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REVIEW ARTICLE

Critical Review on Nutritional, Bioactive, and Medicinal Potential of Spices and Herbs and Their Application in Food Fortification and Nanotechnology

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Abstract
Medicinal or herbal spices are grown in tropical moist evergreen forestland, surrounding most of the tropical and subtropical regions of Eastern Himalayas in India (Sikkim, Darjeeling regions), Bhutan, Nepal, Pakistan, Iran, Afghanistan, a few Central Asian countries, Middle East, USA, Europe, South East Asia, Japan, Malaysia, and Indonesia. According to the cultivation region surrounded, economic value, and vogue, these spices can be classified into major, minor, and colored tropical spices. In total, 24 tropical spices and herbs (cardamom, black jeera, fennel, poppy, coriander, fenugreek, bay leaves, clove, chili, cassia bark, black pepper, nutmeg, black mustard, turmeric, saffron, star anise, onion, dill, asafoetida, celery, allspice, kokum, greater galangal, and sweet flag) are described in this review. These spices show many pharmacological activities like anti-inflammatory, antimicrobial, anti-diabetic, anti-obesity, cardiovascular, gastrointestinal, central nervous system, and antioxidant activities. Numerous bioactive compounds are present in these selected spices, such as 1,8-cineole, monoterpene hydrocarbons, γ-terpinene, cuminaldehyde, trans-anethole, fenchone, estragole, benzylisoquinoline alkaloids, eugenol, cinnamaldehyde, piperine, linalool, malabaricone C, safrole, myristicin, elemicin, sinigrin, curcumin, bidemethoxycurcumin, dimethoxycurcumin, crocin, picrocrocin, quercetin, quercetin 4’-O-β-glucoside, apiol, carvone, limonene, α-phellandrene, galactomannan, rosmarinic acid, limonene, capsaicinoids, eugenol, garcinol, and α-asarone. Other than that, various spices are used to synthesize different types of metal-based and polymer-based nanoparticles like zinc oxide, gold, silver, selenium, silica, and chitosan nanoparticles which provide beneficial health effects such as antioxidant, anti-carcinogenic, anti-diabetic, enzyme retardation effect, and antimicrobial activity. The nanoparticles can also be used in environmental pollution management like dye decolorization and in chemical industries to enhance the rate of reaction by the use of catalytic activity of the nanoparticles. The nutritional value, phytochemical properties, health advantages, and both traditional and modern applications of these spices, along with their functions in food fortification, have been thoroughly discussed in this review

Keywords Phytochemicals · Ethnobotany · Essential oil · Antimicrobial · Bio-prospecting · Nanoparticles

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Introduction

Nowadays, people have been more conscious about the co-relation between the food product and healthy life to cure nutrition-related diseases and promote quality of life [178]. This thought brought many advantages to the food industry, including the provision to provide functional food products that fulfill people's demands along with good standards

In order to meet a purchaser's expectations in the quality and hygiene of food products, nowadays researchers are trying to apply nanotechnology in current food science [361]. Therefore, different types of nanostructures like nanoliposomes [195], nanoemulsions [514, 881], and nanoparticles [700] are used in the food industry to sustain and develop proposal features [102]. The process of better packaging methods and governance of food standards and protectiveness were a few of the very important studied areas in food nanotechnology [179, 336]. There is a debate about the application of nanotechnology in food, as this might compromise food indemnity,therefore, recent provisions of the application of nanomaterials in food and medicine are incipient [73] only through recommendations given by the US (FDA) Department of Health and Human Services 2014 and the European Food Safety Association (EFSA) [265]. The scientific community has focused on nanotechnology-based techniques in order to detect hygiene-related problems and hazards of recent foods that might develop during and after food processing [168]

Investigation into the effectiveness of nanotechnology in the formulation of food products might associate with the encapsulation of nutritious ingredients like vitamins [93], antioxidants [370, 411], and polyphenols [179]. Thus, various additives applied during food development, especially those derived from agricultural processing wastage or naturally like fruits and spices, have a significant potential for application in nanotechnology [179]. All these products are utilized for their unique properties like color, aroma, flavor, and preservation of food [278]

The technology and science in which nanoparticles have been utilized are as follows: medical [709], electronics, agricultural [772], chemical [942], and pharmaceutical [757]. Most of the research studies till now performed on the application of nanoparticles with spices mainly focus on 1) *in vitro* studies, 2) fortification, 3) food industry, 4) packaging, 5) aroma and drug industry and 6) textile industry

Since all spices contain an ample amount of bioactive components that are used to synthesize nanoparticles, these nanoparticles can be used in various types of food products to make them more nutritious that have enormous health-beneficial effects. The antibacterial activity of green synthesized silver nanoparticles has been evaluated against *Klebsiella pneumoniae* and *Bacillus subtilis* [836]. Soshnikova et al. [880] prepared the gold and silver nanoparticles with the water extract of dried fruits of *Amomum villosum* called Fructus Amomi (cardamom) to assess catalytic and antioxidant effects and prevention activity for breast cancer cells [880]. Krishnan et al. [487] synthesized silver nanoparticles with seed extracts of cardamom that showed its cytotoxic effect against Hep-2 cell line [487]. Taami et al. [906] evaluated the antioxidant efficacy of biodegradable starch film containing nanoemulsions of *Bunium persicum* essential oil fortified with cinnamaldehyde [906]. Arif et al. [84] investigated a substitute treatment therapy to cure rheumatoid arthritis with fennel seed selenium nanoparticles in arthritic BALB/c mice [84]

Nowadays, in human nutrition, spices provide eminent historical significance. The bioactive components present in spices make them more popular for centuries. They have been applied for their health advantages and also for coloring or flavoring food products [207]. Day by day, the application of spices in different types of food has been enhanced as they provide various pharmacological and physiological benefits. Medicinal spices have been taken great importance by the recent biomedical research, as spices have been used traditionally in producing either nutraceuticals or functional foods due to their health-beneficial properties. India possesses rank three in the world spices market with an 8.8% share. India possesses the first position in turmeric, coriander, pepper, fenugreek, and some other spices export. The USA, Germany, and Malaysia are the main trading countries. Spices provide aroma due to the presence of volatile oils and oleoresin [147]

Spices play an important role in terms of medicinal benefits. Spices are utilized as anti-inflammatory, carminative, antioxidants, and antiseptic. In the current scenario, spices are gaining interest due to the bioactive compounds and their biological effect and chemical structure. Phytochemicals like alkaloids, phenolic compounds, flavonoids, tannins, and flavones are present in spices and can be used as a powerful drug against dengue and Ebola viruses. Chikungunya virus can be cured by using ginger extract. Spices have antioxidant properties and have proof of oxidative alternation of low-density lipoprotein cholesterol in the formation of atherosclerosis. Spices containing various bioactive components have an anticancer effect as examined in model animals [147]. The active compounds of the spices are essential oils, and the spices, namely black pepper, cinnamon, cloves, coriander, chili, and cumin, are enriched with essential oils having pharmaceutically active components such as piperine, cinnamaldehyde, eugenol, allicin, curcumin, and linalool [658]. Spices are used as therapeutic agents with antimicrobial, anti-inflammatory, anticancer, and antioxidant properties. Carotenoids, eugenol, and curcumin in saffron, clove, and turmeric are the active constituents in spices evidenced by a phytochemical evaluation that exposes the effective nature of these spices. The benefits represented by these spices are immunity boosters, especially during the phase of the pandemic, and their incorporation into our regular diet could enhance disease control mechanisms [773]

In recent years, the societal needs and interest in the application of renewable, natural, and biodegradable resources have enhanced. Food consumers and producers have increased their demands for the quality of processed food products, especially in the area of enhancing shelf life while protecting nutritional and organoleptic properties. Spices have been reported to have a high potential to be applied as important, renewable, and biodegradable sources of chemicals like polyphenols having great antimicrobial/antioxidant properties [460]. Spices have been significantly utilized to increase or improve the flavor of food through their preservative properties [956]. Spices possess a significant role in food safety. The retardation effect of spices and derivatives on the propagation of fungi, bacteria, yeasts, and microbial toxins synthesis has been reported,therefore, they have been applied in food preservation. Spices are recently utilized for increasing the flavor and shelf life of food products because of their bactericidal or bacteriostatic effect [282]

In this review, the ethnobotanical aspects of 24 spices have been covered along with their bioactive and nutritional potential. The role of those spices in food fortification and their potential in nanotechnology have also been explored

Ethnobotanical Knowledge Related to Spices and Herbs

Spices and herbs are the plant parts. Figure 1 describes the botanical perspective of the spices and herbs

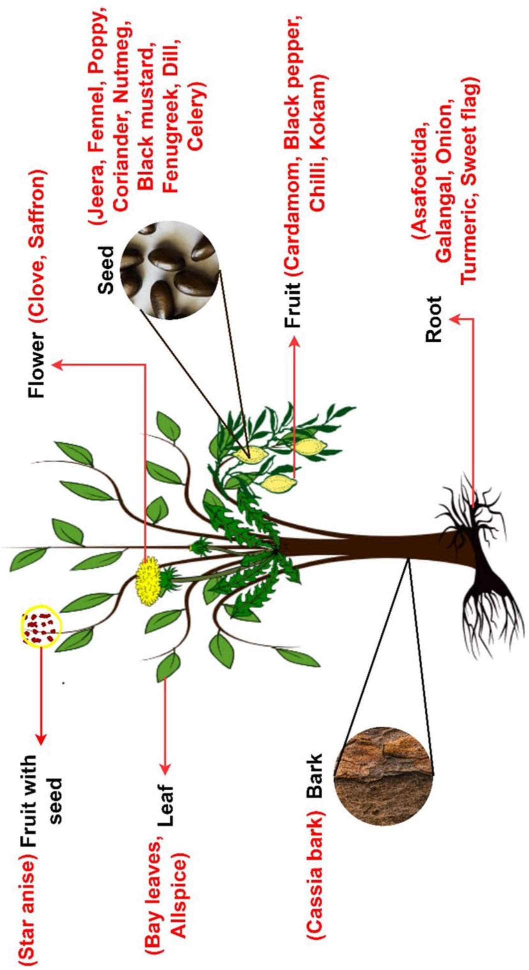


Fig. 1 Spices as different plant parts

Cardamom (*Elettaria cardamomum*)

Small cardamom belongs to the family *Zingiberaceae*. Small cardamom capsules (fruits) show beneficial health effects which are related to the traditional and modern pharmaceutical aspects. It is used in traditional medicines to prevent asthma, nausea, teeth and gum infections, diarrhea, cataracts, indigestion, cardiac attack, and kidney failure. Cardamom fruits are utilized as a fragrance, spice, and flavoring ingredient in food products [89]. In Ayurveda, for the treatment of food poisoning, cardamom has been applied and at present, plant-based creams and soaps are made with cardamom oils [973]. The large cardamom is called 'cash crops' cultivated between altitudes of 600 and 2000 m in the tropical moist evergreen jungle of Eastern Himalayas in India (Sikkim, and Darjeeling regions), Bhutan, and Nepal. The fruit is reddish-brown to dark pink, trilocular, and many-seeded capsule. The seeds possess 2–3% essential oils that contain medicinal properties. These are utilized as a supplement to formulate different types of medicine [379, 866]. India is the highest producer of cardamom (26.51 thousand tons) [563]. The small cardamom is called 'Queen of all Spices' and grows in the tropical rain forest at altitudes of 762–1524 m, where it rains about 381 cm per year. It is cultivated commercially in Guatemala, India, Sri Lanka, and Tanzania. The fruits are narrow-walled, soft-skinned, and oblong. The green fruits contain 15–20 aromatic reddish-brown seeds. The seeds possess volatile oil, which is utilized for the flavoring of bread, cakes, curries, and other culinary purposes. Confectionery and coffee products are also flavored with small cardamom. It is also applied in several neural, gastrointestinal, and cardiovascular diseases [681]

Black jeera (*Bunium persicum*)

In traditional and folkloric medicine, black jeera has been utilized for the treatment of different types of diseases like nasopharyngeal, gastrointestinal, cardiac, respiratory, ocular, neurological, and urinary tract problems [559]. This plant is popular as a spice [352]. The roots and seeds are used as spices that provide flavor to the food [360]. About 70% of the world's cumin is produced in India (725.42 thousand tons) [104]. Black jeera belongs to the family Apiaceae, which is a topical plant and is found in Pakistan, Iran, Afghanistan, and a few Central Asian countries. This plant is a branched and perennial herb, its glandular root is irregular and circular in shape, and the height of this herb is around 40–60 cm. The leaves are properly dissected, freely, pinnate, and capillary, and the white color flowers little in shape have symmetrical little pollen tubes, sepals, and petals and are present in compact umbels. The darkish-brown-colored fruits are round in shape and warm to the taste [617]

Fennel (*Foeniculum vulgare*)

Fennel belongs to the family *Apiaceae* and is an aromatic and medicinal plant applied for the treatment of galactagogue, carminative, digestive, diuretic, respiratory problems, and gastrointestinal diseases. The seeds are utilized as a flavoring ingredient to prepare dishes like ice cream, baked goods, meat and fish dishes, alcoholic beverages, and herb mixtures [749]. Fennel is applied as medicine with purgatives to diminish their side effects due to their carminative properties. Fennel seeds are consumed fresh as a sweetener and help in curing eyesight. Fennel contains phytoestrogens that improve the growth of breast tissue and induces an increased milk supply in breastfeeding mothers [20]. In the year 2020, 137.29 thousand tons of fennel seeds were produced in India [512]. Fennel is an upright, branching perennial herb that has tender, feathery, hair-like foliage. The height of the tree is around 6.6 ft (2 m), and it is used for its anise-flavored foliage. The seeds are utilized in cooking. It has been cultivated in almost all countries [620]

Poppy (Papaver somniferum)

Poppy is a traditional plant commonly called Khashkhash/Afyon belonging to the family *Papaveraceae* and is used as medicine. As per Unani literature, it has significant therapeutic values and is applied as a sedative, analgesic, narcotic, stimulant, and nutritive agent. It helps to prevent various types of diseases like insomnia, headache, cough, cardiac asthma, and biliary colic [582]. Poppy is cultivated throughout the world and is native and grown as an ornamental flower in South East Asia, Europe, South America, and North America. Poppyseed oil is a healthy edible oil and is utilized for various purposes. The purified opium (dried latex from plant fruit) is also used as a major therapeutic component. Purified poppy has been used to balance Vata and Kapha, dosha, and pitta dosha [572]. Poppy seeds are popular as a spice and are utilized to make fortified bread and confections [170]. Afghanistan possesses the highest acreage (6800 tons) for opium poppy cultivation [891]. The opium poppy grows for the whole year and is diploid (2n = 14) with a dominating self-pollinating mode of cross-breeding [926]. Plants are vertical, yearly herbs, height is about 1–1.5 m, stalk green, soft, and hairy. The roots are fine and medium and the leaves are tall, broad, and alternately arranged with serrated margins. The color of the flowers may be varied from red to black to white. The fruits have various cells and are of little size, and they get broken on their own, and the capsule is round and longitudinally grooved [492]

Clove (*Syzygium aromaticum*)

Cloves have many medicinal applications and are popular in treating mouth and throat inflammation and toothache. The main constituent of clove is eugenol possessing wide antibacterial properties against gram-negative, gram-positive, and acid-fast bacteria, and also fungi. Cloves are popular for their carminative, and antiemetic activities. In China, cloves have been consumed for medicinal purposes to prevent different types of diseases since 240 BC. Traditionally, cloves have been consumed for the treatment of stomach irritation, diarrhea, liver disease, bowel problems, flatulence, nausea, vomiting, and to maintain the nerve system. Cloves have been used to prevent different infections such as tuberculosis, malaria, cholera, and scabies. In America, it is traditionally utilized for preventing candida, worms, viruses, and several bacterial and protozoan infections [151]. The flower buds called clove are popular as a spice [119]. India is the leading producer of clove (1.20 thousand tons) [563]. Clove belongs to the family Myrtaceae and is a medium-sized plant (8–12 m), indigenous to the Maluku islands in East Indonesia. Currently, it is cultivated in Malaysia, Indonesia, India, Sri Lanka, Madagascar, Tanzania, and mostly the Zanzibar island [422]

Cassia bark (*Cinnamomum cassia*)

Cassia bark belongs to the family *Lauraceae* and is an evergreen, tropical aromatic plant that is utilized as a traditional spice. It is also used in traditional Chinese medicine utilized throughout the world [1012]. The leaves and bark of this plant are utilized as spices in home kitchens and their synthetic analogs or distilled essential oils are utilized as flavoring agents in the beverage and food industry [188, 230]. Cinnamon is obtained from the bark of tender branches and is utilized as a fragrance. It is used for its spicy flavor throughout the world. It is applied as a regular condiment. Cassia bark is distributed throughout Vietnam, China, India, and Indonesia. The bark of *Cinnamomum cassia* is Cinnamomi cortex that is popular as spices and is used as a seasoning in the western part of the world. It is also used as food supplement in some countries. It is used as a source of coumarin in America [983]. As per the Japanese, Unani, Ayurveda, and traditional Chinese medicine, the herb is utilized to prevent various diseases such as ischemic brain injury, dyspepsia, peptic ulcer, diabetes, and cancer [1005]. The major producer and exporter of cassia bark is Sri Lanka (48,002 MT) [817]. The plant is evergreen, its height is around 10 m, the branches are rigid, the bark is soft, and the color is yellowish. The leaves are leathery and grow up to 11–16 cm with dot tips,the color of the upper leaf is dark green and that of the below leaf is light green. The color of the flower is inconspicuous yellow and has a bad odor; the flowers are cylindrical in shape with 6 lobes. The size of the fruits is small with flabby berrylike structure [385]

Black pepper (*Piper nigrum*)

Piper nigrum belongs to the family *Piperaceae* Black pepper fruit is considered as "King of spices." It is used to increase the flavor, and taste of foods. It shows biological activities due to the presence of different bioactive phytocompounds. Traditionally, the black pepper is used as veterinary drugs and in the treatment of gastrointestinal diseases and ear–nose–throat problems. Black pepper is considered as part of the kingdom of medicinal agents due to its important bioactive compounds with potential pharmacological and nutraceutical utilizations [910]. Black pepper is grown in various tropical regions such as India, Brazil, and Indonesia. Pungent and hot peppercorns are obtained from black pepper and are used as a preservative, medicinal agents, and in perfumery. The application of whole peppercorn or its active components has been used to formulate medicines, to prepare foods, sauces, and meat dishes. It is used in various traditional medicinal systems like Unani and Ayurvedic [821]. India is the greatest producer of black pepper (91.63 thousand tons) [563]. This plant is a flowering timbered perennial climbing vine and easily grows in the shadow of backing trees, maximum height is about 13 feet or 4 m and roots may emerge from leaf nodes if the vine contact with the ground. The plant leaves are heart-shaped, the length is 5–10 cm, and 3–6 cm diagonally, it has 5–7 eminent palmate veins. The flowers are little in shape, monoecious with different male and female flowers but may be polygamous. The fruits are 3–4 mm in diameter, known as a drupe. The dried fruits of black pepper are called peppercorn. The color of fully ripe fruits is dark red, and the diameter is about 5 mm. Each of the fruits consists of one seed, and a stem possesses 20–30 fruits [220]

Coriander (*Coriandrum sativum*)

Coriander seed is used as a spice, which possesses medicinal and nutritional properties. It helps in the treatment of nausea, bed cold, vomiting, belly diseases, and seasonal fever. It is utilized as a medicine to prevent rheumatism, worms, indigestion, and joint pain [737]*Coriandrum sativum* belongs to the family *Umbelliferae* The mature fruits contain delightful and fresh flavor due to the presence of essential oil. It is mostly utilized throughout the world in the ground or volatile isolate form to add flavor to tobacco products, sweets, beverages, and baked goods and as a basic ingredient in curry powder and also to make perfumes and soaps. It is cultivated as a household plant [175]. The largest producer of coriander seed is India (677.21 thousand tons) [701]. It is cultivated in India, especially in Karnataka, Tamil Nadu, Rajasthan, Andhra Pradesh, Madhya Pradesh, and Bihar. This plant is thin, glabrous, and branched. The fresh leaves are round and aerial leaves are extended. The flowers are white and look like an eggplant. The fruits are oval and partitioned into two parts. The flowering season of coriander is winter [611]

Nutmeg (*Myristica fragrans*)

Drugs are produced with the essential oil, and extracts of nutmeg. It has various pharmacological properties. In traditional medicines, nutmeg is utilized as a narcotic, carminative, stimulant, emmenagogue, abortifacient, reduced appetite, diarrhea, rheumatism, and muscle spasm. In China and India, nutmeg is used in producing medicines, and foods due to its availability and biological properties [412]*Myristica fragrans* is called "nutmeg." Two spices are formed from it, namely mace and nutmeg. Nutmeg is the seed kernel beneath the fruit, and mace is the red lacy enveloping the kernel*Myristica fragrans* belongs to the family *Myristicaceae* It is indigenous to the Moluccas, native to Sri Lanka, India, and Indonesia. It is cultivated in many tropical countries like South Africa and Sri Lanka [675]. In 2021, the production of nutmeg in India is 15.24 thousand tons [563]. Nutmeg is an evergreen aromatic plant. The height of this tree is about 5–13 m, occasionally 20 m. The bark possesses watery red to pink juice. Leaves are dark green, have shiny surface, and settled upon alternately along the branches. The leaf stem is about 1 cm long. Flowers are bell-shaped, pale yellow, flabby, and fleshy. The fruits are yellow, fleshy, drooping, soft, and 6–9 cm long with a lengthwise ridge. Seeds are extremely ovoid (2–3 cm long), whitish, firm, fleshy, and lateral by red-brown veins and the mace becomes bright red and is more corneous when fresh, and when dried becomes brittle and the color becomes yellowish-brown. Nutmeg is famous as a spice and contains several therapeutic activities. It shows a characteristic pleasant fragrance and a little hot taste. It is utilized to increase the flavor of puddings, baked foods, confections, meats, sausages, saucers, vegetables, beverages, curry powder, teas, soft drinks, or added to milk, and alcohol [664]

Black mustard (*Brassica nigra*)

Brassica nigra belongs to the family Brassicaceae. It is popular as a spice and a cheap source of antimicrobial agents [732]. It is cultivated in the Mediterranean region and several other countries such as Europe, and India. It is the main source of the mustard seed which is utilized as a spice [22]. In 2019, Nepal is the world's largest producer of mustard seeds accounting for more than 32% of the global production [529]. For the treatment of malaria, seeds are powdered and pasted with water and then taken with or without " *Injera"* [320]. The height of this tree is about 2–7 cm, broadly branching, pubescent or glabrate. The lower leaves are thin petiolate and densely pinnatifid and have one marginal big lobe and 2–4 little adjacent ones,the upper leaves are little-petiolate or sessile, dentate. The flowers are bright yellow colored, 3–5 inches wide [939]. Black mustard seed has been utilized as a remedy for brain and lung edema, neurotic pain, rheumatoid arthritis, paralysis, migraine, and epilepsy in Iranian traditional medicine [470]

Turmeric (*Curcuma longa*)

Curcuma longa L belongs to the family *Zingiberaceae* family. It is a perennial herb. The height of this tree is approximately 3.5 ft [83]. It is indigenous to Southern Asia [345]. In 2021, the major producer of turmeric is India (1102.91 thousand tons) [563]. Curcumin plays an important role as a therapeutic agent. For different diseases, it is used in human clinical trials [496]. Indian turmeric is most famous compared to other countries due to the presence of curcumin*Curcuma longa* rhizome is called Haldi or turmeric. Turmeric is also known as "Indian saffron." It is commonly used as an antiseptic and shows high medicinal and nutritional value. Rhizome of *Curcuma longa* is utilized as a spice for its flavoring properties. It is utilized as medicinal food due to its therapeutic properties [187]. In Ayurveda, it has been utilized as an ethnomedicine and coloring agent to dye unmordant cotton, wool, and silk. It is utilized in the Indian medicinal system to prevent stomachache, antacid, carminative, blood purifier, wound healing, and inflammation [545]. It is cultivated broadly in Asia, especially in China, and India. It is distributed throughout subtropic, and tropic areas of the world. It is also cultivated in Japan, Southern China, Taiwan, Burma, and Indonesia as well as in Africa. The color of the flower of this plant is dull yellow [967]

