Staphylococcus aureus* and *Aspergillus niger* (DIZ-13.8 mm and 14.4 mm) at 1 mg/mL extract concentration.⁴² Chung et al purified lignans from mace through nuclear magnetic resonance spectroscopy and electron impact-mass spectrum. They tested its anticarcinogenic activity against oral pathogens. Among all the tested oral pathogens, *Streptococcus mutants* got inactivated in 1 minute at 20 $\mu\text{g/mL}$ concentration of lignans. MIC obtained from mace was 3.9 $\mu\text{g/mL}$ of the pathogen suspension.⁴³ Bio-preservation of sweets by using nutmeg methanol extracts displayed inhibition of *Staphylococcus aureus*, *Aspergillus niger*, *Saccharomyces cerevisiae*, and *Escherichia coli* at MIC values between 250 and 300 $\mu\text{g/mL}$.⁴⁴ Among the different extracts tested ethyl acetate extracts of flesh of the nutmeg fruit had the highest inhibitory effect against gram-positive and gram-negative bacteria with MIC ranging from 0.625 to 1.25 mg/mL.⁴⁵

Star Anise (*Illicium verum*)

It is known as native to South China and been used as food flavor additive as well as a good herbal medicine since 3000 years. The aroma gives it a name *Illicium*, meaning allurement, and is a major ingredient in Chinese and Vietnamese cuisines.⁴⁶ China and Vietnam are the main producers of star anise. Now it is also cultivated in France, Spain, Italy, and Philippines. It contains anethole, the same constituent that gives anise its distinctive flavor. It is a common ingredient in traditional Chinese treatments, particularly added in tea to cure rheumatism. Star anise has been reported to have carminative, antifungal, antibacterial, analgesic, sedative, anticarcinogenic, and antioxidant properties.⁴⁶ It is one of the secret ingredients in Tamiflu (a drug used to treat bird flu). The pharmaceutical industries use large amounts of star anise to obtain shikimic acid, one of the principle ingredients in Tamiflu.⁴⁷ Though its central role in treating flu is not revealed, people in India always believed that it prevented throat infections. It is a common additive in flavored rice (*Pulav*) and tea. Its consumption in excess can cause severe skin allergies. The main bioactive compound is anethole, which is up to 95%. It also contains α -pinene, phellandrene, p-cymene, limonene, and d-terpineol. Seed from the star anise floret is known to contain about 55% fatty oils along with oleic acid, linoleic acid, myristic acid, and stearic acid. Aly et al concluded that star anise extracts if explored more, it can be considered as an important source for the development of newer and safer drug products.⁴⁸ They identified and estimated the major components of star anise essential oil by GC/MS as transanethole (82.7%), caryophyllene (4.8%), and limonene (2.3%). Their results revealed the growth reduction of *Aspergillus flavus*, *A parasiticus*, and *Fusarium verticillioides* by 83.2%, 72.8%, and 65.11%, respectively, using 100 ppm of the star anise essential oil. Complete inhibition was achieved at 200 ppm for *A flavus* and *A parasiticus*. Aflatoxin B₁ and Fumonisin B₁ production were inhibited completely at

100 and 200 ppm, respectively.⁴⁸ The acetone extracts of *Illium verum* showed the best antibacterial activity against common fish pathogens like *Aeromonas hydrophila*, *A salmonicida*, and *Edwardsiella tarda* at concentration of MIC 0.078 mg/mL.⁴⁹ Biochemical studies of star anise indicated that a major portion of its antimicrobial property was due to anethole in the dried fruit.⁵⁰ Laboratory experiments with fresh extracted anethole showed a significantly higher effect against several bacteria, yeast, and fungal strains compared to pharmaceutical anethole. Studies need to be carried out on phytochemical nature of anise to preserve its originality during storage.