Bay leaves (*Laurus nobilis*)

Laurus nobilis belongs to the family *Lauraceae* It is a small evergreen plant, marketed as sweet bay leaves, and Roman or Turkish laurel [932]. It is a fragrant and aromatic plant that contains volatile components and fixed oil (non-volatile oil of plant origin) as well as camphor. It is indigenous to South Europe [123]. The dried leaves and essential oil are applied in cosmetics, in foods as a spice, in drugs, and also for industrial purposes for the seasoning of fish, meat products, and soups. Bay leaves are utilized in the food industry as food preservatives due to their antimicrobial properties. The volatile and fixed oil present in fruits is mainly required for the formation of soap [163]. It is cultivated in the tropical and subtropical regions of East Asia, South, and North America. The natural residence of this herb is found in the Mediterranean area. Traditionally, bay leaves have been utilized in Mediterranean cuisine for seasoning, as well as fruits are used to treat rheumatism, viral infections, cough, digestive problems, diarrhea, and other health conditions in the folk medicine system [256]. India is the largest producer of bay leaves (6.20 thousand tons) [563]. This plant is a shrub. The height of this plant is about 2–20 m, thin, glabrous twigs, and thin oblong-lanceolate, sturdy leaves and dioecious with the female, and male flowers on a different tree. The flower grows in couples alongside a leaf with a pale yellow-green color. The diameter of fruits is about 1 cm. The fruits ripen in the downfall, and the shape of the fruit is oval [56]

Saffron (*Crocus sativus*)

Saffron is the dried orifice of the *Crocus sativus* flower that is used as a spice. It is considered among the main terroir products and a source of income for many areas of Morocco. According to Chinese, Ayurvedic, Mongolian, Egyptian, Greek, and Arabic medicines, saffron has been taken into account as a preventive measure for various diseases. It is utilized as a source of traditional medicine from ancient times. Saffron shows many therapeutic properties like antidepressant activity, treating sexual problems, digestion problems, lowering cholesterol levels, controlling blood sugar levels, healing second-degree burns, and treating eye disability [633]. The largest producer and exporter of Saffron is Iran (430 tons) [826]. The *Crocus* *sativus* belongs to the family *Iridaceae* It is an herbaceous perennial plant that grows up to 10 to 25 cm long, developing from its bulbs. The bulb is of sub-ovoid shape and available in different forms and sizes [1022]

Star anise (*Illicium verum*)

Illicium verum belongs to the family *Illicuaceae* It is an evergreen aromatic plant sometimes contaminated with very poisonous Japanese star anise and toxic star anise that possess various neurotoxic sesquiterpenes [981]. Star anise is indigenous to the Southwest of China. It is cultivated in tropical, and subtropical areas of Asia [274]. The production of star anise seed in Vietnam is more than 5000 tons per year and the combined production of Vietnam, and China is more than 25,000 tons per year [832]. It is a medium-sized tree. The height of this tree is about 8–15 m and the breadth is 30 cm. The color of the bark is white to bright grey. The leaves are 6–12 cm tall, sturdy, alternate, simple, complete, glabrous, very bright, and usually packed with bundles at the end of the branches. The flower is large, diameter is 1–1.5 cm, bisexual, white–pink to red to greenish-yellow, axillary, and lonely [962]. Dry fruits and seeds of star anise are popular as a spice in Chinese cuisine. Star anise oil is applied naturally for otalgia, and rheumatism, as an antiseptic, cough, toothache, sinusitis, and also as food preservatives traditionally. The star anise oil is utilized to treat dysentery, flatulence, and spasmodic pains and relieves colic [831]

Shallot/ Onion (*Allium cepa*)

A highly consumable vegetable, onion, is well known for its flavor. It is the third most important horticulture spice having remarkable marketable importance [925]*Allium cepa* belongs to the family *Amaryllidaceae*. The edible portion of the onion is the root, which is also called as the bulb. The colors of onion varied from purple to yellow to red to white green and may be categorized by its rancidity [870]. According to the medicinal characteristics, traditionally onion has been utilized in the prevention of several diseases and applied as a blood purifier for athletes in ancient Greece. Onion is used to heal wound, pneumonia, and diuretic. Onion is considered as one of the essential spice or vegetables and has been considered as a medicine in India since the sixth century [416]. India is the highest onion producer (28,853.35 thousand T) in 2020–2021 [257]. Onion is distributed in temperate areas like North America, Europe, Asia, and Africa [156]. This plant is a biennial plant with fortuitous, fibrous roots, and glaucous leaves. The bulb is produced of converging, large flabby leaf bases. When the bulb matures, the outward leaf base dries, becomes slender, many-colored, and produces a defensive coat, while the inside leaf bases thicken and develop the bulb which may be globose, egg-shaped, or extended. According to the cultivar, the size of the onion varies differently [533]

Dill (*Anethum graveolens*)

Anethum graveolens belongs to the family *Apiaceae* It has been utilized since ancient times in Ayurveda. It is a famous, aromatic, and annual herb. Dill seeds are used as a spice and also produce essential oil. The dill seeds are used as a preventive agent for diuretic, carminative, and stomachache in Ayurveda [403]. The highest producer country of dill is India (30.40 thousand T) [563]. The height of this plant is about 90 cm. It has thin stems. Leaves are alternate and are finally divided three or four times into winged sections slightly wider than the same type leaf of fennel, and the yellow flower forms into umbels. The seeds are very little in size. The dry fruits are known as schizocarps [747]. It naturally grows in the Mediterranean area, Southern, and Central Asia. It is cultivated broadly throughout the world [997]

Fenugreek (*Trigonella foenum-graecum*)

Trigonella foenum-graecum belongs to the family *Fabaceae*is. It is an ancient medicinal plant. It is widespread throughout the world. It has been utilized as medicine and traditional food. Current investigation has determined fenugreek as an important herbal tree having a powerful effect on curing diseases and as a source of bioactive compounds for the pharmaceutical industry such as steroidal hormones [871]. The leaf and the seed of fenugreek are consumed as a spice. It is also utilized as an ingredient in traditional medicine due to its strong flavor and aroma [4]. Fenugreek is recommended as a valuable medicine to prevent various diseases like mucosal problems, digestive problems, fever, sore throat, wounds, swollen glands, skin irritation, diabetes, bronchitis, and ulcer in the ancient Indian traditional medicinal system like Ayurveda [687]. The largest producer of fenugreek is India (115,929 metric tons). But a substantial amount of the production is eaten internally in the country [347]. The height of the fenugreek plant is about 1–2 feet. It has green trifoliate leaves. The flower color changes from white to yellow. The plant retains narrow pods. The length of the pods is about 15 cm, and they possess an average of 10–20 seeds [589]

Asafoetida (*Ferula assafoetida*)

Ferula assafoetida belongs to the family *Apiaceae* It is one of the more valuable plants among the 30 species of Ferula. It is distributed in Iran. It is an herbaceous, and perennial plant. It has been found in Iranian folk medicine as a carminative, antispasmodic, aromatic, digestive, expectorant, laxative, sedative, nerving, analgesic, anthelmintic, antiseptic, and aphrodisiac agent. It is a valuable plant used in veterinary, traditional medicine, and also for non-medicinal purposes. Kerman in Iran is the leading producer of this plant [157, 331]. The rhizome or tap root is used as a spice. It is popular in curing digestive disorders. It is utilized in recent herbalism in preventing bronchitis, hysteria, nervous situations, asthma, whooping cough, infantile pneumonia, reduced blood pressure, and flatulent colic. Since ancient times, in Ayurveda, and the Unani system, it is broadly utilized. Asafoetida is naturally found in a topical zone, particularly in Central Asia, Eastern Iran to Afghanistan. Afghanistan is the highest producer of asafoetida (23,021 thousand tons). At present time, it grows in Afghanistan and Iran from where it is exported to other places. It has been utilized as a cookery agent. It has large carrot-shaped roots, and when they become 4–5 years old the diameter is about 12.5–15 cm [554]

Celery (*Apium graveolens*)

Apiumgraveolens belongs to the family *Apiaceae*. The dried and ripe celery seeds are popular as a spice. It has been applied for the treatment of diuretics, spasms, stomach problems, and heart tonic to reduce blood pressure in African traditional medicine [515]. India is the highest producer of celery (30.40 thousand tons) [563]. It is also used to cure joint pain. The center portion of the root of celery is fugitive. The stem is branched, notched, juicy, and hardy. The leaves are winged and ovate. The flower size is small and the color is white to greenish-white. Petals are circular and fruits are schizocarp with two mericarps, suborbicular to ellipsoid in shape and a little bitter in taste [55]. It is mainly famous in countries like Iran, Algeria, the Caucasus, India, and America [479]

Chilli (*Capsicum frutescens*)

Capsicum frutescens belongs to the family *Solanaceae* It is a temperate plant. Cayenne pepper/chili is used traditionally in medicine and in the diet as an ingredient in warm sauces [32]. Chilli is utilized in ethnomedicinal treatments of postnatal care to cure erectile problems, nutrition therapy, pain management, as a circulatory medicine, as a tonic for arthritis, and rheumatic pains, lower the blood glucose level, for cholesterol extraction [413]. India is the largest producer of chili (3992 thousand tons) [563]. It is a perennial shrub/household annual plant. It has little vertical, wheat-shaped fruit that is spicy in flavor, and the fruit color changes from green to pale yellow that converts into red color when it ripens. The most commonly wild pepper species is found in the tropical region of China, namely Hainan and Yunnan territory [238]. This plant is a yearly growing plant or short-lived perennial herb. Its stem is striate, glabrous, 1–4 feet long according to growing conditions and weather. The leaves are oval, slightly leathery, the color is dark green, soft, height is 2.5 inches, and 1 inch broad. The flowers are naturally conifer or funnel, having five petals, combined, and white. The fruits are vertical, ellipsoid-conical to lanceoloid, with a length of about 10–20 mm and a diameter of 3–7 mm [50]

Allspice (*Pimenta dioica*)

Pimenta dioica belongs to the family *Myrtaceae* It contains an aromatic flavor and tastes similar to a mixture of nutmeg, cinnamon, and cloves; hence, it is called allspice. It is topical to the Caribbean area mainly Cuba and Jamaica. It grows naturally at an average temperature between 18^0 and 24^0. The plant is broadly cultivated in temperate areas throughout the world as a decorative plant, because of its catching appearance, and fragrance [745]. It is an evergreen plant. The height of this plant is up to 15 m with pale brown bark. The leaves are normal, opposite, oblong-elliptical, 6–20 cm long, with pellucid glands that provide an all-spice odor when squeezed. The flowers are tiny in size, whitish with a peculiar aroma, each of the flowers contains four petals, and the color of the flower is white and deciduous. The flowers are grown during March–June. The fruits mature in 3–4 months and are picked for spice collection when it is fully matured but still green. The fruits contain two kidney-shaped seeds [859, 860]. Since time immemorial, allspice is popular as a valuable spice due to its medicinal, and culinary properties. Its leaves are utilized to flavor the rice and provide a good aroma. Water extract of the berries is applied to cure diarrhea and flatulence. The powdered fruits are utilized for rheumatism, neuralgia, and aromatic provoking in digestive problems traditionally in India. It is effective in tonics, purgatives, and anodyne against neuralgia. In Turkey, it is utilized as an aphrodisiac when taken along with honey. The oil of the fruits and leaves are used in the food industry, specially in tanning, and meat as well as in cosmetic products, and perfumery compositions [745]

Kokam (*Garcinia indica*)

Garcinia Indica belongs to the family *Clusiaceae* It is a little to moderate-sized plant that is used as traditional house medicine for infections, flatulence, and heart attack. Numerous therapeutic activities of the fruit are documented in Ayurveda, like curing infusion, skin disease (rashes caused by allergies), scalds, chaffed skin, relief from sunstroke, treatment for dysentery, treatment of burns and mucous diarrhea, as an appetizer, to recover appetite, to reduce thirst, cardiotonic, piles, bleeding, and tumors. Kokam is prepared by sun-drying. The outer part of the fruit is used as a spice to add flavor and color to dishes. Kokam is a tropical evergreen tree. It is a thin plant having drooping dals height of about 15–20 m. It is native to the Western ghats area of India and distributed along North, and South Karnataka, Konkan, Goa, North Malabar, Coorg, West Bengal, Wayanad, and Assam [367, 395]

Greater galangal (*Alpinia galangal*)

Alpinia galangal belongs to the family *Zingiberaceae* It is distributed in tropical regions. It is mainly utilized in ethnomedicine and in food preparation. It is native to Indochina and Southeast China, especially Hainan, Guangdong, and Guangxi. It is cultivated throughout Eastern Himalayas, West Bengal, and Assam. It is utilized conventionally in Chinese medicine and Ayurveda. In China, rhizome from this plant has been utilized to treat bracing the circulatory system, stomach aches, colds, and to lower swelling [133]. It is commonly utilized for the treatment of bronchitis, eczema, coryza, gastritis, otitis interna, ulcers, morbilli, pityriasis Versicolor, cholera, to wash the mouth, and emaciation [279]. Indonesia is the leading producing country of galangal (303.53 million kg) [222]. It contains aromatic and tuberous rootstocks. The flowers are 30 cm long, greenish-white, and bracts ovate are lanceolate. Leaves are glabrous, oblong, lanceolate, and green, paler beneath, to some extent callus white margins. The color of the fruits varied from red cherry to orange [904, 965]

Sweet flag (*Acorus calamus*)

Since ancient times, the sweet flag exhibits various traditional, and ethnomedicinal applications in Siddha, Ayurveda, Unani, and Chinese medicine to treat different types of health problems such as bronchitis, nervous problem, appetite loss, chest pain, colic, cramps, diarrhea, digestive problem, flatulence, gastric problem, indigestion, rheumatism, sedative, cough, fever, inflammation, depression, tumors, hemorrhoids, skin ailment, numbness, and vascular diseases. The rhizome is used as a spice to provide flavor to food and alcoholic beverages [741]. Since ancient times, the sweet flag has been harvested. It is commonly cultivated in Asian countries. It is a very important tree in medical sciences [865]*Acorus calamus* belongs to the family *Acoraceae* It is an annual plant having weird and extensively branched, aromatic rhizome, tubular, up to 205 cm thick, the color changes from purplish-brown to lightly brown on the outside and white in the middle portion. The leaves contain one eminent midvein. This plant rarely grows flowers or produces fruits. The flowers are 3–8 cm long, tubular in shape, greenish-brown and are surrounded by a multitude of circular spikes. The fruits are little in size like berries, having some seeds [121]

Nutritional Potential of Spices

Spices help to keep the body healthy and fit [86] (Fig. 2). The spices contain carbohydrates, minerals, proteins, and vitamins. Table 1 and Table 2 portray the nutritional composition of the spices and herbs. Though spices are used in very small quantities in food, the amount of protein, fat, carbohydrate, and energy, which can be acquired from the spices is very negligible; however, the spices are rich source of various essential oils and fatty acids; thus, it is a source of essential nutrients for body development and to maintain immune system

Carbohydrate Carbohydrates are present in fennel, especially glucose, fructose, and sucrose, and are found in all the parts of fennel. The carbohydrates are composed of sugars that are naturally formed. Sucrose is the most valuable sugar in plants. Few percentages of sucrose could have been hydrolyzed to their monosaccharides to enhance the fructose, and glucose level in fennel that plays a valuable role for the contribution of carbon skeletons for the production of other compounds, and in the energetic metabolism. Mainly carbohydrates play an important role as major structural compounds and as short-term energy storage compounds [130]. Fennel and nutmeg contain an abundant amount of carbohydrates [21, 958]. Onion contains nonstructural carbohydrates (NSC) like sucrose, glucose, fructose, and fructo-oligosaccharides (FOS) such as fructo-furanosylnystose, ketose, and nystose [140]. Bay leaves are rich source of carbohydrates especially sucrose, fructose, and glucose [374]. Carbohydrates like L-arabinose, glucose, galactose, rhamnose, and polysaccharides present in asafetida [969]. Kokam contains carbohydrates, especially xylose, and glucose [1004]. The carbohydrate content of different types of spices is described in Table 1. The highest carbohydrate-rich spice is cassia bark (80.59%), and the minimum amount is observed in chili (3%)

Protein Protein helps in building up the body tissue, distributes as fuel source. Protein helps in the survival period of humans, and animal. Protein plays an important role in diet for maintaining proper functions of the body [35]. It is observed that cassia bark contains protein and provides good nutritional quality due to the presence of many essential amino acids like glutamic acid, lysine, aspartic acid, leucine, and valine. Naturally, the protein quality is determined by the amino acid profile [47]. The major amino acids present in onion are glutamine acid, and arginine [897]. Fenugreek is rich source of free amino acids such as histidine, and isoleucine that can provoke the secretion of insulin. Fenugreek provides an adequate amount of lysine. The quality of fenugreek lysine is the same as soybean lysine. For this reason, fenugreek is taken as dietary supplement. It is noted that fenugreek seeds contain significant concentrations of leucine, glutamine, asparagine, threonine, and arginine [1023]. Asafoetida contains mainly arabinogalactan protein [444]. Chili and poppy have several amino acids like isoleucine, tryptophan, threonine, leucine, lysine, methionine, cysteine, phenylalanine, tyrosine, valine, arginine, histidine, alanine, aspartic acid, glutamine acid, glycine, proline, and serine [182, 922]. Black mustard is the rich source of protein among the spices covered in this review article (26.08 g/100 g)

Fatty Acids Nowadays, the importance of essential fatty acids like alpha-linolenic acid, and linoleic acid, and their metabolites in animal, and human health is a vital topic in science [828]. Fatty acids help in the metabolic mechanism of living organisms. It is a source of several bioactive particles, energy, and structural elements [357]. Dietary fatty

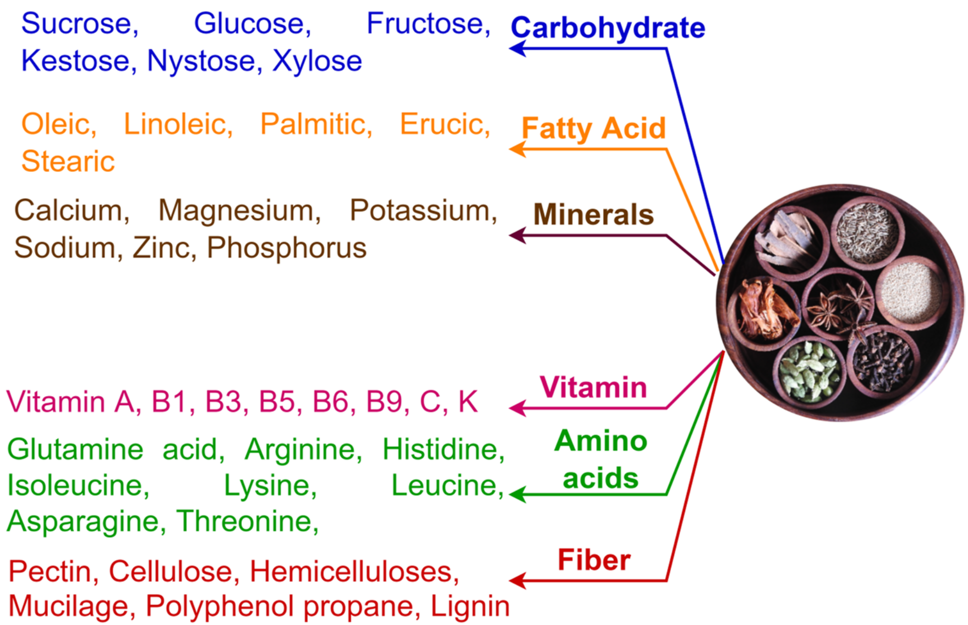


Fig. 2 Nutritional potential of spices and herbs

Table 1 Proximate composition of different spices

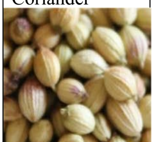
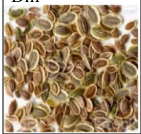
Spices	Protein (%)	Fat (%)	Carbohydrate (%)	Moisture (%)	Ash (%)	Fiber (%)	Reference
Cardamom 	10.6	2.4	68.2	85	5.3	16.3	(Ashokkumar et al., 2020)
Black jeera 	3-20	14.6	49.9	9.87	7.49-6.70	38	(Shahi et al., 2020), (USDA, 2019e)
Fennel 	1.24	0.2	7.3	90.21	1.05	3.1	(Badgujar et al., 2014)
Poppy 	11.9-23.5	32.44-46.24	28	3.4-5.3	0.5-6.6	6.2-30.1	(Muhammad et al., 2021)
Clove 	5.98	20.06	61.22	5.40-6.86	5.88	14	(Kumar Dey et al., 2021)
Cassia bark 	3.99	1.24	80.59	11.10	3.6	53.1	(Goel & Mishra, 2020)
Black pepper 	10	10.2	66.5	8	3.43-5.09	10.79-18.60	(Ashokkumar et al., 2021)
Coriander 	11.49	19.15	6.5	11.37	1.7	28.43	(Nadeem et al., 2013)
Nutmeg	5.84	36.31	49.29	6.23	2.34	20.80	(Kalam, 2020)

Table 1 (continued)

							
Dill 	3.5	1.1	7	4.85-24.81	9.88	2.1	(Ben- Nun, 2022)
Fenugreek 	25.4	9.5	42.3	7.49	3	50- 65	(Singh et al., 2020)
Asafoetida 	4	1	67.39	16	1.5- 10	4	(Amalraj & Gopi, 2017)
Celery 	5.68-7.53	2.21-3.14	41.4	5- 11	9.27	11.8	(Khairullah et al., 2021)
Chili 	0.6	0.9	3	0.4	0.3	1.4	(Chakrabarty et al., 2021)
Allspice 	6.09	8.69	72.12	8.46	4.65	21.6	(Staughton, 2021)
Kokam 	2	1.4	35	80	2.57	14	(Jagtap et al., 2015)
Greater galangal 	0.8	0.7	13	81.50	1.4	1.6	(Zanariah et al., 1997)
Sweet flag 	15.62	-	37.26	68.02	17.3	6.6	(Soman et al., 2014)

acids especially monounsaturated, and polyunsaturated fatty acids constituent the plasma lipoprotein profile and decrease the chances of heart problems [898]. Fatty acids can be divided into (1) saturated (2) monounsaturated (3) polyunsaturated. Cardamom contains fatty acids like saturated (myristic acid, palmitic acid, stearic acid, arachidic acid), monounsaturated (palmitoleic acid, oleic acid), polyunsaturated (linoleic acid, alpha-linolenic acid, eicosenoic acid) [89]. It is evidenced that palmitic acid is the major fatty acid present in the oil of cassia bark [47]. Fennel fixed oil contains some major fatty acids like palmitic acids, oleic acid, and linoleic acid [762]. The major fatty acid in poppy is linoleic acid covering 70.7–75.2% of the total fatty acid content [542]. During the ripening of coriander fruit, the amount of monounsaturated fatty acid has been increased, while the amount of polyunsaturated and saturated fatty acids is decreased. Coriander contains various fatty acids, namely myristic acid, stearic acid, palmitic acid, behenic acid, arachidic acid, petroselinic acid, oleic acid, linoleic acid, and linolenic acid [653]. Palmitic acid, lauric acid, myristic acid, myristoleic acid, stearic acid, oleic acid, palmitoleic acid, and linoleic acid are obtained from nutmeg [1016]. The fatty acids like stearic, palmitic, heptadecanoic, linoleic, oleic, linolenic, eicosenoic, arachidic, behanic, heneicosanoic, erucic, lignoceric, docosadienoic, and nervonic are present in *Brassica nigra* [435, 436]. Saturated fatty acids exist in an abundant amount in saffron [209]. Chinese star anise contains more palmitic, oleic, and linoleic acid [426]. The predominant fatty acid in *Allium cepa* is linoleic acid followed by oleic and palmitic acid [332]. Dill seed oil contains about 8.51% of saturated fatty acids (stearic acid, and palmitic acid) and about 91.35% of an unsaturated fatty acids [873]. Egyptian fenugreek oil contains 13.8% linolenic acid, 33.7% linoleic, and 35.1% oleic acid [898]

Minerals Minerals are known as micronutrients that play an important role in the body's immunity system and metabolism. Spices are considered as good sources of minerals. The insufficiency of mineral content in human body is attributed due to 1) improper absorbance and 2) inadequate intake. Enzymes required several minerals as the co-factor for proper activity and function. These enzymes got deactivated due to the absence of minerals [979]. Minerals are important for the antioxidant activity. Inadequate consumption of mineral-enriched food products is observed among a vast number of economically backward people. Mustafa [631] studied that calcium (Ca), phosphorus (P), potassium (k), sodium (Na), and magnesium (Mg) are present in spices. The spices, *Elattaria cardamomum,* and *Curcuma longa* contain ample amounts of important trace elements like manganese (Mn), iron (Fe), and zinc (Zn). Derivative of minerals in spices helps in various activities of the body's growth like Fe assists in cellular growth, oxygen transport, and oxidative metabolism. Similarly, calcium and copper are critical to maintain various physiological activities. Zn plays a valuable role in replication and cellular immune response. Consumption of spices can add minerals into the diet and contributes a nutritious effect. But excess level of minerals consumption can cause toxicity. It is observed that Ca, Na, K, and Mg were comprehensively higher in all the spices. Ca content is higher in laurus leaves and black seed. Copper is relatively very less in all spices [631]. K, Ca, Mg, P, sulfur (S), and iron (Fe) are present in *Foeniculum vulgare* and cardamom. Particularly, cardamom leaves and capsules possess significant levels of Mn and Zn [89, 749]. Poppy contains minerals like K, P, Ca, Mg, Na, and Fe [630]. Clove is one of the spices that is one of the highest rich sources of manganese and is important for enhancement of bone strength and metabolism and contributes in the development of enzymes. The occurrence of the strong appearance of the clove is due to the presence of K, Mg, and Ca

Table 2 Mineral composition (mg/100 g) of selective spices

Spices	Ca	Mg	Mn	Fe	Cu	Zn	Na	Reference
Cardamom	92.7	181.5	41.7	12.8	0.5	3.6	17	[89]
Shah jeera	689	258	1.3	16.2	0.91	5.5	17	[949]
Fennel	49	17	-	0.73	-	0.2	52	[110]
Poppy	690.50	287.20	3.84	5.47	2.58	2.57	81.16	[621]
Clove	0.64	60	0.25	8.68	0.23	2.32	243	[500, 950]
Cassia bark	1002	60	17.46	8.32	0.33	1.83	-	[329]
Black pepper	400	235.8–249.8	12.8	17	1.33	1.45–1.72	10	[88]
Coriander	709	330	-	17.9	-	4.70	35	[145]
Nutmeg	189	183	2.90	3.04	1.03	2.15	16	[419]
Black mustard	266	370	2.45	9.21	0.64	6.08	13	[636]
Turmeric	200	208	19.8	47.5	1.3	4.5	10	[714, 951]
Bay leaves	834	120	8.16	43	0.41	3.70	23	[135]
Saffron	111	264	28.40	11.10	0.32	1.09	148	[794]
Star anise	646	170	2.3	37	0.91	5.3	16	[948]
Onion	23	10	1.29	0.21	0.03	0.17	4	[947]
Dill	208	55	1.3	6.6	0.14	0.9	61	[138]
Fenugreek	176	191	1.23	33.53	1.11	2.5	67	[560]
Asafoetida	690	80	1.1	39	0.4	0.8	-	[70]
Celery	403–709	243–556	35.3–39.3	101.4–305.2	39.98–56.90	11.96–15.61	80	[443]
Chili	7.8	8	0.1	0.4	-	0.1	1.6	[182]
Allspice	661	135	2.94	7.06	0.55	1.01	77	[892]
Greater galangal	5000	2000	1000	1000	-	1000	-	[228]
Sweet flag	158.56	64.4	-	-	1.15	1.80	182.3	[876]

[151]*Cinnamomum cassia* possesses an ample amount of Ca [47]. The electrolytes like K, and Na and minerals such as Fe, Ca, Cu, Mg, Mn, P, Zn are present in *Myristica fragrans* [21]. Mg, P, Ca, and K are present in adequate amount in turmeric [710]. The seeds of star anise are source of minerals like Cu, Ca, Fe, K, Mn, Mg, and Zn [831]. Calcium is present in a higher amount in the brown skin of the onion and the whole onion contains an ample amount of Zn, Mg, Fe, and Mn [140]. Dill contains micronutrients like Fe, Zn, Cu, and Mn and four macronutrients Mg, K, Ca, and P but Fe, Ca, and P [782]. Fenugreek seed and asafoetida are good sources of Fe and Ca [679, 710]. P, Zn, Mg, Mn, Ca, Se, Cu, Na, Pt, Fe, and K are some important minerals present in celery [822]. Chili contains minerals like K, Ca, Fe, P, Na, Mg, Cu, and Zn that play a valuable role in human health development [669]. kokum contains minerals like Ca, Mn, Mg, and K that protect against heart disease, control blood pressure, and heart rate [109]

Vitamins Vitamins like vitamin A, C, riboflavin, thiamine, niacin, and pyridoxine (B_6) are present at higher amounts in cardamom [281]. The coriander green leaves possess important vitamins like vitamin C, riboflavin, niacin, and vitamin A [634]. The valuable vitamins like niacin (B_3), thiamin (B_1), riboflavin (B_2), pantothenic acid (B_5), pyridoxine (B_6), folic acid (B_9), and vitamins E and C are present in poppy [673]. Cassia bark has important vitamins like vitamin C, and A [329]. Fennel is rich source of vitamins like B_2, C, B_1, B_3, B_6, folate, and vitamins A, E, and K [130]. Vitamins E, A, and C are the main vitamins of nutmeg [21]. Clove is one of the rich sources of vitamin K, and C [151]. Vitamins like B2, vitamin C, K, and B6 are present in abundant amounts in black pepper [853]. Turmeric is an exuberant source of vitamin C, and pyridoxine [710]. One of the main constituents of saffron is vitamins especially B1, and B2 [321]. Many essential B-complex vitamins like riboflavin, pyridoxine, niacin, thiamin, and vitamins C and A are present in adequate amounts in anise seeds [830]. Onion provides high amounts of folic acid, and vitamin B6 [897]. Dill contains mainly vitamin E, and A [782]. Fenugreek seeds contain adequate amount of vitamin C, A, B1, and nicotinic acid [1023]. Vitamin C is mainly present in celery [443]. Chili is one of the great source of vitamin C that is a potent antioxidant that develops natural immunity against diseases. Chili also contains vitamin A which is a fat-soluble vitamin that assists to reduce the health hazards caused by free radicals and assists in the formation of red blood cells and other B-complex vitamins B6, K, B3, B2, and B1 [182]. It is noted that kokam leaves are rich source of ascorbic acid and B-complex vitamins that assist to maintain blood pressure and heart rate [395]. Vitamins C and A are found in adequate amount in greater galangal [122]

Fiber Fiber is a very important nutrient in maintaining the human health and has been found to decrease the level of cholesterol, decrease the chances of different types of cancers and bowel disorders, maintain carbohydrates and lipid metabolism, cure gut function, and assist in constipation problem and well-being of individual [35]. Fibers are composed of a group of compounds such as non-starch polysaccharides (pectin, cellulose, hemicelluloses, and mucilage), polyphenol propane, and lignin. The fibers are present in most of the plants and cannot be hydrolyzed within the human body [310]. Cassia bark contains a high amount of crude fiber [47]. Fennel, nutmeg, and clove are rich sources of dietary fiber [21, 130, 151]. It has been observed that total dietary fiber is high in brown skin of onion [140]. Black pepper, turmeric, onion, and kokam are good sources of dietary fiber [710, 756, 853, 897]. The maximum fiber content is seen in cassia bark (53.1%), and the lowest amount is reported in chili (1.4%)

Bioactive Potential of Selected Spices and Herbs

Nowadays, it has become important to search for natural bioactive components to replace synthetic compounds. The bioactive compounds from natural sources have several advantages over the synthetic drug molecules and have several side effects [809, 810]. Spices are a very necessary resource due to the presence of an ample amount of bioactive components (Table 3), for the searching of a new substitute, and bioactive molecules in drug formation studies for different types of diseases [803]. Spices possess various phytochemicals that contain antioxidative activity and lead to a decrease in inflammation, modulation of detoxification of enzymes, manifestation of the immune system, antibacterial, and antiviral activities [513]. Spices contain various active components like phenolic acids, phthalides, polyacetylenes, flavonoids, coumarins, and terpenes and are recommended to be potent antioxidants [86]

Elettaria cardamomum (Cardamom)

The main constituent present in cardamom is 1,8-cineole, which is responsible for its characteristic aroma. The potential antimicrobial effect is observed in cardamom essential oil (CEO) against gram-negative and gram-positive microorganisms [656]. The volatile oil is the most important component of cardamom, has its characteristic aroma. The oil contains small mono- or sesquiterpene hydrocarbons. It is mainly formed by oxygenated compounds,all of these are potential aroma compounds. The aroma variations in different sources of cardamom are due to the alteration of proportion of the 1,8-cineole and esters. The minor compounds like alcohols, methyl eugenol, and terpene hydrocarbon are present in cardamom. The characteristic aroma of cardamom is formed by the combined effects of major components like 1,8-cineole and alpha-terpinyl acetate. These compounds are found to be carminative, antiseptic, anti-inflammatory, and stimulating [481]. The cancer can be treated by various methods like chemotherapy, radiation therapy, palliative care, surgery, targeted cancer therapy, etc. However, these methods exhibited toxic side effects on the patient's normal cell, and overall health condition. For this reason, spices have been used as an alternative way to treat the breast cancer, with bioactive components like anthocyanin, alkaloids, flavonoids, terpenes, and phenylpropanoids which can retard biological activities occurred with breast cancer cell growth. In traditional Ayurveda, cardamom is used in human diet to prevent the growth of cancerous cell. Cardamom is a profoundly used spice and shows anti-carcinogenic potential due to the presence of DCM (diindolylmethane) and IC3 (indole-3-carbinol) that can destroy breast cancer cells and retard prioliferation. These compounds also give additional anticancer benefits by developing host immune response. For this reason, it is suggested that cardamom should be intake regular basis. Phytochemicals like limenonene and cineole present in cardamom act as chemoprotective [977]

Bunium persicum (Black jeera)

The various extracts of seeds, and essential oil of *Bunium persicum* has been analized for antioxidant activity by three methods, namely ammonium thiocyanate, DPPH assay, and beta-carotene bleaching. It is observed that the highest antioxidant activity is found in methanolic extract of oil. The major components of *Bunium persicum* oil are gamma-terpinene and cuminaldehyde as evaluated by the GC/MS method. With the help of column chromatography, the methanol extract of the plant has been fractioned. In this fraction, p-coumaric acid, kaempferol, and caffeic acid have been observed in the antioxidant activity. It is confirmed that cardamom oil and methanolic extract showed radical scavenging and antioxidant activity*Bunium persicum* is hydrodistillized to form the pale yellow-colored essential oil which contains about 24 compounds that comprise 97.20% of the oil. The oil is made of oxygenated monoterpenes, and hydrocarbons like alpha-thujene, sabinene, alpha-pinene, myrcene, beta-pinene, alpha-terpinene, p-cymene, alpha-terpinolene, p-Menthe-3-ene-7-al, cuminyl alcohol, beta-caryophyllene, gamma-eleman, beta-bisabolene, beta-selinene, myristicin, germacrene B, and dillapiol. Other main components of the oil are limonene, cuminaldehyde, and p-cymene [839]. It has been observed that various phytochemicals like terpenes (sesquiterpene, monoterpene, oxygenated monoterpenes, oxygenated sesquiterpenes), aliphatic compounds, steroids, terpenoids, campesterol, esters, stigmasterol, fatty acids, alkaloids, resins, tannins, thymoquinone, phenolics, saponins, and

Table 3 Bioactive potential and health-beneficial effects of spices

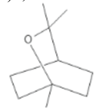
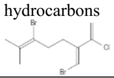
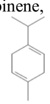
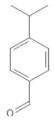
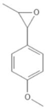
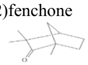
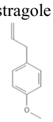
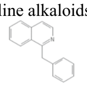
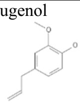
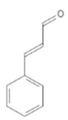
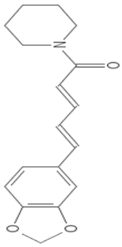
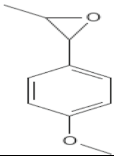
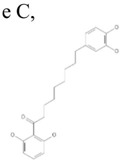
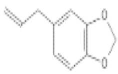
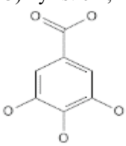
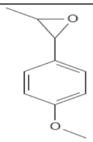
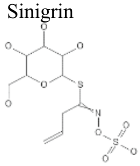
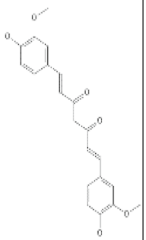
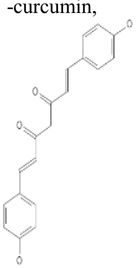
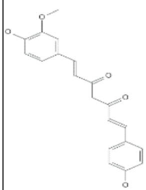
Spices	Main bioactive compounds	Extraction technique	Solvent used	Health beneficial effect	Quantitative bioactive measure	Reference
Elettaria cardamomum	1)1, 8- cineole  2)monoterpene hydrocarbons 	gas chromatography-mass spectrometry (GC-MS)	Ethanol, and methanol	antimicrobial, anti-inflammatory, anticancer, and insecticidal activities	TPC (0.31-1.66 g/100 g), TFC (11.33-4.63 g/100 g)	(Bhatti et al., 2010)
Bunium persicum	1)gamma-terpinene,  2)cuminaldehyde 	GC-MS	Methanol, chloroform, water, and ethanol	Antimicrobial, anti-inflammatory, lipid/ glucose reducing activity, anti-carcinogenic activity, antiparasitic, antinociceptive, anticonvulsant, and antidiabetic activities	TPC (4.22 mg GAE.g[-1])(GAE- gallic acid equivalent/g of sample), TFC(10.91 mg QE.g[-1])(QE- quercetin equivalent/g of sample)	(Ražná et al., 2018)
Foeniculum vulgare	1)trans-anethole  2)fenchone  3)estragole 	GC-MS	methanol	Anticancer, anti-inflammatory, antifungal, anti-bacteria, and estrogenic activities	TPC (0.364 mg/g tannic acid equivalent in FAcSE) (FAcSE- fennel acetonic seed extract), TFC (0.0449 mg/g quercetin equivalent in FMSE) (FMSE- fennel methanolic seed extract)	(Goswami & Chatterjee, 2014)
Papaver somniferum	benzylisoquinoline alkaloids 	GC-MS, and Fourier Transform Infrared Spectroscopy (FTIR)	Methanol, water, and ethanol	Analgesic, narcotic, and sedative activities	TPC (1015-6900 mg/100 g)	(Ishtiaque et al., 2015)
Syzygium aromaticum	Eugenol 	FTIR, and GC-MS	ethanol	Antibacterial, antifungal, herbicidal, nematicidal, antitumor, and anti-inflammatory activities	TPC (255.8 mg GAE/g), TFC (63.9 mg RUT/g)(RUT-rutin equivalents)	(Moradi et al., 2017)
Cinnamomum cassia	Cinnamaldehyde 	GC-MS	Ethanol	Antifungal, anti-diabetic, antioxidant, anti-cancer, anti-H.pylori, gastroprotective, anti-nematodes, anti-ischemic,	TPC (9.534 g GAE/100 g DW) (DW- dry weight), TFC (2.030 g Quercetin/100 g DW)	(Yang et al., 2012)

Table 3 (continued)

				neuroprotective, anti-inflammatory, anti-melanin, and anti-allergic activities		
Piper nigrum	Piperine 	High-Performance Thin Layer Chromatography	methanol	Antimicrobial, antioxidant, anticancer, antidiabetic, hypolipidemic, anti-inflammatory, analgesic, anticonvulsant, and neuroprotective activities	TPC (1.728 mg/g), TFC (1.087 ug/g)	(Ahmad et al., 2015)
Coriandrum sativum	Linalool 	GC-MS	Hexane	Anti-bacterial, antifungal, and antioxidant effects	TPC (12.2 GAE/g), TFC (12.6 quercetin equivalents/g)	(Deepa & Anuradha, 2011)
Myristica fragrans	1)malabaricone C,  2)safrole,  3)myristicin,  4)elemicin	HPLC	Methanol, ethyl acetate, ethanol, n-hexane	Antioxidant, anticonvulsant, analgesic, anti-inflammatory, anti-diabetic, antibacterial, and antifungal effects	TPC (112.41 mg GAE/100 g), TFC (26.12 mg QE/100 g)	(Pashapoor et al., 2020)

flavonoids are obtained in *Bunium persicum*. Some components such as gamma-terpinene-7-al, and beta-sinensal are found in black jeera. The pleasant aroma of the oil is mainly contributed by cumaldehyde. The oil is used to produce perfumes, and other cosmetics. The reduction in the quality of the spice is due to the presence of beta-pinene, gamma-terpinene, and p-cymene*Bunium persicum* showed potential antifungal effects due to the existence of p-cymene and cuminaldehyde [126]

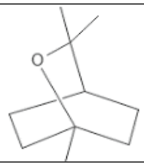
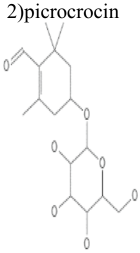
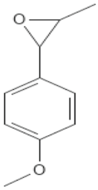
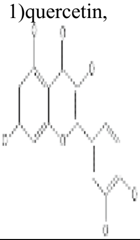
Table 3 (continued)

						
Brassica nigra	Sinigrin 	GC-MS, HPTLC (High Performance Thin Layer Chromatography), TLC, and FTIR	Ethanol	Anticancer, anti-diabetic, anti-obesity activities	TPC (19.9-32.2 mg GAE/g), TFC (3.9-7.4 mg QEs/g)	(Dordevic et al., 2021)
Curcuma longa	1)Curcumin,  2)bidemethoxy-curcumin,  3)demethoxycurcumin 	GC-MS	Ethanol, methanol, and water	Anti-inflammatory, antioxidant, antimutagenic, antidiabetic, antibacterial, hepatoprotective, expectorant, and anticarcinogenic effects	TPC (745.76 mg GAE/100 g), TFC (741.36 mg NG/g DW) (NG-naringenin equivalents)	(Nisar et al., 2015), (Akinola et al., 2014)
Laurus nobilis	1,8-cineole	GC-MS, SFME (Solvent Free	methanol	Antibacterial, antifungal, antioxidant,	TPC (25.32-54.42 ug PEs/mg) (PE-	(Kivrak et al., 2017)

Foeniculum vulgare (Fennel)

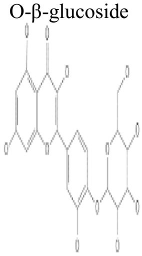
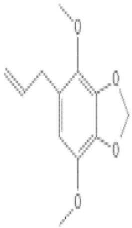
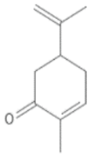
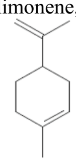
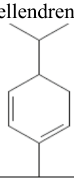
In the methanolic extract of fennel seed, 56 bioactive phytochemical compounds were determined. The phytochemicals detected depend on the molecular formula, peak location, retention time, molecular weight, MS-fragments, and pharmacological actions. Alcohols,

Table 3 (continued)

		Microwave Extraction)		insecticidal, and nematicidal effects	pyrocatechol equivalents), TFC (5.48-8.60 ug QEs/mg)	
Crocus sativus	1)crocin,  2)picrocrocin 	Conventional maceration, UAE (Ultrasound-Assisted Extraction)	Water, and methanol	Antidepressant, sexual dysfunction, antioxidant, anticarcinogenic, antispasmodic, digestive tonic, anti-inflammatory, analgesic, hypocholesterolemic, and anti-diabetic activities	TPC (25.24-65.34 mg GAE/g), TFC (12.17-60.64 mg of CE/g) (CE-catechin equivalents)	(Jadouali et al., 2019)
Illicium verum	trans-anethole 	GC-MS, TLC, HPTLC	Methyl alcohol, ethyl acetate, petroleum ether, n-hexane, and methanol	Antimicrobial, antioxidant, and anticancer activities	TPC (63.51 ug GAEq/mg), TFC (24.30 ug quercetin Eq/mg	(Asif et al., 2016)
Allium cepa	1)quercetin, 	GC-MS	Methanol, and water	Antioxidant, antimicrobial, anti-diabetic, anti-obesity, hyperlipidemic, and hypertensive effects	TPC (56-156 mg GAE ml^{-1}), TFC (12.21-52.43 mg/100g FW) (FW-fresh weight)	(Nile & Park, 2013)293,(Rodrigues et al., 2017)

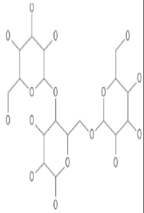
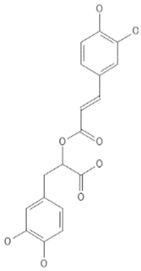
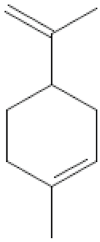
alkanes, ethers, carboxylic acids, esters, nitro compounds, alkenes, hydrogen-bonded alcohols, aliphatic fluoro compounds, and phenols are identified in fennel seeds through Fourier Transform Infrared Spectroscopy (FTIR). Fennel contains ample amounts of phytochemical compounds like cyclohexene, 4-isopropenyl-1-methoxymethoxymethyl, O-alpha-D-glucopyranosyl-(1- > 3)-beta-D-fructo, L-fenchone, estragole, 2-propyl-tetrahydropyran-3-ol,

Table 3 (continued)

	2)quercetin 4'-O-β-glucoside 					
Anethum graveolens	1)apiol,  2)carvone,  3)limonene,  4)α-phellendrene 	GC-MS	Methanol, hexane, and dichloromethane	Antibacterial, antifungal, antioxidant, insecticidal, anti-inflammatory, anti-diabetic, antispasmodic, and hypolipidaemic effects	TPC (7.06-19.09 mg GAE/g), TFC (2.45-5.07 mg QE g^{-1})	(Kaur et al., 2018)
Trigonell	Galactomanna	UHPLC-ESI-	Ethanol,	Anti-diabetic,	TPC (1.35-	(Bhanger et

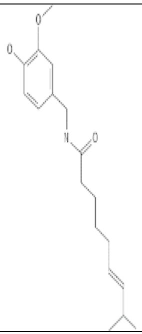
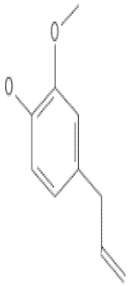
benzaldehyde, 4-methoxy, anethole, 2-methoxy-4-vinylphenol, ascaridole epoxide, d-mannose, pterin-6-carboxylic acid, 4-methoxybenzoic acid, allyl ester, arisaldehyde dimethyl acetal, 1-propyl-3, 6-diazahomoadamantan-9-ol, 4-(2,5-dihydro-3-methoxyphenyl) butylamine, corymbolone, apiol, fenretinide, dihydroxanthin, 1-(4-methoxyphenyl)-1, 5-pentanediol, 1-heptatriacotanol, gibberellic acid, 2, 3-dimethoxy-5-methyl-6-decaisoprenyl-chinon, 2-[4-methyl-6-(2,6,6-trimethylcyclohex-1-enyl) hexa-1,3,5-trienyl] cyclo, cis-vaccenic