Black Pepper (*Piper nigrum*)

Black pepper is popularly known as the “king of spices.” It is a good substitution for red chilies, if one has to avoid it in the food. The pungency in the seed is due to the presence of piperamides of which the main bioactive alkaloid is piperine.⁵¹ It is established to possess several therapeutic properties and is one of the important constituents in *Ayurveda* prescriptions for cough, cold, asthma, and sinusitis problems. It has antiseptic properties, and its potential for antibacterial and antifungal activity has been tested in laboratories by a number of researchers. The antibacterial activity of black pepper was tested by agar well diffusion method and fungicidal activity by poisoned food technique.⁵² The crude piperine extracts from black pepper showed maximum antibacterial activity against multidrug resistant gram-positive bacteria, *Staphylococcus aureus* (DIZ-18 mm) and antifungal activity toward *Fusarium oxysporum* (DIZ-14 mm). Same findings were also reported by Palaksha et al, wherein pepper produced considerably higher antibacterial activity against *Staphylococcus aureus* (MIC-100 µg/mL) compared to other gram-negative bacteria.⁵³ Ethanol extract of pepper seeds showed antibacterial activity against all the tested bacteria like *Staphylococcus aureus*, *Escherichia coli*, *Bacillus subtilis*, and *Pseudomonas aeruginosa*, with zone of inhibition ranging between 15 mm and 22 mm. Similarly, Ghori and Ahmad reported the extract to be significantly effective against *Salmonella* sp and *Bacillus subtilis* at 50 µL stock solution concentration.⁵⁴ All the results were compared with pharmaceutically prepared antibiotics.

Cloves (*Syzygium aromaticum*)

Highly aromatic, tropical tree that grows well in warm, humid regions of Indonesia, Sri Lanka, Brazil, India, and Tanzania. Whole cloves are used as food flavors in meats, pickling, and making syrups. Ground cloves are used for baking breads/cakes, preparation of spice powder (*masalas*), and in perfumes. It has therapeutic properties. It is known to control nausea, vomiting, cough, diarrhea, dyspepsia, flatulence, stomach distension, and gastrointestinal spasm. It is recognized to possess anticarcinogenic, antioxidant, and antiparasitic properties.⁵⁵ Clove extracts can be used as analgesic, antispasmodic, and general antiseptic in dental practices. It is believed to cause uterine contractions and stimulate nerves. Oral dose of clove

oil concentrates of 3.75 g/kg body weight was found to be lethal when tested in animals.⁵⁶ Excess dose can cause acute respiratory distress syndrome in human beings.⁵⁷ The principal active ingredient of cloves is eugenol (eugenyl-acetate, methyl-eugenol, dehydrodieugenol, and isoeugenol), and other compounds are β-caryophyllene, 2-heptanone, α-humulene, methyl-salicylate, phenylpropanoids, bioflorin, aldehydes, and oleanolic acid. Eugenol and caryophyllene exhibit antibacterial and antifungal activity. The antimicrobial activity of clove oil was tested against dental caries, with, for example, *Streptococcus mutans*, *Staphylococcus aureus*, *Lactobacillus acidophilus* (bacteria), *Candida albicans*, and *Saccharomyces cerevisiae* (yeast). The maximum inhibition occurred for *Saccharomyces cerevisiae* (DIZ 25.3 mm) in methanol clove extracts at MIC 50 mg/mL. Clove oil showed maximum activity against *Streptococcus mutans* (DIZ 34.3 mm) with MIC 3.125 mg/mL, indicating that clove and clove bud oil can be used as an effective cure for dental caries. According to Ayoola et al, volatile oils extracts of cloves display broad spectrum antibacterial properties against *Escherichia coli* ATCC35218, *Klebsiella pneumoniae*, *Salmonella paratyphi*, *Citrobacter* spp, *Enterobacter cloacae*, *Staphylococcus aureus*, and yeast *Candida albicans* at different concentrations. *Staphylococcus aureus* was most sensitive (MIC 0.067 mg/mL) while *Escherichia coli* ATCC35218 was sensitive at (MIC 0.23 mg/mL) and *Candida albicans* at higher concentration (MIC 2.4 mg/mL).⁵⁸ Cloves can be considered for biopreservation. It suppresses food spoilage organisms like *Bacillus subtilis* when used at different concentrations (0.5% to 2.5%).⁵⁹ Bread supplemented with 2.0% to 2.5% clove extract inhibited *Bacillus subtilis* but dropped the score for sensory evaluation. However, 1% concentrates of clove extract gave better flavor to the bread. Solvent extract showed MIC ranging between 17 to 23 mm and aqueous extract displayed MIC up to 17 mm. Hoque et al tested extracts of cloves and clove oil along with antibiotic gentamycin on *Listeria monocytogens*, *Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, and *Salmonella enteritidis* that cause spoilage of ground chicken meat. Extract concentration was 10 mg/mL, clove oil at 10%, and antibiotic gentamycin at 10 µg/mL.⁶⁰ The essential oil was reported to be more effective against all gram-positive bacteria as well as gram-negative bacteria compared to ethanol and water extracts of cloves.