Table 3 (continued)

a foenum-graecum	n 	MS/MS(Ultrahigh Performance Liquid Chromatography-Electrospray Ionization-Mass Spectrometry	petroleum ether, acetone, and hexane	hypocholesterolaemic, immunomodulatory, anti-toxic, anti-cataract, antioxidant, and anticarcinogenic activities	6.85 mg GAE/g), TFC (208-653 ug QE/g)	al., 2008)
Ferula assafoetida	rosmarinic acid 	GC-MS	methanol	Antispasmodic, carminative, expectorant, laxative, sedative, stimulant, emmenagogue, and vermifuge effects	TPC (55.56-90.14 mg GAE/g), TFC (21.48-35.75 mg QE/g	(Kavoosi & Rowshan, 2013)
Apium graveolens	Limonene 	SFE (Supercritical Fluid Extraction)	Water, and hexane	Aphrodisiac, anthelmintic, antispasmodic, carminative, diuretic, emmenagogue, laxative, sedative, stimulant, anti-toxic, antifungal, antihypertensive, hypolipidemic, and anticancer activities	TPC (56.3-73.1mg GAE/100 g), TFC (29.2-56.95 mg quercetin/g)	(Aydemir & Becerik, 2011)298,(Kooti & Daraei, 2017)
Capsicum frutescens	Capsaicinoids	GC-MS	Ethanol, water, and methanol	Antimicrobial, antiseptic, anticancer, counterirritant, appetite stimulator, antioxidant, and immunomodulatory activities	TPC (90.86-221.21mg GAE/g DW), TFC (543.09-867.24 mg QE/g DW	(Olatunji & Afolayan, 2019)

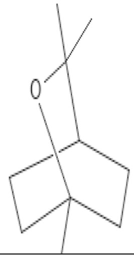
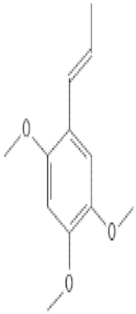
acid, 6,9,12,15-docosatetraenoic acid, methyl ester, dl-3beta-hydroxyl-d-homo-18-nor-5 alpha, 8 alpha, 14 beta-androst-13 (1), 5 Ah-3a, 12-methano-1H-cyclopropa [5', 6'] cyclodeca [1', 2': 1, 5] cyclo, (22S)-21-acetoxy-6alpha, 11beta-dihydroxy-16alpha, 17alpha-propylmethylenedioxyp, oxiraneoctanoic acid, 3-octyl-, methyl ester, ingol 12-acetate, alpha-D-glucopyranoside, and 2,24a,6a,8a,9,12b,14a-octamethyl-1,2,3,4,4a,5,6,6a,6b,7,8,8a,9,1 as identified by chromatogram GC–MS method [381]. Essential oil is present in ample

Table 3 (continued)

						
Pimenta dioica	Eugenol 	GC-MS	Water	Antibacterial, hypotensive, anti-neuralgic, analgesic, antiproliferative, anti-tumor, anti-prostate cancer, and anti-breast cancer activities	TPC (99.09 mg Gallicacid equivalent/g), TFC (136.71mg Rutin equivalent/g)	(Dharmadasa et al., 2015)
Garcinia indica	Garcinol 	LC-MS (Liquid Chromatography-Mass Spectrometry	water	Antioxidant, anti-obesity, anti-arthritic, anti-inflammatory, antibacterial, hepatoprotective, cardioprotective, antidepressant, anxiolytic, and anti-diabetic effects	TPC (8.34 mg GAE/g FW), TFC (27.14 mg CE/g FW	(Singh et al., 2022)
Alpinia galangal	1,8-cineol	GC-MS	Ethanol	Anti-inflammatory, analgesic, antiallergic, antifungal, antidiabetic, antibacterial, antiulcer, immunostimul	TPC (5.01-31.49 mg GAE/g), TFC (0.20-13.78 mg CE/g)	(Mahae & Chaiseri, 2009b)

amount in fennel seeds that provides the characteristic flavor. Seeds contain several lipophilic and hydrophilic compounds like carotenoids, phenols, chlorophylls, unsaturated fatty acids, and phytosterols. These compounds act as potential antioxidant agent and prevent various types of diseases [760]. The major phytoconstituents of fennel seeds are volatile aroma compounds, phenols, and phenolic glycosides like trans-anethole (81.63% and 87.85%), fenchone, and estragole. It is reported that the major acaricidal agents are

Table 3 (continued)

				atory, anticancer, antioxidant, antiamoebic, and antidermatophytic activities		
Acorus calamus	α- asarone 	GC-MS	Petroleum ether, chloroform, hexane, and ethyl acetate	Anti-inflammatory, anti-spasmodic, anti-protective, and anti-hepatotoxic activities	TPC (2398.40 mg GAE/100 g), TFC (190.46 mg QE/100 g)	(Susanah et al., 2018)

fenchone and p-anisaldehyde that have proven effectiveness against dermatoghagoides pteronyssinus, and dermatophagoides farinae. In another investigation, anethole and its polymer like photo anethole, and dianethole are proved to be active oestrogenic agents. It is proved that anethole acts as protective antithrombotic agent due to its vasorelaxant action, antiplatelet activity, and clot destabilizing effect. However, estragole may cause anxiety as the structure of estragole is similar to methyleugenol. Estragole has carcinogenic property. The maximum limit of estragole in non-alcoholic beverage is 10 mg/ kg. Phenolic acids like 5-O-caffeoylquinic acid, 3-O-caffeoylquinic acid, 4-O-caffeoylquinic acid, 1,3-O-di-caffeoylquinic acid, and 1,4-O-di-caffeoylquinic acid, and the flavonoids such as rosmarinic acid, eriodictyol-7-rutinoside, and quercetin-3-rutinoside are found in fennel. Phenolic compounds are considered to be a preventive measure against various diseases like inflammation, cardiovascular disease, and cancer [749]

Papaver somniferum (Poppy)

The main active secondary compound of poppy seed is benzylisoquinoline alkaloids (BIAs). Several bioactive compounds like phenolic compounds, alkaloids, flavonoids, and polyunsaturated fatty acids are present in poppy seed. It has been utilized as food ingredients. Poppy seed oil is a rich source of polyunsaturated fatty acids. Poppy possesses lactic acid, meconic acid, and alkaloids like morphine, codeine, noscapine, thebaine, papaverine, aporphines, protoberberine, rhoeadines, benzophenanthridine, and tetrahydroisoquinolines. Poppy seed oil contains tocopherol, and unsaturated fatty acids. At present, poppy seed oil is utilized in infant formulas due to the absence of narcotic properties. Due to the presence of important phytochemicals like tocopherol, the seed oil is used as a nutraceutical supplements in different types of food products. Linoleic acid (68%) is the major fatty acid found in poppy seed oil. Poppy seed oil contains unsaturated fatty acids like linolenic acid, oleic acid, linoleic acid, and palmitoleic acid, and the principal saturated fatty acids such as arachidic acid, stearic acid, and palmitic acid. The poppy seed oil is used for food processing due to the presence of a high amounts of linoleic acid. Poppy possesses neutral elements like melanoidin, opionin, and meconin. Poppy contains organic acids such as meconic, lactic, caffeic, and ferulic acids. Tocotrienols and tocopherols have made the poppy seeds valuable for preventing various diseases like cancer, autoimmune, cardiovascular, metabolic, bone, and neurological disorders. Due to the presence of excessive amounts of tocotrienols and α-tocotrienols in the plasma membrane, the poppy seed oil possessed antioxidant activity and it has the potential to retard the lipid oxidation [621]. Various secondary metabolites such as saponins, tannins, cardiac glycosides, phytosterols, and terpenoids are present in poppy seed. Volatile compounds like 9-octadecanoic acid, methylester, (E, E),9-tetradecen-1-ol, acetate, (E),9,12-octadecadienoic acid, cis-9,10-epoxyoctadecan-1-ol, and undec-10-ynoic acid as determined by GC–MS. Different types of functional compounds like carboxylic acid, alcohols, phenols, aldehydes, anhydrides, amides, esters, ketones, unsaturated aliphatics, unsaturated heterocycles, aromatics, amines, nitro compound, alkanes, and alkenes are determined by FT-IR in poppy seed. It is utilized potentially in various ways in the field of pharmacy and food technology to prevent various human diseases [632]

Syzygium aromaticum (Clove)

Phenolic compounds like hydroxycinnamic acids, flavonoids, hydroxybenzoic acids, and hydroxyphenyl propens are present in abundant amounts in clove flowers. Eugenol is the main bioactive compound of clove ranging from 9381.70 to 14,650 mg/100 g of fresh plant material. Clove contains gallic acid, phenolic acid, and other gallic acid derivatives as hydrolysable tannins at a higher level. Clove possesses phenolic acids like elagic, ferulic, caffeic, and salicylic acid and the flavonoids such as quercetin, kaempferol, and its glycosylated moiety. Eugenol is contributed 89% of the clove essential oil. Eugenol acetate and β-cariofileno contributed 5%-15% of the clove essential oil. The other valuable compound is obtained in the essential oil of clove is α-humulene at a level up to 2.1%. Clove has some volatile compounds in its essential oil like farnesol, limonene, benzaldehyde, 2-heptanone, β-pinene, and ethyl hexanoate in lower concentrations. This plant is utilized for centuries as a medicinal plant and food preservative especially as an antioxidant agent and also showed antimicrobial effects [607]. The phytochemicals like hydrocarbon, monoterpenes, and sesquiterpenes are found in ample amounts in clove. Various studies demonstrated that eugenol showed anticancer, antioxidant, antiseptic, antidepressant, antispasmodic, anti-inflammatory, antiviral, antifungal, analgesic, and antibacterial effects against various pathogenic bacteria like *S. aureus* and *methicillin-resistant Staphylococcus epidermidis* It has protective activity against CCl_4-induced hepatotoxicity and it provides powerful lethal effectiveness against the propagation of several parasites such as *Haemonchus contortus, Giardia lamblia, Fasciola gigantica, and Schistosoma mansoni*. Eugenol is broadly applied in dentistry due to its penetrating power into dental pulp tissue. Sesquiterpenes have been found to possess anti-carcinogenic activity. It is reported that eugenol is able to donate the hydrogen atom and subsequently neutralized the phenoxyl radical that results in the occurrence of steady molecules which do not develop or enhance the rate of oxidation.

Eugenol possessed carbon chain link combined with the aromatic ring that can be engaged in phenoxil radical stabilization with the help of resonance. Calamenene, calacorene, and humulenol are identified in clove by gas chromatography–mass spectroscopy (GC–MS). Biflorin, 5,7-dihydroxy-2-methylchromone-8-C-β-D-glucopyranoside, orsellinic acid glucoside, myricetin, rhamnocitrin, and oleanolic acid are found in clove and showed their efficacy in retarding oral pathogens [134]. The gas chromatography evaluation of hexane extract of clove determined the presence of compounds like chavibetol, 2,6,6,9-tetramethyl-1,4,8-cycloundecatriene, and copaene [113]

Cinnamomum cassia (Cassia bark)

The main active component of cassia bark is essential oil like cinnamaldehyde (0.003 mg/mL). Essential oil consists of cinnamic acid, coumarin, cinnamyl alcohol, and 2-methoxycinnamaldehyde. Essential oil showed anti-platelet aggregation, antioxidant, anti-diabetic, and antifungal activities [1017]. Terpenes are found in cassia bark oil in abundant quantity. Four chemical classes are obtained in the crude extract of cassia bark like oxygenated sesquiterpenes, oxygenated monoterpenes, sesquiterpene hydrocarbon, and other oxygenated compounds. Trans-cinnamaldehyde is predominantly present in the extracted cinnamon oil. The other compounds are guaiacol, benzenepropanal, cis-cinnamaldehyde, bornyl acetate, acetophenone, geranyl acetate, tetradecanal. Oxygenated monoterpenes are eucalyptol, linalool, borneol, L-α-terpineol, benzaldehyde, anethole, and eugenol. The sesquiterpene hydrocarbons are α-cubebene, copaene, β-caryophyllene, α-muurolene, trans-α-bergamotene, α-humulene, α-amorphene, 1 s-cis-calamenene, calarene, cedrene, and β-cadinene. Oxygenated sesquiterpenes consist of caryophyllene oxide, and tau.-muurolol [410]. Glycosides, terpenoids, and phenylpropanoids are other main compounds in cassia bark. Cinnzeylanol, anhydrocinnzeylanol, 2,3-dehydroanhydrocinnzeylanine, 1-acetylcinncassiol A, 16-O-β-D-glucopyranosyl-19-deoxycinncassiol G, perseanol, and D_1 glucoside are the diterpenoids isolated from cassia bark. Cinnacasside B, cinnacassoside D, cinnacasolide E, and samwiside are glycosides isolated from cassia bark. Other chemical compounds are present in cassia bark like benzyl benzoate, 2-hydroxybenzaldehyde, 3-phenylpropanol, 2,2,4,6,6-pentamethylheptane, 2,5,9-trimethyldecane, 2-ethyl-5propylphenol, 3,4-dimethoxyphenethyl alcohol, 2,5-dimethylundecane, benzaldehyde, phenylethyl alcohol, benzenepropanal, acetophenone, 1,3-dimethylbenzene, styrene, 2,2,4-trimethyl-1,3-pentanediol, decanal, 2,6,10-trimethyldodecane, rosavin, coumarin, dihydromelilotoside, evofolin B, and cinncassin C [1012]

Piper nigrum (Black pepper)

The most abundant chemical alkaloid present in black pepper is piperine. Other alkaloids are piperanine, piperylin A, piperettine, pipericine, and piperolein B. Black pepper possesses an abundant amount of polyphenols as compared to white pepper. It is recorded that alkaloids, some aromatic compounds, flavonoids, amides, and lignans are found in black pepper. Some volatile oils like γ-cadinol, γ-guanine, and (E)-β-ocimene were determined by high-resolution gas chromatography, column chromatography, and gas chromatography-mass spectrometry (GC–MS) in black pepper [5]. Piperine enhances the bioavailability of many medicines, and nutrients by retarding several metabolizing enzymes. Piperine shows various pharmacological activities like antioxidant, antihypertensive, antiplatelet, antitumor, anti-asthmatic, analgesic, anti-inflammatory, anti-diarrheal, antidepressants, antispasmodic, immunomodulatory, anti-thyroids, anticonvulsant, antibacterial, antifungal, hepato-protective, larvicidal, and insecticidal activities. Piperine is found to increase fertility, cognitive action, provoke the intestinal activity, and improve the pancreatic enzymatic activity that help to fight indigestion. Most of the researchers identified various compounds in black pepper-like phenolics, steroids, neolignans, terpenes, and chalcones. Some of the compounds are brachyamide B, dihydro-pipericide, N-trans-feruloyltyramine, N-formylpiperidine, guineensine, pentadienoyl as piperidine, isobutyl-eicosatrienamide, piperamide, sarmentine, sarmentosine, and retrofractamide. Four isomers have been isolated from piperine like chavicine, piperine, isopiperine, and isochavicine [220]. Phytochemical compounds of black pepper fruit are 3-carene, propanedioic acid, dimethyl ester, cyclohexene, 1,6-octadien-3-ol,3,7-dimethyl, 2-methyl-1-ethylpyrrolidine, 2-isopropenyl-5-methylhex-4-enal, L-α-terpineol, pyrrolizin-1,7-dione-6-carboxylic acid, methyl ester, 7-epi-cis-sesquisabinene hydrate, phenol, eugenol, α.copaene, naphthalene, epiglobulol, caryophyllene,1,4,7-cycloundecatriene, 1,5,9,9-tetramethyl-,Z,Z,Z,α-ylangene, cedran-diol, 8S,13,isocalamendiol, cinnami acid, desacetylanquidine, trans-1,2-diaminocyclohexane-N,N,N,N-tetraacetic acid, phytol, eicosanoic acid, 2,5,5,8a-tetramethyl-6,7,8,8a-tetrahydro-5H-chromen-8-ol, Z-5-methyl-6-heneicosen-11-one, 2H-1,2-benzoxazine-3-carbonitrile, fenretinide, 11-dehydrocorticosterone, ursodeoxycholic acid, 5α-cholan-24-oic acid, and stigmasterol as determined by GC/ MS [607]

Coriandrum sativum (Coriander)

Coriander seed contains geranyl acetate, linalool, and camphor as phytochemical compounds. Coriander seed possesses phenols and flavonoids. Essential oils from coriander seeds contain camphene, β-pinene, β-myrcene, and 4-carene. Monoterpene hydrocarbons like limonene, γ-terpinene, and p-cymene are the second principal chemical group found in the essential oil, the other chemical classes include the sesquiterpenes compounds [2]. Linalool is present at high concentrations in the essential oil of coriander seed. The other essential oils are triglyceride oil and petroselinic acid. The compositional evaluation of coriander seed revealed the presence of alcohols (linalool, geraniol, α-terpineol, terpinene-4-ol), hydrocarbons, ketones (camphor), and esters (linalyl acetate). Linalool provides a pleasant, and floral-like odor [570]. In an investigation, the HPLC analysis revealed the existence of hesperidin, apigenin, luteolin, hyperoside, diosmin, vicenin, orientine, dihydroquercetin, chrysoeriol, catechin, salicylic acid, ferulic acid, dicoumarin, gallic acid, esculetin, 4-hydroxycoumarin, esculin, maleic acid, tartaric acid, and arbutin in coriander [634]

Myristica fragrans (Nutmeg)

Nutmeg seeds contain malabaricone C, dehydrodiisoeugenol, and malabaricone B. Malabaricone C is the active component present in high amount in nutmeg seed which showed higher antioxidant activity than the other two compounds. Polyphenols are isolated at higher amount in the methanol extract of nutmeg [525]. Secondary metabolites like steroids, saponins, alkaloids, flavonoids, phenols, tannins, phlobatannins, anthraquinones, coumarins, cardiac glycosides, anthocyanin, emodins, chalcones, and triterpenoids are identified by qualitative evaluation of the nutmeg seed extracts. Nutmeg seed contains resin, quinines, thiols, terpenoids, gum, and mucilages [933]. Nutmeg seed contains major components like terpene hydrocarbons (camphene, sabinene, pinene, phellandrene, p-cymene, terpinene, myrcene, and limonene,all together they constitute approximately 60%-80% of the oil. Oxygenated terpenes (terpineol, linalool, and geraniol contribute at least 5%-15% of the oil. Aromatic ethers like safrole, myristicin, elemicin, eugenol derivatives, and eugenol contribute about 15–20% of the total composition. Lignans have been found in nutmeg seed and showed antimicrobial effects against *Shigella dysenteriae, Bacillas subtilis,* and *Staphylococcus aureus* [585]

***Brassica nigra* (Black mustard)**

Black mustard contains some bioactive compounds like indoles, isothiocyanates, thiocyanates, and oxazolidine-2-thiones [663]. Various phytochemical compounds are found in *Brassica* plants like phenolic acid, phenolics, polyphenols, carotenoids (β-carotene, zeaxanthin, and lutein), tannins, saponins, anthocyanins, phytosteroids, aromatic, and aliphatic amines, flavonoids, phytosterols chlorophyll, alkaloids, glucosinolates, glycosides, and terpenoids. Black mustard seed contains phenolics (catechin, epicatechin, myricetin, quercetin, gallic acid, and rutin), phlobatannins, tocopherols, glutathione reducing sugar, and volatile oil and possessed antiradical and antioxidant potential [643]. The major glucosinolate present in black mustard seed is sinigrin (24.5–61.2 g/kg fresh weight) present in black mustard seed. Sinigrin can be hydrolyzed to allyl-isothiocyanate which provides the characteristics of the pungent odor. The other glucosinolate is sinalbin [529]

***Curcuma longa* (Turmeric)**

The main active component of turmeric is curcumin (10.16 mg/g-16.48 mg/g). Turmeric is an orange-yellow-colored lipophilic polyphenol substance which is derived from the rhizomes of the plant. Curcumin has anticancer, antioxidant, anti-inflammatory, anticoagulant, antifertility, antifungal, antiprotozoal, antiviral, antifibrotic, antivenom, antiulcer, hypotensive, and anticholesteremic activities. It plays a valuable role in the treatment, and prevention of different types of diseases like neurological, cancer, autoimmune, cardiovascular disease, and diabetes [328]. Curcumin possessed antimicrobial activity against *Mycobacterium tuberculosis, Staphylococcus aureus, Salmonella paratyphi, and Trichophyton gypseum* Curcumin is a compound naturally considered as safe, and effective. Turmeric root possesses curcuminoid, which is comprised of bidemethoxy-curcumin, curcumin, and demethoxycurcumin. Curcumin is a valuable compound of the traditional treatment method known as Jiawei Xiaoyao in China. The compound also prevents metabolic disease, lung disease, and liver disease. Curcumin is applied to decrease postoperative inflammation and is safe to consume at a high dose without any toxicity [476]. Some bioactive compounds found in the rhizome of turmeric are α-turmerone, ar-turmerone, and β-turmerone as determined by high-performance liquid chromatography (HPLC) [189]. Turmeric contains volatile compounds like camphor, eucalyptol, and β-pinene which are considered as strong antifungal compounds. Other volatile compounds are present in ample amounts in the essential oil of turmeric like phenyl propionoids, monoterpenes, and sesquiterpenes. Some other volatile compounds are α-pinene, camphene, α-phellandrene, 3-carene, β-cymene, β-elemene, α-santalene, caryophyllene, α-farnesene, zingiberene, β-cedrene, α-bisabolol, and β-sesquiphellandrene as identified by SH-GC–MS in turmeric essential oil [375, 377]

Laurus nobilis (Bay leaves)

Bay leaf contains volatile oils and alkaloids. Current investigation on bay leaves proposed that leaves contain the major sesquiterpene lactone, costunolide, and its α-methylene-γ-butyrolactone moiety [584]. They play an important role in preventing flatulence colic and enhancing the gastric fluid secretion. Bay leaves possess isoquercitrin compound which is responsible for its alkyl radical scavenging activity. Dehydrocostus lactone, zaluzanin D, and (1 R,4S)-1-hydro-peroxy-p-menth-2-en-8-ol acetate are identified from methanol extract of bay leaves that is responsible for the trypanocidal activity. Isoquercetin (flavonoid) is an active principle of bay leaves. In another investigation, bay leaves contain guaianolides eremanthin and germacronolide costunolide [129]. 1,8-cineole is the major component of bay leaves. The other predominant components are α-terpinyl acetate, sabinene, apinene, limonene, linalool, terpinene-4-ol, β-pinene, bornyl acetate, aterpineol, myrcene, α-phellandrene, p-cymene, methyleugenol, germacrene D, α-thujene, β-elemol, camphene, and eugenol [239]. The other sesquiterpene lactones are (1 3b-chlorodehydrocostuslactone, and (2 5a,9-dimethyl-3-methylene-3,3a,4,5,5a,6,7,8-octahydro-1-oxacyclopenta [c] azulene-2-one as identified by chromatographic separation. Various secondary metabolites are isolated from bay leaves like monoterpene, germacrene alcohols, catechin, procyanidin derivatives, laurenobiolide, glycosylated flavonoids, and megastigmane glucosides [217]

Crocus sativus (Saffron)

Safranal, crocins, and picrocrocin constituents present in saffron provide flavor and color to food products and have health-promoting properties. Other phytochemical compounds are phenolic (flavonols and anthocyanins), flavonoids, degraded carotenoid compounds like crocins, and crocetin. Crocin 1 or α-crocin is the major compound of saffron flower. It exhibits antioxidant potential through neutralizing free radicals and by defending cells, and tissues from oxidation [432]. Saffron contains little amount of carotenoids like zeaxanthin, carotenes, lycopene, xanthone-carotenoid glycosidic conjugate, mangicrocin, and picrocrocin. Picrocrocin is colorless glycoside and product of zeaxanthin degeneration. It is the second most abundant constituent which is responsible for the bitter taste of saffron [528]. The odor of saffron occurs due to the presence of safranal which is a product of natural deglycosylation of picrocrocin [548]. Some investigations revealed that saffron flower extract contains an abundant amount of polyphenol components that help to decrease the free radicals activity and contributes in building the defense mechanism to the various organs like lung, kidneys, liver, and heart. It is proved that saffron and its carotenoid pigment, crocin, showed antioxidant and hypolipidemic properties. Some studies showed that crocin has neuroprotective activity [725]. Saffron flower contains other compounds like delphinidin, and kaempferol (flavonoid) that exerted antioxidant activity and these can be used in cosmetics, food products, and phytopharmaceuticals. The red color and yellowish red hues of saffron occurs due to the presence of crocetin esters. Pollen has isorhamnetin glycosides and kaempferide compounds. Malvidin glycoside, delphinidin, kaempferol aglycone, and petunidin are the phenolic compounds found in the perianth. Flavonol, quercetin, and 3-O-β-sophoroside are found in the petals of saffron flower [615]. The aroma rich active compounds of saffron like 4-ketoisophorone, isophorone, phenylethyl alcohol, 2-pentanol, α,β-ionone, isophorone oxide which are evaluated by GC–MS [211]

Illicium verum (Star anise)

Shikimic acid is the precursor molecule present in abundant amount in star anise fruit. It is applied in the preparation of oseltamivir, which acts as an antiviral drug for influenza A and influenza B. The essential oil of anise consists of sesquiterpenes, prenylated C_6-C_3 compounds, lignans, and flavonoids that provide various medical properties. The characteristics taste of anise is due to the presence of anethole compound. Star anise essential oil contains myrcene, α-pinene, γ-terpineol, α-phellandrene limonene, linalool, estragole, α-cubebene caryophyllene oxide, trans-anethole, and α-humulene that have various biological properties. Tannins, alkaloids, limone, safrol, and farnesol and some small amount of nitrogenous compounds, 14 hydrocarbon compounds, and 22 oxygenated hydrocarbon derivatives such as p-allylanisole, anisyl acetone, anisaldehyde, p-cumin aldehyde, p-allylpen, palmitic acid, linoleic acid, and foeniculin are isolated from the fruit of anise [201]. Other investigations suggested that anise fruit contains β-sitosterol, car-3-ene, cineol, 4 (10)-thujene, and hydroquinone ethyl ether. Sesquicitronellene, copaene, anisketone, methyl-3-methoxy-benzoate, methyl isoeugenol, p-hydroxy benzoic acid, nerolidol, and m-methoxy-a-benzyl benzene acetic acid are identified in anise [748]. Sabinene, 1,8-cineole, anisaldehyde, borneol, 4-methoxypropiophenone, bisabolene, O-nitrobenzoic acid, germacrene D, trans-nerolidol, geranyl isobutyrate, chavicol, and p-cumic aldehyde are some volatile oils which have been identified in star anise. Star anise fruit also contains toluene, octane, and undecane [693]. Trans-anethole is the main active compound present in star anise fruit which provides a characteristics aroma. Researchers observed that anethole shows a peripheral antinociceptive activity, and provides treatment for painful, and inflammatory problems [231]. Antifungal properties are found in anise fruit due to the presence of trans-anethole in the oil. Trans-ocimene, β-clemene, bergamotene, and α-cadinol are the other most valuable compounds found in star anise [831]

Allium cepa (Onion)

Onion contains several secondary metabolites like saponins, flavonoids, and phytosterols. The most active compounds of onion are quercetin, and quercetin 4'-O-β-glucoside which are responsible for the formation of brown, and yellow compounds [579]. Various phytochemicals that present in onion are polysaccharides, organosulfur compounds, and phenolic. Sulfur-containing compounds such as onionin A and cysteine sulfoxides are the major bioactive compounds of onion. Anthocyanins are also found in onion. The compound cysteine sulfoxides consists of methiin, cyclophilin, isoalliin, and propiin [1015]. Quercetin aglycon is also found in onion. Onion contains three types of alkyl cysteine sulfoxides (ACSOs,(1 trans-(+-S-1-propenyl-L-cysteine sulfoxide (PECSO which is naturally obtained in the higher amount and is responsible for the lachrymatory activity, (2 (+-S-methyl-L-cysteine sulfoxide (MCSO, and (3 (+-S-propyl-L-cysteine sulfoxide (PCSO [140]

Anethum graveolens (Dill)

Some phytochemicals like polyphenols, essential oil, and furanocoumarin are present in dill. Dill seeds essential oil contains 1-methoxy-4-(2-propenyl)benzene, D-(+)-carvone, humulene, 6-methyl-2,4-di-t-butyl-phenol, 1-allyl-2,5-dimethoxy-3,4-methylenedioxybenzene(diplaniol), eicosane, heptadecane, docosane, n-heneicosane, n-pentacosane, tricosane, octacosane, dioctyl ester of 1,2-phenyldicarboxylic acid, and n-nonacosane [999]. Dill seeds possess the most valuable bioactive compounds like flavonoids, glycosides, alkaloids, tannins, saponins, steroids, terpenoids, phenols, resins, and iridoid glycosides [45]. The main active components of dill seeds are dill apiol, carvone, limonene, and α-phellandrene. Ethanol extract of dill exhibited phenolic acids like protocatechuic, vanillic, caffeic, ferulic, p-coumaric, syringic, chlorogenic, o-coumaric, rosmarinic, and trans-cinnamic acid. Dill seed essential oil consists of sabinene, α-thujene, α-pinene, p-cymene, myrcene, dill ether, γ-terpinene, trans-carveol, iso-dihydro carveol, and anethole in small amounts. Other compounds of dill seed essential oil are myristicin, trans-dihydrocarvone, E, E-2,6 dimethyl-3,5 octatetraene, linalyl acetate, piperitone, thujyl alcohol, grandisol, 2-carene, o-isopropenyltolune, 1,2-diethoxyethane, diphenol, and bis-1,2 benzene dicarboxylic acid. 3-hydroxy-α-ionol, 8-hydroxygeraniol-D-glucopyranoside, p-menth-2-ene-1,6-diol-D-glucopyranoside, 3-hydroxy-β-ionol 3-O-β-D-glucopyranoside, and quercetin 3-O-β-D-glucuronide [180]

Trigonella foenum-graecum (Fenugreek)

Fenugreek seeds contain tannins and polyphenol. Alkaloids, steroids, and saponins are present in fenugreek seed showed anti-diabetic effects. Some other bioactive compounds like trigonelline, orientin, isoorientin, isovitexin, and vitexin are isolated and quantified by HPLC system. The method UHPLC-ESI–MS/MS identify some compounds like sarsasapogenin, and pinitol [857, 861]. Fenugreek seed also contains flavonoids that provide anti-inflammatory and antinociceptive properties. Polysaccharides and volatile compounds are obtained in an abundant amount in fenugreek seed. Some volatile compounds are dextroamphetamine, 2-methyl pyrrolidine, benzene methanol,a-(chloromethyl), astaxanthin, buffa-20,22-dienolide, 4a-phorbol 12,13-decanoate, psi.,.psi.-carotene, 9,19-cyclolanost-24-en-3-ol,acetate, hydrocortisone acetate, 2-propane-1-amine,N-ethyl, methyl ester, ethyl iso-allocholate, lycoxanthin, betulin, 1,1,2,2-tetrahydro-1,1'-dimethoxy, and rhodopin [838]. The main active compound of fenugreek seed is galactomannan which is a long-chain polysaccharide. Galactomannan occupies a huge portion in the total bioactive composition of the seed extract. 4-hydroxy isoleucine and diosgenin are isolated in fenugreek seed. Fenugreek seed provides its characteristics odor due to the presence of trigonelline [888]. It is applied in the production of imitation maple syrup, rum, artificial flavoring for licorice, vanilla, and butterscotch. The other phytochemicals found in fenugreek seeds are sapogenins, diosgenin, gitogenin, yamogenin, yuccagenin, neogitogenin, sarsasapogenin, tigogenin, smilagenin, and choline. The secondary metabolites are lignins and flavonoids (flavones, flavonones, flavanols, flavonols, proanthocyanidins, isoflavones, and anthocyanins). The most common flavonoids obtained from fenugreek are kaempferol, quercetin, and luteolin. Fenugreek contains phenolic compounds such as chlorogenic, scopoletin, coumarin, caffeic, and p-coumaric acids [519]

Ferula assafoetida (Asafoetida)

Assafoetida is rich source of polysulfides, sesquiterpene, coumarins, phenolic acid, and flavonoids. The main active compound of assafoetida is rosmarinic acid (RA) (phenolic acid) which is isolated by the HPLC. RA shows anti-inflammatory properties by decreasing the manifestation of COX-2 enzymes and their activity. The strong defensive and therapeutic activities of this compound for communicable diseases are recommended because of its antioxidant, and anti-inflammatory effects. The other phenolic acids are apigenin, luteolin, rutin (asafetida), vanillic acid, and ferulic acid which are formed by SBUp1 isolate [685]. Assafoetida root contains various coumarins, and terpenoids that provide anti-HSV activity. The sesquiterpene coumarins are badrakemin acetate, Pellerin, assafoetidnol A, assafoetidnol B, gummosis, polyanthus, neveskone, galbanic acid, 5-hydroxyumbelliprenin, and 8-acetoxyumbelliprenin are identified in the gum resin of assafoetida [3]. Assafoetida possesses polyphenols like flavonoid glycosides, and tannins which have anti-HSV effect [322]. Monoterpenes, and sulfur-containing compounds are volatile compounds found in assafoetida. Three main sulfur compounds are 2-butyl 3-(methylthio)-2-propenyl disulfide, 2-butyl 1-propenyl disulfide, and 1-(methylthio) propyl 1-propenyl disulfide. The other chemical compounds present in asafetida are umbelliprenin, tadshiferin, galbanic acid, conferol, franesiferol A, assafoetidin, ferocaulicin, kamolonol, saradaferin, 10-R-acetoxy-11-hydroxyumbelliprenin, 10-R-karatavicinol, lehmferin, feselol, ligupersin A, epi-conferdione, microlobin, asadisulfide, foetisulfide C, 7-oxocallitristic acid, picealactone C, 15-hydroxy-6-en-dehydroabietic acid, vanillin, taraxacin, and fetidone A [946]

Apium graveolens (Celery)

Celery seed oil contains flavonoids, terpenoids, and lactones. Essential oil is extracted from celery seed by steam distillation. The main active constituent of celery seed is limonene (essential oil). The other oils are a-p-dimethyl styrene, caryophyllene, N-pertyl benzene, a-selinene, sedanenolide, N-butyl phthalide, b-element, sabinene, linalool, trans-1 2-epoxylimonene, isovaleric acid, cis-dihydrocarvone, terpinene-4-ol, trans-dihydrocarvone, trans-p-menth-2,8-diene-1-ol, 1-cis-p-menth-2,8-diene-1-ol, α-terpineol, trans-8-diene 1-ol, carvone, salience, several sesquiterpene, thymol, and perialdehyde. The characteristics flavor of celery is mainly due to the presence of two lactones which are 3-butyl 4,5 dihydrophthalide (sedanolide), and 3-n-butylphthalide [293]. Various phenolics like furanocoumarins, and flavones found in celery. Glycosides, and steroids are present in celery. Celery seeds contain phytochemicals like apiin, caffeic acid, chlorogenic acid, apigenin, ocimene, rutaretin, isopimpinellin, bergapten, seslin, osthenol, umbelliferone, isoimperatorin, and gravebioside A and B. Sedanolide, and sedanonic anhydride found in celery seed oil that is responsible for its aroma. The other chemical constituents of celery are 8-hydroxyl-5-methoxypsoralen, myristic acid, and octadecanoic acid [42]

Capsicum frutescens (Chili)

Chili contains valuable bioactive compounds like steroids, phenolic compound, flavonoids, saponins, coumarins, anthroquinones, proanthocyanidins, carotenoids, polyphenols, terpenoids, and alkaloids. The main active component of chili is capsaicinoids [665]. The capsaicinoid alkaloid is responsible for pungent taste of chili. The major capsaicinoids are dihydrocapsaicin (DHCap), and capsaicin (Cap). The minor capsaicinoids are homodihydrocapsaicin (HDHCap), nordihydrocapsaicin (NDHCap), and homocapsaicin (HCap) [311]

Pimenta dioica (Allspice)

Allspice leaves contain bioactive compounds like gallic acid, ferulic acid, rutin, and chlorogenic acid. Allspice is utilized in traditional medicine and provides characteristic aroma due to the presence of volatile oil. Allspice contains phenolic compounds like quercetin, ericifolin, and eugenol [924]. Some other phytochemical compounds are catechin, methyl gallate, syringic acid, caffeic acid, pyro catechol, ellagic acid, coumaric acid, vanillin, naringenin, cinnamic acid, taxifolin, and kaempferol. Polyphenols are also found in allspice [270]. The main active constituent of allspice leaves is eugenol present in essential oil. The others are β-caryophyllene, linalool, cineole, and α-humulene. Eugenol showed therapeutic activities like anti-inflammatory, analgesic, local anesthetic, and antibacterial effects. Some of the essential oils are α-pinene, β-myrcene, limonene, α-terpineol, chavicol, and germacrene [248]. Volatile compounds of allspice leaves are methyl eugenol, β-guaiene, and naphthalene. The compounds α-phellandrene and β-phellandrene are identified in allspice [923]

Garcinia indica (Kokum)

Kokam is a rich source of anthocyanin pigments like cyaniding-3-sambubioside, and cyaniding-3-glucoside. Hydroxyl citric acid that has been isolated from kokum possess anti-obesity effect. A polyisoprenylated benzophenone derivative garcinol is the main active component present in kokam fruit. It provides chelating, and antioxidant activity. The chemical constituents of kokam fruits are tannin, pectin, and organic acid [644]. Isogarcinol is also found in kokam fruit. Xanthohumol and isoxanthochymol are isolated at higher amounts in kokum. Flavonoids, benzophenones, xanthones, and lactones are identified in kokam fruit. Kokam fruit contains an abundant amount of Cambogia, besides Garcia-2, and garcim-1, which are the main oxidative products of garcinol along with mangosteen, macurin, clusianone, guttiferone (I, J, K, M, N), gambogic acid, and oblongifolin (A, B, C) [485]. Garcinol is a fat-soluble and yellow-colored pigment. It is isolated by hexane and ethanol extraction. Garcinol exhibits antimicrobial effects against *Staphylococcus aureus* It acts as an antitumor agent by apoptosis through the initiation of caspases and also acts as an anticancer agent. Flavonols, leucoanthocyanidins, and catechins are the bioflavonoids that alter the permeability of capillaries, accelerate the ethanol metabolism and decrease inflammation and edematic reactions [395]

Alpinia galangal (Greater galangal)

Greater galangal contains various phytochemical compounds like 1’S-1’-acetoxy eugenol, α-fenchyl acetate, β-farnesene, α-bergamotene, β-bisabolene, β-sitosterol diglucoside (AG-7), β-pinene, 1’-acetoxychavicol acetate (galangal acetate), β-sitsterylarabinoside (AG-8), 1’S-1’-acetoxychavicol acetate (ACE), and p-hydroxycinnamaldehyde. The essential oils like mono sesquiterpene, as well as (E)-methyl cinnamate, are present in greater galangal root and are responsible for the characteristic odor. These essential oils are used in food products, and medicine. Volatile oils and flavonoids are isolated from galangal. 1’S-1’-acetoxychavicol acetate (ACE) provides a pungent flavor of galangal root. Galangal also possesses p-hydroxybenzaldehyde, and phenylpropanoids. 1,8-cineol is the main active compound of galangal root. Galangal rhizome possesses P-coumaryldiacetate, 4-hydroxybenzaldehyde, trans-coniferyldiacetate, phenylpropanoids, (E)-4-acetoxy cinnamyl ethylether, (E)-4-acetoxy cinnamyl alcohol, (E)-4-hydroxycinnamaldehyde, (S)-1’-ethoxy chavicol acetate, and 4-acetoxy cinnamyl acetate. Some other compounds are diterpene ((E)-8β,17-epoxylabd-12-ene-15,16-dial), curcuminoid (1,7-bis (4-hydroxyphenyl)-1,4,6-heptatrien-3-one), and bisdemethoxycurcumin [203]. Rhizome essential oil consists of camphor and guaiol. Galangal rhizome exerted eleven flavonols (galangin, major flavonols), one flavan 3-ol, dihydroflavonols, and flavanone [203]. The non-methylated flavonols are myricetin, kaempferol, and quercetin,methoxylated flavonols are galangin 3-methyl ether, kaempferide, kumatakenin, isorhamnetin, and quercetin 3-methyl ether; polyglycosylated flavonol called as galangoflavonoside is isolated from galangal rhizome. The dihydroflavonol ((2R,3R-alpinone (sd, pinobanksin 3-acetate, flavan 3-ol (catechin, and flavanone (pinocembrin are also isolated from this spice [944]

Acorus calamus (Sweet flag)

The main active compound of sweet flag rhizome is α-asarone (essential oil) [741]. The essential oil of sweet flag rhizome consists of (E)-methyl isoeugenol, methyl eugenol, α-cedrene, β-asarone, and camphor. Other chemical constituents of essential oil extracted from sweet flag rhizome are α-pinene, camphene, (D)-limonene, 1,8-cineol, linalool, terpinene-4-ol, α-terpineol, bornyl acetate, estragole, α-funebrene, copaene, α-gurjunene, α-bulnesene, β-caryophyllene, germacrene D, cuparene, α-cadinene, β-calacorene, α-cadinol, acorenone, α-bisabolol, acorone, preisocalamenediol, shyobunone, cryptoacorone, (Z)-sesquilavandulol, dehydroxyisocalamendiol, α-selinene, cedrol, berganotene, α-palchoulene, α-guaiadiene, 4-(5-hydroxy-2,6,6-trimethyl-1-cyclohexen-1-yl)-3-buten-2-one, dehydrofukinone, elemicin, monoterpenoids, and sesquiterpenoids [538]. Sweet flag also contains some bioactive compounds like 2-allyl-5-ethoxy-4-methoxyphenol, lysidine, epieudesmin, spathulenol, furylethyl ketone, borneol, nonanoic acid, galgravin, retusin, (9E,12E,15E)-9,12,15-octadecatrien-1-ol, geranyl acetate, butyl butanoate, sakuranin, acetic acid, acetophenone, α-ursolic acid, dehydroabietic acid, methyl ether, and apigenin 4,7-dimethyl ether. Phenylpropanoids, xanthone glycosides, flavones, lignans, and steroids are found in sweet flag, which possesses several pharmacological activities such as antibacterial, insecticidal, larvicidal, mutagenic, cytotoxic, hepatoprotective, anticonvulsant, smooth muscle relaxant, neuroleptic, and smooth muscle stimulant activity. The essential oil also contains trans-β ocimene, aristolene, α-humulene, viridiflorene, kessane, asaronaldehyde, aspidinol, and phytol [684]

Health Benefit Potential

Spices and herbs provide phytochemicals that protect from various diseases, inhibit oxidation, and remove free radicals (the byproducts of biochemical methods). They also provide preventive measures against various neurological diseases, cardiac disorders, other physiological diseases and protect valuable biomolecules from oxidative damage [643] (Fig. 3). Table 3 summarizes the health benefit potential of the important spices and herbs

Elettaria cardamomum (Cardamom)

Anti-inflammatory Effects Cardamom seed oil has been applied at a dose of 175–280 μl/kg on carrageenan-induced hind paw edema in male albino rats to analyze its anti-inflammatory effects [52]. 30 mg/kg of indomethacin has been taken as standard. 86.4% inhibition has been found with 280 μl/kg of cardamom oil,thus, the cardamom oil has a high

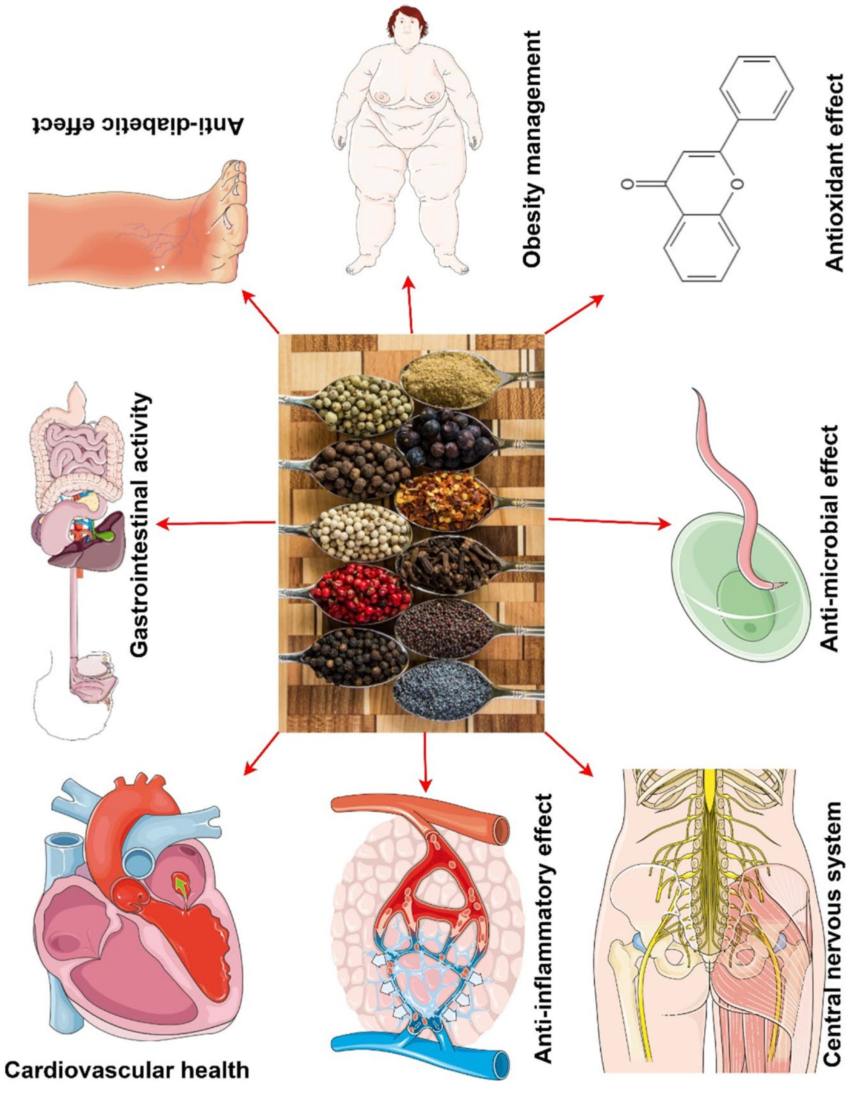


Fig. 3 Health-beneficial effects of the selected spices

potency with respect to the inflammatory activity of indomethacin. 69.2% inhibition has been observed with 175 µl/kg of cardamom oil [494]

Cardiovascular Health Various bioactive compounds such as flavonoids, alkaloids, saponins, terpenes, and glycosides steroids have been extracted from cadamom, which have cardioprotective effects. It has been observed that at a high dose of 500 mg/kg of cardamom extract is able to reduce the SGPT (serum glutamic pyruvic transaminase) levels, LDH (lactate dehydrogenase) levels, SGOT (serum glutamic-oxaloacetic transaminase) levels, total protein levels, serum albumin levels, cholesterol levels, LDL cholesterol level, VLDL cholesterol level, total chlorides level, alkaline phosphatase levels, and triglycerides, and recover HDL cholesterol level. It has been observed that at a low dose of 100 mg/kg.bw the cardamom extract is able to reduce the triglyceride level in doxorubicin-induced cardiac problem in rats [829]

Gastrointestinal Activity Cardamom extract (unfiltered methanolic extract (TM), petroleum ether solution (PS), insoluble (PI) methanolic extract, and essential oil (EO)) at a dose of 100–500, 12.5–50, 12.5–150, and 450 mg/kg has been administered to rats to analyze its gastrointestinal protective activity. The extracts of cardamom considered are able to retard the gastric damages induced by aspirin and ethanol significantly though the damage induced by pylorus ligation has not been inhibited successfully. For the EtOH-induced gastric ulcer, TM reduced lesions by 70% at the dose of 500 mg/kg of cardamom oil. At the dose of 50–100 mg/kg of cardamom oil, the PS fraction lowered the problems by 50%; the same effect has been observed for the fraction of PI at a dose of 450 mg/kg. The best gastroprotective activity has been observed in the PS fraction at the dose of 12.5 mg/kg of oil, which retarded lesions by 100% [400]

Anti-diabetic Effect The role of cardamom has been proved and accepted by accurate scientific analysis to control diabetes. At a dose of 1 mg/mL, aqueous and methanol extracts of cardamom have been analyzed for their *in vitro* α-amylase and α-glucosidase inhibition activity and antioxidant properties. 10.41% and 13.73% retardation of α-glucosidase have been observed for aqueous and methanol extract of cardamom, respectively. 82.99% and 39.93% retardation for α-amylase have been observed for methanol and aqueous extract of cardamom, respectively [28]