Cinnamon (*Cinnamomum verum*, *C cassia*, *C zeylanicum*, *C loureirii*)

This powerful spice was extensively used in Egypt, Rome, and China since prehistoric times. It was used on the funeral pyres by the royals of Rome as family pride and respect to the dead. It is an evergreen tropical tree, considered as native to Sri Lanka. The leaves and inner bark are used to make cinnamon oil and sticks. It was considered as perfect coat for masking off the smell of meat and delay spoilage in ancient times. It is known to have phenolic compounds that can inhibit growth of meat spoilage bacteria. Cinnamon is widely used as a food flavoring agent. Cinnamon powder mixed with sugar goes well with

bread, cakes, muffins, pies, and pancakes. It is known to contain a number of nutrients beneficial for proper functioning of body parts. The active ingredients in cinnamon are cinnamaldehyde, cinnamate, cinnomyl-acetate, β -caryophyllene, and even some amount of eugenol.⁶¹ As reviewed by Vangalapati et al, cinnamon has several applications in the clinical problems as well as in therapeutics.⁶² It possess antimicrobial, antioxidant, anti-inflammatory, blood purifying and blood thinning properties, and it is also used in reducing blood sugar levels and cholesterols. It can be used as antiseptic for skin applications. However, excess consumption of cinnamon can be toxic to body organs. Antimicrobial nature of cinnamon extracts and its oil has been reported by several investigators. Nimje et al described antimicrobial effect of chemical extracts of *Cinnamomum zeylanicum* and *C cassia* oil on 3 spoilage bacteria, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus*. The essential oil of *C cassia* was found to have more effect on *Escherichia coli*.⁶³ According to the investigation by Ranjan et al, purified cinnamon extracts can be the best replacement to chemical preservatives. They carried out a time-dependent antibacterial study in fish using gum acacia coating with the aqueous cinnamon extract and cinnamon paste. It was observed that the microbial load present on fish was totally reduced on the second day displaying a wide range of antibacterial activity at 40°C to 60°C.⁶⁴ It satisfied all the criteria required for antibacterial agent as compared to antibiotic gentamicin.

Conclusion

Considering consumers' safety, there have been continuous efforts by scientists to introduce complementary antimicrobial agents and achieve partial use of chemical preservatives and antibiotics. Chemicals are known to have a number of detrimental effects like liver damage, kidney failure, skin allergies, discoloration of teeth, and development of multidrug-resistant pathogens. Some bacteria that show resistance to conventional antibiotics are found susceptible to essential oils and extracts of spices, condiments, and other herbal products. It has been demonstrated through laboratory study (*in vitro*) that there is high possibility of utilizing these constituents as potential antimicrobial agents. Minimum inhibition concentration is a well-defined and internationally accepted technique for testing antimicrobial activity against pathogens. There are numerous uses of this technique and quite often has been used in the scientific research to formulate the dose of administering drugs to the minimum utilization of active ingredients. Although spices and condiments are considered as natural products, sometimes when used in excess they can result in toxic effects to human health. Therefore, the World Health Organization, European Union for Food Safety Control, Generally Regarded as Safe, and US Food and Drug Administration should provide specifications and authorizations for administering the products obtained from spices and condiments safely in human beings. These safety regulations are already included in general pharmaceutical legislation. Endorsement of spices and condiments as alternative and complementary

medicines can be achieved by several *in vivo* trials through which safe use of these natural products can be assured.

Acknowledgments

We acknowledge the University of Agricultural Sciences, Bangalore, for providing us the research platform. We appreciate researchers (cited reference authors) for their effort in recognizing spices and condiments as perspectives for future medicines.

Author Contributions

Savita P. D'Souza: Understanding original research articles and writing of the review. Suvarna V. Chavannavar: Editing and discussion. Kanchanashri B and Niveditha S B: Reference editing and collection of original articles.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Ethical Approval

The review narrates in brief the work already carried out and published in local and international journals by researchers in Asia, Africa, and European continent. It does not require any ethical commitment.

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