Obesity Management In an experiment, cardamom has been given at the dose of 3 g/day for 3 months to the non-alcoholic fatty liver patients, suffering from excess level of SIRT1 (sirtuins) [221]. Researchers have suggested that several parameters related to diabetes, and obesity like fat mass and obesity-associated (FTO), leptin receptor (LEPR), carnitine palmitoyltransferase 1A (CPT1A), lamin A/ C, and peroxisome proliferator-activated receptor gamma (PPAR-gamma) can be managed by the administration of green cardamom at a 3 g/day doses for 16 weeks in women suffering from polycystic ovary syndrome [197]. Researchers have observed that obesity can be managed with a dose of 1% of cardamom powder for 8 weeks for high-fat diet-induced obese rats [992]

Antimicrobial Effect The growth of *Salmonella typhi, Staphylococcus aureus, E. coli, Streptococcus mutans, Candida albicans, Bacillus pulmilus, and Listeria monocytogenes* have been inhibited by the application of 10 mg/ml of cardamom essential oil (CEO). CEO showed a potential antifungal, and antibacterial effects [89]

Antioxidant Activity The thiocyanate method has been used by researchers to estimate the antioxidant potential of methanolic extract of green cardamom extract. The percentage retardation of peroxidation is 84.2–90%. With varying solvent concentrations, the antioxidant activity of green cardamom extract various [148]

Central Nervous System Activity Scholars have investigated the effectiveness of cardamom extract and its main phytoconstituents over Alzheimer's disease (AD). It has been reported that multiple drug targets have been bound with α-terpinyl acetate. Cardamom extract retarded the butyrylcholinesterase (BuChE), acetylcholinesterase (AChE), decreased Aβ-induced neurotoxicity, hydrogen peroxide-induced oxidative stress, and anti-amyloidogenic activity. The cardamom extract has improved the effects of AD and multi-targeted directed ligand (MTDL) capacity [204]

Bunium persicum (Black jeera)

Anti-inflammatory Effects Hydroalcoholic extract and essential oil derived from *Bunium persicum* extracts have been tested for anti-inflammatory activity. The extracts of black jeera exhibited significant anti-inflammatory effects. Researchers have studied the anti-inflammatort activity of black jeera extract on Carrageenan-, Formalin-, and Croton oil-induced ear edema for rats [824, 825]

Anti-diabetic Effect and Anti-obesity Effect The extract of *Bunium persicum* has been investigated for its anti-diabetic and anti-obesity activities. It has been evidenced that black jeera is able to retard the glycoside hydrolase activity. Hydroalcoholic extract of *Bunium persicum* is able to reduce the albumin glycation and aggregation because of the presence of higher concentrations of polyphenolic compounds [126]

Antimicrobial Effect Different types of extracts of *Bunium persicum* essential oil (BPEO) have been studied for their antimicrobial properties against various strains of bacteria. The test revealed that essential oil possessed higher inhibition effect on gram-positive bacteria than gram-negative bacteria. Phenolic compounds like cuminaldehyde, γ-terpinene, and p-cymene are responsible for antimicrobial activity. The essential oil present in black jeera is responsible for the bacterial decay. Various food-borne pathogens like *Escherichia coli, Bacillus cereus, Bacillus subtilis, Klebsiella pneumonia, Listeria monocytogenes, Proteus vulgaris, Pseudomonas aeruginosa, Salmonella enteritidis,* and *Staphylococcus aureus* have been inhibited by BPEO. P-cymene and cuminaldehyde are responsible for the antifungal activities against various phytopathogenic fungi like *Candida albicans, Aspergillus spp., Saccharomyces cerevisiae, Penicillium chrysogenum, Alternaria mali, Botrytis cinerea, Colletotrichum lindemuthianum, Fusarium oxysporum,* and *Verticillium dahlia* [126]

Cardiovascular Health In animal (rats) model, the cardiovascular effect of *Bunium persicum* extract have been analyzed. Hypercholesterolemic rats have been selected in the experiment, and *Bunium persicum* extract has been administered to them to measure the effectiveness of black jeera extract in terms of protecting cardiovascular health. Researchers observed that the extract is able to maintain the lipid profile; thus, the cardiorespiratory ability has also been enhanced [824, 825]

Gastrointestinal Activity A placebo-controlled, randomized, and double-blind study have been indicated the potential of *Bunium persicum* as an herbal remedy for gastrointestinal problem. Anti-inflammatory, spasmolytic, antioxidant, carminative, and immunomodulatory properties have been reported for caraway [439]. No significant activity of caraway has been found on the symptoms or inflammatory markers like irritable bowel syndrome. Researchers found the neutral effect of caraway on gastrointestinal symptoms [1]

Antioxidant Activity The essential oil derived from black jeera and methanol and aqueous extract of the same have been analyzed for its antioxidant potential. It has been reported that the methanol extract possess higher antioxidant potential in comparison with the other extracts as evidenced by DPPH assay and inhibitory effect against the lipid peroxidation and betacarotene oxidation [839]

Foeniculum vulgare (Fennel)

Anti-inflammatory Activity Compared to the indomethacin, fennel essential oil showed significantly lesser anti-inflammatory activity. The fennel oil exhibited the similar activity at the doses of 0.050 and 0.200 mL kg^{-1} in comparison with etodolac. It has been reported that fennel essential oil possessed anti-inflammatory activity as observed in animal model (rats) [672]

Anti-diabetic Effect Essential oil is derived from fennel has been administered to diabetic rats. It has been reported that the essential oil is able to reduce the hyperglycemia. The serum glutathione peroxidase can be managed successfully with the fennel essential oil. The detrimental effects on pancreas, and kidney can also be recovered. Therefore, fennel seed can be utilized as a anti-diabetic drug [269]

Anti-obesity Effect It has been reported that ethanolic extract of fennel seed is able to decrease the body weight of rats by 12%, while the same has been reduced by 6.4% for rats fed with Orlistat enriched diet. The triglyceride level has not been influenced by Orlistat and plant extract. The ethanolic extract of fennel seed has been used as a promising anti-obesity drug as it is able to maintain the lipid profile; simultaneously, it is able to decrease the body weight. Molecular docking study revealed that stigmast-5-en-3-ol (a bioactive compound found in fennel seed) is able to control the obesity problem [323]

Antimicrobial Effect Essential oil of fennel seed is more effective in terms of antimicrobial activity in comparison with the alcoholic and hexane extracts of the seed. Essential oil, alcoholic, and diethyl ether extracts exhibited potential inhibition effect against *Bacillus cereus, E. coli, Salmonella typhi, and Staphylococcus aureus* Lower minimum inhibitory concentration (MIC) value has been found in essential oil extract for the microorganisms, namely *Bacillus subtilis, Bacillis cereus, Bacillus megaterium, E. coli, Klebsiella sp., Pseudomonas aeruginosa, Salmonella typhi, Sarcina lutea, Shigella boydii, Shigella dysenteriae, Shigella shiga, Shigella sonnie,* and *Staphylococcus aureus*. The alcoholic, diethyl ether, and hexane extracts showed lower MIC value against *Candida albicans, Aspergillus flavus, Bacillus cereus, E. coli, Salmonella typhi,* and *Staphylococcus aureus* Both the methanolic, and ethanolic extracts have showed similar antimicrobial effect. In the same experiment, acetone extract showed lower MIC value compared to aqueous extract. The higher antifungal effect has been reported in acetone and diethyl ether extracts compared to essential oil [44]

Cardiovascular Health Methanolic, and water extracts of fennel had potential cardiovascular activity. The extract has been reported for its ability to decrease down the level of plasma lipid. The decreased triglyceride level has the ability to cure the fatty liver problem and it also helps to maintain a healthy blood flow in the coronary arteries. The fennel extract has been given intravenously to the rats, which is able to decrease the blood pressure significantly without influencing the heart rate and respiration. This may be due to its anti-atherogenic and hypolipidemic properties. The water extract possessed lower hypotensive activity [110]

Gastrointestinal Effect Researchers have studied the effectivity of *Foeniculum vulgare* aqueous extract (FVE) for its effectiveness in prevention of gastrointestinal ulcer. Fennel aqueous extract has been administered at the doses of 75, 150, and 300 mg/kg to rats. It has been reported that the ethanol-induced gastric problem can be cured with the FVE. The research has been provided to evaluate the potential of heated fennel therapy in increasing the recovery of gastrointestinal function [193]. Three hundred and eighty-one patients suffering from gastric tumor, hepatobiliary, and pancreatic have been selected. The patients are partitioned into two groups: 1) group has given heated fennel therapy, while 2) the other group has taken heated rice husk therapy. Researchers have reported that time to first flatus, first defecation, and fasting time are significantly reduced for the group has been treated with heated fennel therapy [593]

Antioxidant Activity Researchers have investigated the effectiveness of water, and methanolic extracts of ajwain, and fennel seeds for their antioxidant activity, and phenolic potential. Ascorbic acid has been considered as control. At a concentration of 240 µg/ml of methanolic extract of fennel seed possessed 71.67% greater OH-scavenging activity by in comparison with control. It has been reported by the researchers that the FRAP activity of methanol, and aqueous extracts is in the range of 7–48 µm Fe (II)/g. Polyphenolic compounds derived from fennel seed may be responsible for antioxidant capacity [887]

Central Nervous System Activity Researchers have investigated the neuroprotective activity of fennel seed on lead (Pb)-induced brain neurotoxicity of rat model. The male BALB/c mice of same age group have fed with 75%, 100% ethanol extracts of fennel seed, simultaneously, 0.1% Pb has also been administered at various doses (20 mg/kg/day, and 200 mg/kg/day). The 75% of ethanol extract has been found with most promising effect. Researchers have concluded that neuronal toxicity can be reduced with fennel seed by controlling the oxidative stress [149]

Papaver somniferum (Poppy)

Cardiovascular Health Poppy seed helps in increasing the oxygen flow in the blood. The seed protects the activity of the heart may be due to the presence of essential micronutrients [599]

Anti-diabetic Effect Poppy seed is considered as an effective ant-diabetic agent. The seed helps in the treatment of diabetes may be due to the presence of manganese [599]

Antimicrobial Effect Poppy seed has been tested for its antimicrobial potential against *E.coli,* and *Salmonella* It has been reported that the methanol extract of poppy seed successfully inhibits the growth of *E.coli* and *Salmonella* species. The aqueous extract inhibits the growth of coliform bacteria [599]

Antioxidant Activity Researchers have considered poppy seed oil as a potential antioxidant agent. They have fed 35 Wistar rats with poppy seed oil, and sun flower oil have been administered orally at a doses of 250, and 500 mg/kg/day to 35 Wistar rats. The diesel has been dissolved in equal levels of sunflower oil for 21 days, while untreated rats have been introduced as control. The serum nitrite concentrations have been progressively increased for all of the rats included in the experiment. The blood MDA (malondialdehyde) concentrations have also increased. Though it has been reported that the rats were fed with poppy seed oil at a dose of 500 mg/kg/day, the blood MDA level has enhanced slightly for the rats those have fed with poppy seed at a dose of 500 mg/kg/day. The erythrocyte catalase activity and blood glutathione concentrations have been reduced for poppy seed oil-treated rats [41]

Central Nervous System Activity The opium alkaloids like codeine, morphine, thebaine, and papaverine are present in small amounts in dry poppy seed. The components have a little effect on the human nervous system. In contrary, the chemicals may possess few health benefits. The poppy seed may act as a painkiller for nervous irritability [751]

Syzygium aromaticum **(Clove)**

Anti-inflammatory Activity At the doses of 50 mg/kg, 100 mg/kg, and 200 mg/kg, the ethanol extract of clove showed a significant anti-inflammatory activity for formalin-induced edema in rats. The anti-inflammatory activity is exerted may be due to the presence of tannins, and flavonoids, as these compounds are able to retard the phosphodiesterases activity. The activity of the compounds rely on the biosynthesis of protein cytokines. Prostaglandin is one of the key anti-inflammatory substance. Prostaglandins can be retarded by tannins and flavonoids. The anti-inflammatory activity has been demonstrated for different types of non-steroidal anti-inflammatory agents (NSAIDS) [917]

Anti-diabetic Effect The anti-diabetic effect of essential oil of clove has been evaluated by researchers with the help of an α-amylase enzyme assay. α-amylase is an enzyme in humans that breaks down the starch into simple sugars. Researchers have observed a decrease in carbohydrate digestion and glucose absorption value may be due to the lower enzyme activity. The postprandial rise is reduced in blood glucose. The clove essential oil showed poor anti-diabetic activity than the standard anti-diabetic compound like ascorbase. The presence of insulin-mimetic agents in clove is responsible for anti-diabetic activity [907]

Anti-obesity Effect Researchers have evaluated the anti-obesity effect of *S. aromaticum* ethanol extract (SAE) both *in vitro* and *in vivo* condition. *In vitro* study, the effect of SAE treatment on adipocyte differentiation in 3T3-L1 cells has been evaluated for analyzing the anti-obesity activity of SAE*In vivo* study, to investigate the anti-obesity activity of SAE, mice are divided into 3 groups: a control group, a group that consumed a high-fat diet (HFD group), and a group that consumed an HFD supplemented with 0.5%(w/w) SAE (HFD + SAE group). All the parameters like serum triglyceride (TG), the body weight, white adipose tissue (WAT), total cholesterol (TC), high-density lipoprotein (HDL) cholesterol, glucose, insulin, leptin, hepatic lipid accumulation, and levels of lipid metabolism-related parameters have been assessed after 9 weeks of feeding*In vitro* evaluation of the effect of SAE treatment on 3T3-L1 cells showed that it had potentially retarded the transformation of cells into adipocytes in a dose-dependent manner. SAE supplementation had significantly reduced HFD-induced enhancement in the body weight, liver weight, WAT mass, serum TG, TC, lipid, glucose, insulin, and leptin levels. In HFD-fed mice, fat deposition are retarded by SAE via the suppression of transcription factors integral to lipogenesis, and adipogenesis [414]

Antimicrobial Effect The alcoholic extract of clove has decreased the bacterial propagation as perceived by the researchers through zone inhibition test. The extract contains quinine, which may responsible for the reduction in bacterial growth [242, 607]

Cardiovascular Health Clove extract have a membrane-stabilizing effect on the cardiac cell membrane. Clove extract is able to reduce the enzyme salvation. The clove extract possessed free radical scavenging activity, lipid peroxidation, and antioxidant activity may be due to the presence of flavonoids, and other phenolic compounds. Researchers have investigated and showed that clove extract is able to prevent myocardium damage as evidenced by isoproterenol-induced damages in myocardium [721]

Gastrointestinal Effect Gastric mucus is a protective factor for the gastric mucosa and contains viscous, elastic, adherent, and transparent gel, which has been made by water, and glycoproteins, which enveloped the whole gastrointestinal mucosa [797]. Eugenol, and clove oil have been examined in the rat model with gastric problem. Compared to the control, it has been found that the doses of 100 and 250 mg/kg of clove oil and eugenol have increased the mucus formation. The free radical scavenging activity of the clove extract may be the reason for a decreased mucosal injury. It is concluded that the gastroprotective mechanism of the eugenol and clove essential oil is connected to factors that enhanced the resistance of the mucus barrier and mucus production [798]

Antioxidant Activity Researchers have investigated the antioxidant potential of clove essential oil with DPPH radical scavenging activity and ferric reducing power. They have found the DPPH radical scavenging activity and the ferric reducing power. With the help of the DPPH method, the samples have been estimated for their radical scavenging capacity, which relied on the scavenging of the stable DPPH [816]

Central Nervous System Activity Researchers have carried out *in vivo* investigation to estimate the neuropharmacological effects of the ethanolic extract of clove with the help of behavioral models of mice. The anxiolytic activities of clove extract have been evaluated through plus maze (EPM), open field test (OFT), hole cross test (HCT), and hole-board test (HBT), respectively. The tail suspension test (TST), and forced swimming test (FST) have been conducted to identify the antidepressant effects. The thiopental sodium (TS)-induced sleeping time test have been conducted to analyze the sedative-hypnotic capacity of the extract. Researchers have observed that in the extract-treated group, the behavior of the mice are altered as perceived through HCT, and OFT in comparison with the control group. Thus, it is obvious that the locomotor actions of the mice have been reduced. The potential sedative response of the extract has been ensured by a TS-induced sleeping time test. The sleeping time for control group is 45.4 min, while the same for 500 mg/kg BW extract-treated group is 87 min. It can be concluded that the inlaying effect of any phytoconstituents with γ-aminobutyric acid (GABAA) or benzodiazepine (BZD) receptors is responsible for the neurological response [373]

Cinnamomum cassia (Caasia bark)

Anti-inflammatory Activity Researchers have investigated the anti-inflammatory activity of cinnamic acid, cinnamic aldehyde, cinnamic alcohol, and coumarin, the compounds derived from cassia bark. The carrageenan (Carr)-induced mouse paw edema and lipopolysaccharide (LPS)-stimulated mouse macrophage models have been considered to analyze the anti-inflammatory activity. The nitric oxide (NO) generation and tumor necrosis factor have been retarded in cinnamic aldehyde-treated mouse. The Carr-induced paw edema of mouse has been reduced by cinnamic aldehyde. The glutathione peroxidase, catalase, and superoxide dismutase activities are enhanced in the paw tissue with cinnamic aldehyde. It is reported that cinnamic aldehyde has emaciated myeloperoxidase (MPO) and MDA activities in the paw edema after Carr administration [527]

Anti-diabetic Effect 500 mg of capsules of cassia bark is supplied twice daily to the patients. For the treatment of type 2 diabetes, 1 g of cassia bark powder is given for 12 weeks to reduce glycosylated Hb, fasting blood glucose level, and serum level of malondialdehyde, to enhance serum glutathione and superoxide dismutase level [778]. In another investigation, at various doses of cassia bark extract are given for 6 weeks. It is observed that blood glucose level is significantly reduced in a dose-dependent manner in comparison with the control. The intestinal glycosidase activity is reduced, while the serum insulin level and HDL-cholesterol level are increased after 6 weeks of administration of cassia bark extract. It can be concluded that blood glucose level has been maintained with cassia bark extract. The cassia bark extract is able to reduce the blood glucose level by decreasing the carbohydrate absorption in the small intestine [49]

Anti-obesity Effect Researchers have demonstrated that at various doses of 50, 100, and 200 μg/mL of cassia bark extract are able to increase the lipid deposition in white adipocytes and to enhance the oxidation ability of fatty acid and are able to prevent obesity-induced type 2 diabetes. The doses of 100 and 300 mg/kg of WEBC (water extracts of barks of *C. cassia*) are able to reduce the total cholesterol level, serum glucose level, insulin, and lipid storage significantly in obese mice. The doses of 0.1 and 0.2 mg/mL of WEBC are capable to enhance the ATP levels [1012]

Cardiovascular Health Scholars have reported that various doses of 10, 30, and 50 μg/mL of WEBC are able to retard the proliferation of vascular smooth muscle cells (VSMCs), which may prevent cardiovascular disorder. It is demonstrated that a dose of 750 mg/kg of WEBC is able to reduce the serum levels of LDL, TG, and BNP (brain natriuretic peptide) significantly and is able to increase the $Ca^{2+}Mg^{2+}$-ATP enzyme activity, and to incresae the contents of PCR (polymerase chain reaction), ATP, and ADP in streptozotocin (STZ)-induced myocardial damage diabetic rats [1012]

Antimicrobial Effect Researchers have investigated about the antimicrobial activity of cassia bark extract. The extract exhibited a wide spectrum of antibacterial effects against fish pathogenic bacteria. Particularly, it showed the potential inhibitory effect against *Listonella anguillarum, Streptococcus iniae,* and *Edwardsiella tarda* In liquid medium, the Minimum Inhibitory Concentration (MIC) value of the extract is 75.8 ~ 189.6 µg/mL against gram-positive bacteria and is 75.8 ~ 113.8 µg/mL against gram-negative bacteria. It showed potential bactericidal action against gram-negative bacteria in comparison with gram-positive bacteria. The viable cell counts of *L. anguillarum* and *S. iniae* are decreased with the increase in the concentrations of the cassia bark extract [610]

Gastrointestinal Effect Researchers have investigated about the strong co-relation between bioactive components present in cinnamon bark and its gastrointestinal (GI) actions. Trans-cinnamic acid (TrCin), an organic acid, and its derivatives have been analyzed for regulating the activity of gastrointestinal track. The gastric emptying (GE) test has been conducted to analyze the gastrointestinal activity. 6 cinnamic derivatives like 3,4,5-trimethoxycinnamic acid, cinnamic acid, p-methoxy cinnamic acid, 2-(trifluoromethyl) cinnamic acid, 3-(trifluoromethyl cinnamic acid, and trans 4-(trifluoromethyl) cinnamic acid showed better delaying effect. TrCin, rosmarinic acid, p-coumaric acid, and its derivatives have been analyzed for their α-glucosidase inhibitory action, which may be co-related with gastric emptying and leads to weight loss, and satiety. Therefore, tannins, which are present in cassia bark extract, are able to reduce the demand for food intake by delaying the digestion action and by delaying the digestive track emptying. Researchers have reported that cassia bark extract is helpful in different GI-related disorders like constipation, and diarrhea [815]

Antioxidant Activity Researchers have investigated the antioxidant activity of cassia bark extract. 70% of ethanol and warm aqueous extracts of cassia bark have been used to evaluate its antioxidant activity by the DPPH radical scavenging activity, and ABTS radical scavenging activity. It is reported that the warm aqueous extract possess the DPPH radical scavenging activity and ABTS radical scavenging activity of 84.93% and 82.20%, respectively, while the ethanolic extract possesses the DPPH radical scavenging activity and ABTS radical scavenging activity of 90.25% and 92.21%, respectively. Researchers have analyzed the NO retardation activity for the cassia bark extract. It has been reported that the NO generation is reduced by 10.15 µM in the ethanol extract and 14.57 µM in the warm aqueous extract [523]

Central Nervous System Activity Scholars have proposed that the ischemic injury in the animal brain is improved by the administration of 80 mg/kg of cinnamophilin (component of cassia bark). The oxygen–glucose deprivation-induced neuronal injury can be treated with cinnamophilin. The aqueous-soluble extract of cassia bark possessed a substance known as procyanidin Type-A trimer (trimer1), which is able to decrease the cell lumps through improving the movement of intracellular calcium. It is also able to reduce the oxygen–glucose deprivation-induced decreasing activities on glutamate uptake [746]

Piper nigrum (Black pepper)

Anti-inflammatory Activity At the doses of 10 and 15 mg/kg of plethysmometer, piperine showed anti-inflammatory activity in rats. At a dose of 10 mg/kg, both ethanol and hexane extracts exhibited the anti-inflammatory effect [919]

Anti-diabetic Effect Piperine (main component of black pepper) showed hypoglycemic effect in normal mice. In hyperglycemic rats, anti-lipid peroxidative, anti-hyperglycemic, and antioxidant activities are found through the administration black pepper orally. In acute and subacute study models, blood glucose levels are influenced with piperine in alloxan-induced diabetic rats. Piperine is given orally at doses of 10, 20, and 40 mg/kg body weight to alloxan-induced diabetic rats. It is reported that piperine is able to increase the blood glucose level at the high dose in the acute study. In the subacute study, piperine is given at a doses of 5, 10, and 20 mg/kg body weight. It is reported that piperine is able to reduce the glucose level. 5% of black pepper has been administered for 8 weeks in the diet of rats. It is reported that it is able to enhance the serum cholesterol, serum liver cholesterol concentration, and hepatic cholesterol-7a-hydroxylase level [445]

Anti-obesity Effect Researchers investigated the effect of black pepper to control the obesity as a herbal drug [781]. Scholars have investigated the anti-obesity activity of black pepper, *Terminalia arjuna,* and *Lagenaria siceraria*. Obesity has been induced in Wistar albino rats with high-fat diet for 28 days. Group I is considered as control (1% of carboxy methyl cellulose (CMC)); group II is considered as obese control (1% of CMC) with high-fat diet; groups III, IV, V, and VI have been treated with several polyherbal tablet formulations of *Lagenaria siceraria* alone or in combination with other plant extracts of black pepper and *Terminalia arjuna* (400 mg/kg bw); group VII is taken formulation (400 mg/kg bw), and group VIII is considered as standard (Orlistat 45 mg/kg bw). In comparison with standard, the organ weight, food consumption tendency, body weight TC, TG, LDL, and locomotor activity are decreased, and HDL levels are enhanced in high-fat diet-fed rats treated with the black pepper, *Terminalia arjuna,* and *Lagenaria siceraria* [730]

Antimicrobial Effect A dose of 40 μg/disc of black pepper extract has been selected for examining its inhibitory effect against gram-positive bacteria like *S. albus,* and *B. megaterium* and gram-negative bacteria such as *E. coli, S. typhi,* and *P. aeruginosa,* and a fungus *A. niger*. Carbon tetrachloride, benzene, chloroform, ethyl acetate, acetone, ethanol, and aqueous extracts of black pepper showed the inhibitory activity against *S. albus*. Carbon tetrachloride, benzene, chloroform, ethyl acetate, acetone, and ethanol extracts showed the inhibitory activity against *P. aeruginosa* and *S. typhi*. carbon tetrachloride, benzene, ethanol, and distilled water exhibited inhibitory activity against *E. coli* and *B. megaterium* [453]

Cardiovascular Health The alkaloid piperine is derived from black pepper ranging from ~ 5–13%. Piperine is a compound with proven beneficial effect on cardiovascular disease (CVDs). In CVDs, the oxidation status, lipid metabolism, and inflammation have been mediated by the use of black pepper. Piperine showed favorable effects for atherosclerosis. Piperine is capable to inhibit lipid droplet development, lipid peroxidation, oxidized low-density lipoprotein uptake in macrophages, adherence of inflammatory cells to endothelial monolayer, to develop cholesterol efflux from macrophages, to recover lipid profile, to promote myocardial ischemia, cardiac damage, cardiac fibrosis, show antihypertensive, antithrombosis effect, and to protect arterial stenosis through retarding vascular smooth muscle cell proliferation [980]

Gastrointestinal Effect Researchers have proved that the black pepper and its main constituent piperine is an effective gastrointestinal stimulant and relaxant [707]. A neurotransmitter of the parasympathetic nervous system is Ach, cause gastrointestinal stimulation by the activation of muscarinic receptors. The piperine, and pepper extract showed similar effect to that of Ach [569]. Pepper has been utilized for medicinal purpose like constipation [591]

Antioxidant Activity Few *in vitro* investigations proved that reactive oxygen species are retarded by piperine and showed defensive activity against oxidative lesions [244]. In an *in vivo* study, it has been observed that piperine or black pepper are able to reduce lipid peroxidation and exhibited antioxidant potential. The oxidative stress is inhibited by black pepper by holding superoxide and hydroxyl free radicals, retarding lipid peroxidation and human lipoxygenase, and reducing lung carcinogenesis in rats [220]

Central Nervous System Activity At various doses of 50, and 100 mg/kg of methanolic extract of black pepper are administered orally for 21 days for memory increasing activity in Alzheimer's disease model in rats. In an *in vivo* study, the memory-increasing activities through the administration of the extract of black pepper have been estimated by radical arm-maze. In the radical arm-maze task, the reference memory is reduced and work memory is increased. The memory activity is enhanced by the use of the methanolic extract of black pepper. Researchers have proposed that amyloid β (1–42)-induced local memory diminished has been ameliorated by methanolic extract of black pepper through depletion of the oxidative stress in the hippocampus of rats [220]

***Coriandrum sativum* (Coriander)**

Antimicrobial Activity Researchers have reported that coriander essential oil is able to retard a wide spectrum of micro-organisms. The essential oil showed antibacterial activity against *Staphylococcus aureus,* gram-negative bacteria strain like *E. coli, Klebsiella pneumonia, Salmonella typhimurium,* and *Pseudomonas aeruginosa* The cell death may be due to the action of coriander essential oil. The fungicidal activity has been found in coriander essential oil against the *Candida* strains, which has been examined by minimal lethal concentrations (MLC). It is similar to that of MIC value extent from 0.05 to 0.4% (v/v). Coriander essential oil constitutes cyclodecane, 2-Hexen-1-ol, and 3-hexane-1-ol, which may responsible for the antimicrobial activity [87, 412]

Anti-diabetic Effect In an obese-hyperglycemic, and hyperlipidemic rat model, a dose of 20 mg/kg of coriander extract is given orally that is able to control insulin resistance, and glycemia. It also able to reduce the increased level of insulin, total cholesterol (TC), LDL-cholesterol, triglyceride (TG), and various components of the metabolic syndrome. It can able to enhance the cardioprotective indices. It is concluded that the extract of coriander is capable to enhance insulin secretion, glucose uptake, metabolism, and to reduce hyperglycemia [87, 412]

Anti-inflammatory Activity The injection of carrageenan is given to hind paw of rats, resulting in the development of edema, arising at its highest within the first 60 min. During the first hour, the retardation is peaked by 29% for the group of rats, which has been examined by polyphenol fraction of *Coriandrum sativum* seed (PCS) at the dose of 25 mg/kg body weight (BW). The retardation is peaked by 48% for the group, which has been treated with 50 mg/kg BW of coriander seed. The retardation is peaked by 34% for the group, which has been experimented with diclofenac. The retardation is peaked continuously at the 3rd hour by 39, 55, and 57% for group, which has been tested with PCS at a dose of 25 and 50 mg/kg BW and diclofenac, respectively. At the later stage of the experiment, the amounts have been fixed on an ultimate retardation, which is around 87, 92, and 95%. Carrageenan is applied as a chemical, which is able to provoke the salvation of inflammatory mediators. During the first hour after injection, the first phase is characterized by the salvation of histamine, serotonin, and kinins. The second phase is characterized by salvation of prostaglandin [586]

Cardiovascular Health Arterial blood pressure of anesthetized rabbits is partly blocked through atropine, which is due to the use of coriander crude extract. In rabbit aorta, the development of vasodilatation for phenylephrine and K^+-induced constriction are due to the utilization of coriander crude extract and caused cardio-depressant effect. In the organic, and water fractions, bioassay-directed fractionation showed the isolation of spasmolytic, and spasmogenic components. Therefore, diuresis is developed by coriander crude extract at a dose of 1–10 mg/kg. Coriander seed extract is able to retard the electrically evoked constrictions of spiral strips and tubular segments of separated central middle ear artery of rabbits [587]. The analysis of the protective effect of coriander seed on the cardiac injury has been done on isoproterenol-induced cardiotoxicity model in male rats. Rats are pre-examined with methanolic extract of coriander seed at various doses of 100, 20, or 300 mg/kg orally for 30 days. They are subsequently given with isoproterenol (85 mg/kg BW) for the last 2 days. It has been reported that in the cardiac tissue of isoproterenol-tested rabbits the levels of endogenous antioxidants, ATPases, plasma lipids, and the other markers of cardiac injury have been reduced. It is concluded that myocardial infarction are inhibited with methanolic extract of coriander seed through retarding myofibrillar injury and also postulated the oxidative damage, which is inhibited due to the presence of the ample amount of polyphenolic content in coriander seed extract. It has been reported that the coriander seed extract is able to scavenged the isoproterenol generated reactive oxygen species (ROS) efficiently [51]

Gastrointestinal Effect In rats, the activity of coriander has been examined for gastric mucosal damage caused through ethanol, NaCl, NaOH, indomethacin, and pylorus ligation. In the treatment, the doses of 250 and 500 mg/kg of coriander have been administered orally. It is observed that it is able to prevent the gastric mucosal damage through pylorus ligation, ethanol-related reduction in nonprotein sulfhydryl groups (NP-SH), ulcerogenic activities of various necrotizing agents, and ethanol-induced histopathological wounds. The gastroprotective effect of coriander is able to prevent gastric mucus, and indomethacin-induced ulcers. The protective activity of coriander against ethanol-induced injury of gastric tissue has been connected to the free-radical scavenging property of various antioxidant constituents like coumarins, linalool, flavonoids, catechins, terpenes, and polyphenolic compounds that exist in coriander. The compounds create a protective layer through hydrophobic interactions to retard the ulcer [51]

Antioxidant Activity Researchers have evaluated the free radical scavenging activity and antioxidant activity of coriander seed. Coriander seed is able to minimize the oxidative stress of streptozotocin-induced diabetic rats. The insulin level is enhanced and blood glucose level is reduced by the administration of seed powder in the diet of diabetic rats. The method of peroxidative destruction is retarded, antioxidant levels, and antioxidant enzymes are reactivated by the administration of coriander seed powder to diabetic rats. The scavenging effect has been observed in the seed against hydroxyl radicals, and superoxides in a concentration-related manner [234]

Central Nervous System Activity Scholars have identified the chemical composition of coriander essential oil to analyze its cytotoxic activity in SH-SY5Y human neuroblastoma cells, to evaluate its neuronal electrophysiological effects. Apart from this the changes in the extracellular signal-regulated kinase (ERK) and adenylate cyclase1 (ADCY1) expression are also been evaluated. It has been evidenced from the Western blotting, and 3-(4, 5-dimethylthiazol-2-yl)-2, 5-diphenyltetrazolium bromide MTT assay that the coriander essential oil can influence the ERK and ADCY1 expression. The cytotoxic effects of the coriander essential oil and linalool has been reported by researchers [173]

Myristica fragrans (Nutmeg)

Anti-inflammatory Activity Researchers have proved that nutmeg seed extract possessed anti-inflammatory activity through the retardation of TNF-α, IL-6, IL-1β, and NO formation. It is observed that the main macrophage-derived inflammatory mediators are $PGE_{2,}$ and NO. IL-1β, IL-6, and TNF-α are valuable inflammatory cytokines. However, it has been recommended that inhibition of IL-1β, IL-6, TNF-α, and NO is the best technique to decrease inflammation [243]

Antimicrobial Effect Some investigations exhibited that 60% of nutmeg seed essential oil is able to inhibit the *S. typhi, S. aureus, S. dysenteriae,* and *S. epidermidis* The growth of *S. aureus,* and *E. coli* are inhibited by the use of nutmeg essential oil. 0.5% of essential oil is able to inhibit the growth of *E.faecalis,* which has been found in teeth canals. Nutmeg essential oil is considered as a safe protective component for oral care products [585]

Anti-diabetic Effect Scholars have evaluated the effectiveness of nutmeg seed fot the anti-diabetic effect on alloxan-induced diabetic rats. Normal fasted, glucose fed, and alloxan-induced diabetic rats are given the petroleum ether extract of *Myristica fragrans* (PEMF) orally. It is observed that a dose of 200 mg/kg of PEMF is able to reduce the blood glucose level after regular treatment of PEMF for 2 weeks. The body weight, organ-like pancreas, liver weight, Hb content, and lipid profile are improved in alloxan treated rats in comparison with diabetic control rats [878]

Anti-obesity Effect Nutmeg is utilized as tonic, stomachic, carminative, aphrodisiac, and nervous stimulant. It has been demonstrated that in the tetrahydrofuran type lignans (THF)-treated mice, the body weights, and weight gain have been reduced compared to the high-fat diet (HFD)-induced obese mice. A group treated with THF can inhibit the enhancement in the body weight, adipose tissue mass, glucose, and LDL levels than HFD treated group. The acetyl-CoA carboxylase (ACCs) and AMP-activated protein kinase (AMPK) activators are the important factors which regulate the energy storage and management within the animal body. The ACCs, and AMPK are abundant in nutmeg extract, which may responsible for the anti-obesity effect of nutmeg [652]

Cardiovascular Health Hyalinization of muscle fibers with focal cellular infiltration or infarction of muscle fiber has been revealed by the administration of isoproterenol (ISO) in the heart tissue of rats. Deposition of inflammatory substance is found in the focal cells, which revealed that ISO may destroy the heart tissue. There are no changes in cardiac structure by the administration of nutmeg extract (NM) in heart tissue of treated rats. The effect is same as that of the control group. It is revealed that cardiac tissue is not injured by NM. It is concluded that NM showed protective activity on the myocardium against ISO [429]

Gastrointestinal Effect Ethanol-induced ulcer models are mostly recommended for the investigation of the gastro-protective effect of nutmeg. In the ethanol-induced ulcer model, the histopathological evaluation of gastric mucosa revealed the damage in lamina propria, damage of superficial epithelium, infiltration of mononuclear cells in the mucosa, degenerative changes in gastric glands, completion of blood vessels, and gastric damage. But pre-treatment with sucralfate, and nutmeg ethanolic extract significantly decreased the changes in gastric mucosa and have been reported to provide protection against alcohol-induced gastric damages. Therefore, researchers have concluded that ethanol-induced gastric ulcer is suppressed with nutmeg seed ethanolic extract [812]

Antioxidant Activity Researchers have compared that the antioxidant activity of nutmeg seed with the synthetic antioxidants like propyl gallate butylated hydroxytoluene (BHT), and butylated hydroxyanisole (BHA). Nutmeg exhibited potential activity in the deoxyribose assay. It is able to maintain the durability of fats like margarine, and butter and oils such as olive, sunflower, and corn against oxidation at 110^0 C. In comparison with the BHT, the greater antioxidant activity of nutmeg has been evidenced through Trolox equivalent antioxidant capacity. The antioxidant activity of nutmeg may be due to the presence of compounds like phenylpropanoid, lignans, monoterpenoid including 4-allyl-2, 6-dimethoxyphenol, terpinene-4-ol, and α-terpineol [399]

Central Nervous System Activity Psychoactive properties such as anxiogenic, and hallucination can be prevented with nutmeg. The physiology of central nervous system has been modulated by the use of nutmeg. The forced swim test (FST) and the tail suspension test (TST) have been used to assess the antidepressant activity of the n-hexane extracts of nutmeg seed in mice. They are subjected to three various doses, e.g., 5, 10, and 20 mg/kg BW, orally. It has been reported that the nutmeg seed extract exhibited antidepressant activity in nutmeg extract treated mice [346]

Brassica nigra (Black mustard)

Anti-inflammatory Activity Researchers have analyzed the anti-inflammatory effect of ethanolic and water extracts of black mustard seed. At the doses of 200 mg/kg, and 500 mg/kg the extract of black mustard seed are made. Wistar albino rats have been considered for Carrageenan-induced paw edema *in vivo* analysis to ascertain the anti-inflammatory activity of the black mustard seed. Aspirin-treated group has been considered as the control group. Both the ethanolic, and aqueous extracts of black mustard seed showed the significant retardation of paw edema in comparison with the control group as reported by the researchers [146]

Antimicrobial Effect Silver nanoparticles along with antibiotics Vancomycin has been applied as a standard anti-bacterial agent against *K. pneumonia, P. acnes,* and *P. aeruginosa* The organisms cannot be inhibited by 1 mM $AgNO_3$ But the fabricated silver nanoparticles alone, and a combination of antibiotics exerted significant inhibitory activity against the bacteria considered. The highest synergistic and antibacterial effects have been observed for *P. acnes*. Researchers have reported that the efficacy of silver nanoparticles are increased in conjunction with standard antibiotics. The organisms, namely *P. acne, Candida albicans, Microsporum canis,* and *Trichophyton mentagrophytes*, can be inhibited with mustard seed-silver nanoparticles. The free radicals generated from silver nanoparticles, the interaction between microbial cell membrane and the AgNPs, and the interaction between silver ion and the respiratory cycle of microbes may be the reason for which the inhibitory activities can be observed [680]

Anti-diabetic Effect The acetone, aqueous, ethanol, and chloroform extracts of black mustard seed are selected to treat streptozotocin-induced diabetic rats. The dose of 200 mg/kg BW of aqueous extract are given to diabetic rats daily for 30 days. The mustard seed extracts are able to reduce the fasting serum glucose (FSG) levels compared to control groups. The serum lipid is lowered, and glycosylated hemoglobin (HbA1c) is enhanced in tested rats in comparison with the control group [76]

Cardiovascular Health The black mustard seed is a rich source of antioxidant α-tocopherol. The aqueous extract of mustard seed is able to retard the lipid peroxidation induced through ferrous sulfate ascorbate in the human erythrocyte membranes. The mucilaginous fraction of mustard seed is administered into rats. It showed no differences in triglyceride levels and serum cholesterol [284]. The activities between mustard seed oil and fish oil have been evaluated in 360 patients suffering from acute myocardial infarction (MI) in a 1-year randomized placebo-controlled experiment. The treatment has been given to all patients for 18 h after symptoms of an acute MI. 1.08 g/day of fish oil are administered orally to group A patient, 2.9 g/day of mustard seed oil are given to group B orally, and 118 patients are taken as the control group. It has been reported that decrease in total angina pectoris, cardiac arrhythmias, and left ventricular is observed in mustard seed oil- and fish oil-treated patients [642]

Antioxidant Activity Superoxide dismutase (SOD) is antioxidant enzyme. The enzyme catalyzed the transformation of superoxide to hydrogen peroxide. It defends the cell against oxidative stress. Researchers have carried out an investigation, where 150 mg/kg of *Brassica nigra* seed has been used to enhance the SOD level of pentylenetetrazole (PTZ)-treated mice. It has been reported that the mustard seed extract is able to remove free radicals and is a potent antioxidant [470]

Central Nervous System Activity Researchers have evaluated the effect of *B. nigra* fixed oil (BNO) on the alterations in memory caused by β-amyloid. 42 Wistar rats are divided into 7 groups: 1) control, 2–3) the group is taken BNO at the doses of 462.5 and 925 mg/kg, 4) sham group, 5) Alzheimer group is taken 50 mg/μl/side β-amyloid. The regular gavage of BNO has been carried out for 2–21 days post-amyloid injection. In Morris water maze task, the spatial memory has been analyzed from 21 to 26 days. It is reported that the BNO treated rats the journey distance has been reduced in comparison with the group, which has been treated with β-amyloid alone. The brain memory improving activity of BNO may be due to the presence of 11-eicosenoic acid and erucic acid [647]

Curcuma longa (Turmeric)

Anti-inflammatory Activity Researchers have reported about the effect of curcumin derived from turmeric on anti-inflammatory activity in rats, and human trials [583, 989]. The laboratory investigation has determined the number of various molecules like cyclooxygenase 2, phospholipase, lipoxygenase, leukotrienes, thromboxane, prostaglandins, nitric oxide, collagenase, elastase, hyaluronidase, monocyte chemoattractant protein-1 (MCP-1), interferon-inducible protein, tumor necrosis factor (TNF), and interleukin-12 (IL-12) that evolved in inflammation. These molecules can be inhibited with curcumin [181]

Antimicrobial Effect The antimicrobial effect of various fractions of *Curcuma longa* rhizome has been evaluated against *Staphylococcus aureas*. The *Staphylococcus aureas* has been treated with *C. longa* extract. The microbial cell death may be due to the deformation of cytoplasmic membrane as reported from the scanning electron microscopic observation. It is reported that *C. longa* rhizome extract showed a wide spectrum of antimicrobial activity. Thus, it can be stated that the turmeric is able to control the microbial infections [345, 851]

Anti-diabetic Effect Diabetes is treated with turmeric rhizome powder mixed with amla juice, and honey. Researchers have reported that postprandial serum insulin levels are enhanced by the administration of 6 g of turmeric. But it is not able to influence the plasma glucose concentrations or GI within healthy persons. Turmeric showed the activity on the secretion of insulin. Curcuminoids are the active component derived from turmeric rhizome. The curcuminoid is able to reduce the lipid peroxidation by controlling the effects of antioxidant enzymes such as glutathione peroxidase, superoxide dismutase, and catalase at maximum levels [290]. Curcumin and its derivatives like diacetyl curcumin, dimethoxy curcumin, and bisdemethoxycurcumin are responsible for antioxidant activities. Freeze-dried turmeric rhizome powder along with milk can be used as an efficient and safe anti-diabetic supplement as explored by the researchers [729]. Isopropanol and acetone extracts of turmeric are capable to retard the enzyme Human Pancreatic Amylase (HPA) resulting in the lowering of the starch hydrolysis, which ultimately reduce the glucose levels [961]

Gastrointestinal Effect The curcumin functions by nuclear factor (NF)-$_{k}$B inhibition. The formation of adherence molecules and inflammatory cytokines are decreased with curcumin. It is able to ameliorate the gastric damage, to recover from gastric mucosal injury, to reduce the leucocyte adherences, intracellular adherence molecule 1, and tumor necrosis factor (TNF)-α formation in nonsteroidal anti-inflammatory drugs (NSAIDs)-induced gastropathy in rats [934]. Abdominal pain or irritation, and Irritable Bowel Syndrome (IBS) are reduced by the administration of *Curcuma longa* extract. It is also able to enhance the IBS quality. Curcumin is able to treat the acetaminophen (APAP)-induced hepatitis through the recovery of liver histopathology through reduced restitution of GSH, oxidative stress, and inflammation of the liver [877]

Cardiovascular Health Turmeric contains antioxidants that inhibit damage to cholesterol; therefore, has provided a protective activity against atherosclerosis. Turmeric is able to reduce free radicals as it contains vitamins C and E. It is reported that triglycerides, cholesterol, and other lipids move in the bloodstream. They are the risk factors for cardiovascular disorders which may be reduced with curcumin. A standard American diet rich in refined saturated fat, carbohydrates, and fiber has been administered to mice. The diet has been mixed with turmeric has been given to mice. It has been reported that the mice those have been fed with the turmeric added diet possessed 20% less blockage of the arteries after 4 months in comparison with that mice fed with the American diet. In another investigation, rabbits fed with turmeric enriched diet to treat the atherosclerosis disease. It has been reported that the cholesterol, and triglycerides levels have been reduced in the turmeric treated rabbits [961]

Anti-obesity Effect Researchers have investigated about the potential anti-obesity activity of the turmeric, and curcumin extracts. A high level of turmeric extract is able to prevent the formation of cholesterol and triglycerides [743]. The anti-adipogenesis potential of turmeric extract may be due to its ability to retard the formation of lipid droplets, triglycerides, and cholesterol in HepG2 cells. The turmeric extract showed better anti-obesity activity in comparison with curcumin [165]

Antioxidant Activity Researchers have evaluated the antioxidant activity of different fractions of methanolic extract of turmeric rhizome [761]. The ethylacetate fraction possessed DPPH free radical scavenging activity with IC50 = 9.86 µg/mL. At a similar concentration, the ethylacetate fraction showed higher DPPH radical scavenging activity, and ABTS radical scavenging activity in comparison with n-hexane, and water fractions [199]

Central Nervous System Activity Researchers have investigated the chemical composition of the essential oil of turmeric rhizome to analyze its neuropharmacological effect. At a dose of 50–200 mg/kg of EO of turmeric has been given to albino mice to assess its sedative, behavioural, anxiolytic, and anticonvulsant activities. It is reported that the head dips are reduced, locomotor activities are retarded, and total sleeping time are extended with the application of EO. EO is able to defend the mice from pentylenetetrazol-induced convulsions. It is reported that EO of turmeric possessed anticonvulsant, anxiolytic, and sedative effects [671]

Laurus nobilis (Bay leaves)

Anti-inflammatory Activity Researchers have considered mice for analyzing the anti-inflammatory activity of bay leaf essential oil. In the carrageenan-induced hind paw edema in mice, the water, and ethanol extracts of bay leaf have been reported for its potential of anti-inflammatory effect without causing any gastric injury [931]

Antimicrobial Effect A wide range of microorganisms are inhibited with Laurus leave essential oil [124]. The greater antibacterial activity has been found in Laurus essential oil in comparison with tetracycline antibiotics [212]. It is reported that bay leave essential oil can alter membrane-embedded proteins, damage cellular membranes, enhance the permeability of the membrane, damage the transit system of the membrane [868]. The EO showed antibacterial properties may be due to the presence of terpenes. Researchers have revealed the gram-positive bacterial strains and the gram-negative bacteria can be inhibited with essential oil. The outside membrane of gram-negative bacteria provides protection against the EO, that is why the essential oils are more effective against the gram-positive bacteria than the gram-negative bacteria [909]. 1,8-cineole is the main active compound responsible for the antimicrobial effect of bay leave EO [172]. The antagonistic, and synergistic effects of 1,8-cineole along with the oxygenated terpenes may be the reason behind the inhibitory potential of Laurus essential oil on microbial growth. Microorganisms like *Kocuria rhizophila, Staphylococcus aureus, E. coli, Pseudomonas aeruginosa,* and *Salmonella abony* can be inhibited with bay leaf essential oil [298]

Anti-diabetic Effect Researchers have investigated the effect of bay leave extract on biochemical, and histopathological changes in β-cells for Streptozotocin (STZ)-induced diabetic male albino rats. 30 healthy adult male albino rats have been considered. The rats have been divided equally into 5 groups: diabetic *Laurus nobilis* extract group (DLN), control group (C), diabetic group (D), *Laurus nobilis* extract group (LN), and diabetic acarbose (DA) group. It is reported that the D group rats have exerted several degenerative, and necrotic changes in their kidney, liver, and pancreas, while the normal histology is found in DLN rats. D groups showed a reduction in insulin immunostaining in the pancreatic β-cells in comparison with the C groups. The diabetic rats have been treated with *Laurus nobilis*, and have also been treated with acarbose, which have exhibited the reduction in glucose concentration, aspartate aminotransferase (AST), γ-glutamyltransferase (GGT), and alanine aminotransferase (ALT) enzyme in comparison with D groups. It is reported that bay leave showed important activity on blood glucose levels. The bay leave is able to increase the regeneration of pancreatic islets. It is also able to restore the altered liver enzymes, total protein levels, urea, creatinin kinase, calcium, and ferritin to near-normal levels [609]

Gastrointestinal Effect Scholars have considered rats to evaluate the gastroprotective effect of various extracts of bay leave (chloroform and methanol). The methanolic and chloroform crude extracts can decrease the gastric damage significantly. The extracts are able to provide more efficient protection. The extracts of bay leave is able to ensure the relationship between the antiradical activity, and pharmacological efficacy [885]

Antioxidant Activity Various flavonols and glycosides are present in bay leave. Bay leave contains water-soluble antioxidant compounds that can be connected to the several health-beneficial effects [216]

Crocus sativus (Saffron)

Anti-inflammatory Activity Anti-inflammatory effect has been found in water extract of saffron petals. The presence of crocin in saffron is responsible for the anti-inflammatory activity [633]

Antimicrobial Effect Researchers have evaluated the antimicrobial activity of the non-polar extract of saffron flower stamens. It has been reported that saffron flower extract can inhibit both the growth of gram-positive, and gram-negative bacteria [903]. The diethyl ether extract of saffron stamens (DES) is able to inhibit the foodborne pathogen species like *Listeria monocytogenes, Salmonella enterica subsp In. bongori, Staphylococcus aureus,* and *E. coli* [1009]

Anti-diabetic Effect Scholars have evaluated the anti-diabetic activity of water extract of saffron. α-Amylase and α-glucosidase enzymes are retarded with saffron water extract. Thus, researchers have concluded that saffron water extract is able to prevent diabetes [509]. It is reported that phenolic compounds derived from saffron showed hypoglycemic activity through the maintenance of insulin sensitivity, postprandial blood glucose levels, and acute insulin secretion. The extract is also able to retard the glucose absorption rate from the intestines into bloodstream [1001]

Gastrointestinal Effect Many studies have demonstrated that the effectiveness of saffron on gastrointestinal system. It is reported that saffron is able to treat the stomach related problems, amenorrhea, menstruation problem, the problem related to anus displacement, hemorrhoids, decrease in appetite, intestinal fermentation related problems. Safranal derived from saffron is able to decrease the surface spreading of gastric ulcers, to normalize gastric volume, and to maintain the histological changes in gastrointestinal track [633]

Cardiovascular Health Researchers have demonstrated the capability of saffron on cardiovascular activity. The saffron is able to provoke chronotropic, inotropy, and to decrease KCI induced constriction in vascular, non-vascular smooth muscle. In hypertensive and normotensive anesthetized rats, the blood pressure is decreased with water extract of saffron. This investigation recommended that smooth muscle contractility may not be affected with crocin [706]. The hydroalcoholic extract of saffron showed the hypotensive effect because of the retardation of the rennin-angiotensin system in angiotensin II hypertensive rats. The saffron extract showed hypotensive activity by decreasing the calcium salvation into the sarcoplasmic reticulum, antagonism toward adrenergic receptors, and retardation of calcium channel [1011]

Anti-obesity Effect The body weight of rats is decreased with saffron stigma ethanolic extract. The ethanolic extract of saffron is able to reduce the appetite. It is reported that the saffron extract has possessed mood-improving activity. The saffron extract is able to reduce snacking, and appetite. It is observed that saffron extract intake in women can reduce their body weight, and snacking within 60 days. Researchers have recommended that body weight can be reduced with the consumption of saffron supplemented diet [581]

Antioxidant Activity Researchers have identified the antioxidant potential of saffron in various extracts [725]. Saffron is able to protect the free radical-induced injured organs like lungs, kidney, liver, and heart as observed in hamsters [955]. It is reported that at a dose of 0.45 mg/ml of soaked, and decocted saffron is the most efficient one to cure the injured organs. The superoxide dismutase activity can be enhanced with saffron extract, while the lipid peroxidation can be reduced [561]

Central Nervous System Activity Scholars have evaluated the neuropharmacological activities of crocetin, saffron, crocin, and safranal in the peripheral, and CNS [984]. Saffron and its active constituents showed protective activities like anxiolytic, antidepressant, antinociceptive, hypnotic, and cytoprotective [506]. Saffron, and its constituents are able to decrease the opioid withdrawal syndrome, and to cure neurodegenerative diseases such as Parkinson's disease, epilepsy disease, brain ischemia, and memory impairment. It is reported that age-related macular degeneration and Alzheimer's disorders are prevented with saffron [640]

Illicium verum **(Star anise)**

Antimicrobial Effect The crude ethanol extract of star anise exhibited antimicrobial properties against *S. aureus and A. baumannii*. The star anise ethanol extract is also able to inhibit *P. aeruginosa*. The diethyl ether (EE) fraction of star anise has provided greater inhibitory activity in comparison with crude extract. The supercritical CO_2 extract of star anise exhibited an antibacterial effect against *A. baumannii*. Though the supercritical CO_2 extract did not show any antibacterial property against the other two bacteria. The EE fractions and alcohol extract showed a wide antibacterial spectrum against these three bacteria. The EE fraction of star anise has possessed MIC value of 0.25 mg/mL. It showed higher antimicrobial activity against *S. aureus* in comparison with the crude extract. Similar results have been reported by the researchers for gram-negative bacteria, namely *A. baumannii* and *P. aeruginosa* [994]

Anti-inflammatory Activity Researchers have revealed the anti-inflammatory activity of star anise. The anti-inflammatory activity has been reported in water extract of star anise as per the investigation carried out on the intestinal smooth muscles of mice. The water extract of star anise is able to reduce the serum level of TNF-α, and IL-1β [94]

Anti-diabetic Effect Scholars have investigated the anti-glycation effect of ethanolic extract of star anise. The protein glycation retardation has been evaluated by human serum albumin (HAS)-fructose glycation model. Similarly, sodium dodecyl sulfate (SDS) polyacrylamide gel electrophoresis has been conducted to analyze the cross-linked advanced glycation endproducts (AGEs). The star anise extract has been given to streptozotocin-induced diabetic rats for 7 weeks. After that, the anti-glycation activity has been analyzed. Star anise extract exhibited a good inhibitory activity in comparison with the standard inhibitor (rutin). The extract of star anise is able to decrease the lipid, blood glucose level, urea, liver functions parameters, and renal AGEs levels in streptozotocin-induced diabetic rats. It is reported that star anise can prevent diabetes-associated problems [447, 448, 455]

Gastrointestinal Effect Researchers have investigated the star anise extract as an anti-gastroulcerogenic agent in the rat model. Various extracts like aqueous–alcoholic, petroleum ether, and essential oil have been considered. The rats are fed with a dose of 1250 mg/kg bw petroleum ether extract and 2500 mg/kg bw for aqueous ethanol extract. Rats have been divided into three main groups: treated animals, negative control groups (fed with distilled water), and positive control groups (administered with various extracts). It is reported that aqueous–alcoholic extract possesses the greatest antioxidant activity. The petroleum ether extract showed the lowest effect. The higher anti-ulcerogenic activity has been found in aqueous–alcoholic extract in comparison with famotine (a reference drug). The aqueous–alcoholic extract is able to increase the superoxide dismutase activity and catalase activity and is able to induce the glutathione reductase activity [382]

Central Nervous System Activity Scholars have investigated the action of star anise extract on the central nervous system (CNS). In this experiment, the male albino mice and rats have been examined. The parameters like locomotor activity, general behavior, sleeping pattern, anxiety, and myocoordination activity have been used to analyze the CNS activity. The rats and mice are separated into 5 groups with 6 animals in each group and have examined for 1 week. At a dose of 200 mg/kg of all extracts have been administered through intraperitoneal injection. It is reported that the extracts of star anise are able to decrease the locomotor activity, prolong the phenobarbitone induced sleeping time, form alteration in a general behavior pattern, and possess anxiolytic effects. Though, the extracts are not able to alter the muscle coordination activity. The methanol extracts are more effective in comparison with the ethyl acetate, and hexane extracts. It is reported that the most potential CNS depressant activity and anxiolytic effects are found in these three extracts without altering the motor coordination [202]

Antioxidant Activity Researchers have evaluated the antioxidant activity of star anise constituents. The methanolic extract of star anise showed antioxidant potential (as appeared in DPPH assay) with IC50 of 61 mg/ml. Among the different types of fractions, antioxidant activity has been found in the ethyl acetate (IV-EA) with IC50 of 18 mg/ml. In the sub-fractions, the most potent antioxidant activity has been observed in the ethyl acetate soluble sub-fraction of ethyl acetate fraction (IV-EA-EA-S) with IC50 value of 42 mg/ml. The protocatechuic acid, *Illicium verum* extract (IV-E), and IV-EA showed antioxidant potential with IC50 of 2000, 1400, and 600 mg/ml, respectively [92]

Allium cepa (Onion)

Anti-inflammatory Activity Researchers have evaluated the anti-inflammatory activity of ethanolic extract of onion. Sprague Dawley rats (250–300 g) have been considered to analyze the anti-inflammatory activity of onion extract. The standard drugs like tramadol and diclofenac sodium have been considered to compare the anti-inflammatory activity of onion. The carrageenan-induced paw edema of rats can be retarded with the administration of ethanolic extract of onion [415]

Antimicrobial Activity Scholars have evaluated the antimicrobial activity of onion EO at various concentrations (50, 100, 200, 300, and 500 ml/l) against *Salmonella enteritidis and Staphylococcus aureus*. The EO extracts of onion are able to inhibit fungies like *Aspergillus niger, Penicillium cyclopium,* and *Fusarium oxysporum* [141]

Anti-diabetic Activity Researchers have analyzed the anti-diabetic activity of onion in alloxan-induced diabetic rats. Thirty-six male albino rats are given with alloxan through intraperitoneal route to evaluate the anti-diabetic activity of onion. The rats have been divided into six groups (6 rats/group). The group A consists of rats those are not induced with alloxan and untreated, group B rats (induced but untreated), group C rats (administered with glibenclaimide), rats of group D, E, and F are induced, treated with 1, 2, and 3 mL/100 g BW of onion juice, respectively. It is reported that onion is able to reduce the blood glucose levels, and the lipid profile significantly in untreated rats [33]

Anti-obesity Activity Scholars have investigated the effects of the onion extract on the expression of inflammatory mediators from the adipose tissue in a high-fat diet-induced obese rat model. Dawley rats have been separated into three groups: control, high-fat diet (HF), and high-fat diet with onion extract. The all the groups have been treated for 8 weeks. It is reported that the epididymal, and perirenal fat weights are not influenced significantly, whereas the mesenteric fat weight is reduced significantly in the groups treated by high-fat diet with onion peel extract in comparison with the HF groups. A greater adiponectin mRNA level has been identified for the group fed with high-fat diet with onion supplementation in comparison with the other groups. IL-6 mRNA level has been reduced slightly in rats fed onion extract supplementation in comparison with the HF groups [579]

Cardiovascular Activity Flavonoids derived from onion, which are able to prevent cardiovascular disease, and heartburn. Quercetin is able to decrease the blood pressure in hypertensive persons, to activate platelets, and to treat cardiovascular disease [398]. Stroke, coronary heart disease, and hypertension have been associated with inflammation or atherosclerosis. Researchers have revealed that oxidative stress can be reduced with quercetin through mopping free radicals. Therefore, quercetin is able to decrease the chances of stroke, and heart disease. In another study, 24 healthy persons with ages between 35 and 55 years have been considered. They have been separated into two groups of 12 each having 7 females and 5 males suffering from moderate hypercholesterolemia. One of the groups has been administered with 100 mL of onion, while the other group has been considered as control. It is reported that LDL-C, waist circumference, and total cholesterol are decreased after 8 weeks substantially for the group fed with onion. It is reported that onion juice is able to enhance the LDL oxidation lag time, and antioxidant activity, which is helpful in the prevention of CVD [183]

Antioxidant Activity Researchers have evaluated the antioxidant capacity of flavonoids, organosulfur compounds, and polyphenols are present in ample amounts in onion. Three onion cultivars, namely *Borettana di Rovato, Dorata di Parma,* and *Rossa di Toscana*, have been considered to evaluate their antioxidant potential in terms of total phenolic content, DPPH, FRAP (ferric reducing antioxidant power), and TEAC (Trolox equivalent antioxidant capacity) potential. The highest antioxidant potential has been observed in *Rossa di Toscana* [536]. The subcritical water, hot water, and ethanol extracts of onion have been considered to evaluate the antioxidant potential in terms of ferric thiocyanate

(FTC), DPPH, and lipid peroxidation inhibitory ability [518]. Other researchers have investigated a relevance between the antioxidant activity, and organosulfur compounds of the onion by the methods like ABTS (2,2'-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid), ORAC (oxygen radical absorbance capacity), and DPPH [473]. The antioxidant activity has been reported in organosulfur compounds. Researchers have selected 400 broiler chickens to evaluate the effects of phenol-rich onion for their antioxidant capacity, production, digestion, and immune response. At various concentrations, the phenol-rich onion extract (PROE) has been given to each group (100/group) for 35 days. It is confirmed that antioxidant enzyme activities (glutathione peroxidase, catalase, and superoxide dismutase) are enhanced with PROE because of flavonoids, and phenol [667]

Central Nervous System Activity Researchers have evaluated the neuroprotective effect of Onion in aluminium chloride-induced neurotoxicity. 50 mg/kg/day of aluminium chloride, and 50–200 mg/kg/day of onion have been administered to Swiss albino male mice. It is reported that onion is able to enhance catalase, and glutathione (GSH) activities and to lower the nitrate/ nitrite, acetylcholinesterase (AChE), and lipid peroxidation. Quercetin, kaempferol, cycloartenol, and phytosterols like lophenol, 24-ethyl cycloartenol, and 24-methyl lophenol present in onion possessed neuroprotective effect [183]

Anethum graveolens (Dill)

Anti-inflammatory Activity Researchers have evaluated the effects of dill seed, and the extract of aerial part to determine its anti-inflammation potential. The dill extract has been evaluated for its anti-inflammatory activity against formalin-induced inflammation in rats and the diclofenac gel as a reference. The inflammation has been induced by injecting formalin in the paw of rats. After that the weight of the rats has been measured by plethysmometer and the paw volume has been assessed. The experiment has been conducted for 8 days. Researchers have divided the rats into 3 groups of 6 male rats: the diclofenac gel groups, formalin groups, and dill-oil groups. Two grams of dill oil with 100 mg dill extract has been administered to dill-oil groups. Two grams of gel with 20 mg diclofenac Na has been given to the diclofenac groups. In these groups, the mean paw amounts have been changed after Formalin-induced inflammation on the 1st day. In diclofenac gel and dill-oil-administered groups, the paw volume has been changed after injecting the formalin on daily basis for 8 days in comparison with the control groups, which may show a significant reduction. Paw volume has been more reduced in dill groups in comparison with the diclofenac groups. Plethysmometer has been conducted to evaluate the results of paw volume. It is reported that the dill-oil is capable to reduce the paw volume significantly [639]

Antimicrobial Activity Dill extracts have been reported for its *Helicobacter pylori* inhibiting activity. The potential antibacterial activity has been found in organic, and water extracts, and the essential oils of dill against fungi (two molds like *Aspergillus flavus, Penicillium islandicum,* yeast such as *Candida albicans*)*Candida albicans, Aspergillus niger,* and *Saccharomyces cerevisiae* are inhibited by D-carvone and D-limonene. The antimicrobial effect may be characterized by furanocoumarin present in dill [607]

Gastrointestinal Activity The dill extract has been reported to possess antisecretory, and mucosal protective activities against ethanol, and HCl-induced gastric mucosa damage in mice. Dill extract is capable enough to reduce the total acid content as perceived by the researchers. Rabbit intestine constrictions are decreased with dill essential oil. Ethanol extract of dill has been retarded histamine and acetylcholine-induced constrictions of guinea-pig ileum. Some digestive problems like flatulence, stomachache, and indigestion are improved with dill [354]. Dill water is reported to show a cooling effect in stomach. Dill is able to prevent gripe, to improve colic, and hiccups. It is reported that essential oil is able to decrease foaming, and also to act as a light carminative [378]

Antioxidant Activity The antioxidant potential of the acetone, and essential oil extracts of dill has been investigated by researchers through the methods like DPPH, reducing power, and chelating effect. The ethanol, hexane, and ethyl acetate extracts of dill have been evaluated for their antioxidant potential through the methods like reducing power, DPPH radical scavenging, Trolox equivalent antioxidant capacity, chelating power, and β-carotene bleaching [854]. The carbon tetrachloride-induced hepatotoxicity in albino rats have been considered to analyze the antioxidant activity of ethanolic extract of dill [914]. It is reported that ethanolic extract of dill (100 mg/Kg wt) is able to restore the antioxidant enzymes and serum enzymes activity that are increased in treated rats. The antioxidant capacity of ethyl acetate, dichloromethane, n-hexane, and ethanol extracts of dill have been examined by nitric oxide radical scavenging, DPPH, N,N-dimethyl-p phenylendiamine, ferric ion-chelating capacity, ferric reducing antioxidant power, and phosphor molybdenum-reducing antioxidant power. It has been reported that the ethanolic extract of dill possessed the highest antioxidant power. Though, in terms of ferric ion chelation effect the dichloromethane extract possess the maximum value. The chlorogenic acid (6.04 μg/g extract) is the dominant phenolic acid as reported by the researchers. The EO fraction contains lower amounts of phenolic compounds (35.1 mg GAE g^{-1} extract) [180]

Anti-diabetic Activity Various extractions of dill, and its essential oil have been given to diabetic rats. The extracts, and EO of dill are able to decrease low-density lipoprotein cholesterol, triglycerides, total cholesterol, very-low-density lipoprotein cholesterol, and glucose levels remarkably, and to enhance the HDL-C levels. The antioxidant and hypoglycemic activities have been found in dill. Flavonoids, and phenolic proanthocyanidins compounds derived from dill showed antioxidant potential. The anti-diabetic activity of dill may be due to the enhancement of fecal excrement, bile acids formation, retardation of the absorption of intestinal cholesterol, and the ability to bind the bile acids in the intestine [402]. The hypolipidemic activity of dill may be due to the presence α-phellandrene, carvone, and limonene. Histopathological tests exhibited various extracts of dill, which are used to treat diabetic rats are able to normalize the deposition of lipid in the heart, liver, and pancreas. The hypoglycemic effect of dill may be due to the presence of alkaloids, flavonoids, terpenoids, tannins, and phytosterols in dill extract. It is proposed that the dose of 300 mg/kg of hydroalcoholic extract of dill is able to reduce the fasting blood glucose level. Various extracts of dill at the concentrations of 0.032, 0.065, 0.125, 0.25, 0.5, and 1 mg/ml have been fed to the type 2 diabetic rats to decrease the fructosamine level [333]

Anti-obesity Activity Researchers have investigated the anti-obesity activity of *Anethum graveolens* aqueous extract (AGAE). AGAE is able to act as a strong anti-obesity agent through the 5-hydroxytryptamine (5-HT) metabolism mediation, to enhance 5-HT turnover in the brain of rats, the concentrations of tryptophan in the brain and blood. AGAE has been administered to rats orally for 7 days. It is able to decrease the tendency in food consumption of obese rats, resulting in reduced body weight. Researchers have described important facts about the 5-HT concentration in the brain which is a neurotransmitter. It plays an important role in feeding behavior. Obesity and hyperphagia have been produced with reduced concentration of 5-HT in the brain [125]

Cardiovascular Activity Scholars have evaluated the effectiveness of the hydroalcoholic extract of dill on the cardiovascular activity of overweighted male rats. Thirty-two overweight male rats weighing 350–400 g having aged 12 weeks have been separated into four equal groups like endurance training + dill extract (ETr + DEx), endurance training (ETr) for 10 weeks in 5 sessions/week, dill extract (DEx) at a dose of 300 mg/kg BW, and control (Ct). Eight rats weighing 240–280 g in the non-obese control (NCt) groups have been considered to analyze the cardiovascular activity. After the final intervention session, the fasting plasma lipid concentration has been assessed for 48 h. It is reported that in the Ct groups, LDL-C, TC, TG, VLDL-C, TC/HDL-C, and HDL-C levels are enhanced in comparison with the NCt groups. The plasma concentration of LDL-C, VLDL-C, TG, TC/HDL-C, and LDLC/HDL-C is reduced in the ETr + DEx groups and in the ETr groups in comparison with Ct groups. It is reported that the plasma lipid profile is maintained with endurance training. It has been confirmed by the researchers that the dill extract is more efficient to prevent cardiovascular disease [59]

Trigonella foenum-graecum (Fenugreek)

Anti-inflammatory Activity Researchers have evaluated the anti-inflammatory effect of petroleum ether extract of fenugreek. Fenugreek petroleum ether extract (FSPEE) has been evaluated and examined on rats against formaldehyde, and carrageenan-induced paw edema. At a dose of 0.5 mL/kg of FSPEE has been given to rats to analyze the anti-inflammatory activity. It is reported that FSPEE is able to decrease 37%, and 85% inflammation of the paw in the formaldehyde and carrageenan-induced paw edema, respectively. It is reported that anti-inflammatory activity has been found in fenugreek petroleum ether extract because of the presence of linoleic, and linolenic acids [716]

Antimicrobial Activity Scholars have evaluated the antimicrobial activity of acetone, aqueous, and methanol extracts of fenugreek against *Staphylococcus* and *E. coli*. The methanol extract has been reported as the most efficient one in terms of antimicrobial activity followed by acetone extract, and aqueous extract [840]

Anti-diabetic Activity Researchers have evaluated the anti-diabetic effect of extract of *Trigonella foenum-graecum* (IND01) on the neonatal streptozotocin-induced rat (n-STZ) model with diabetes mellitus (DM). At a dose of 50 mg/kg of streptozotocin (STZ) has been injected in the rat pups. It is reported that DM has been evaluated after 8 weeks through measuring fasting serum glucose (SG) level. At a dose of 10 mg/kg of standard drug (glyburide) has been given to n-STZ rats orally. At a dose of 100 mg/kg of IND01 has been given to n-STZ rats for 28 days. In the acute study, the SG levels have been taken at periodical intervals. In the subacute study, the serum insulin, and glycosylated hemoglobin (HbA1c) levels have been recorded on day 28. The HbA1c, SG levels, and body weights are increased significantly for n-STZ induced rats. Pancreatic islet β-cells and serum insulin levels are reduced in control groups. The treatment with glyburide and IND01 exhibited significant reversal of n-STZ-induced changes. The histology sections of the pancreas showed the ability of IND01 to enhance the size and number of pancreatic islet β-cells. It is reported that IND01 is able to treat DM and also to maintain the glycemic activities in n-STZ induced diabetic rats [491]

Anti-obesity Activity Scientists have evaluated the anti-obesity activity of Fenugreek (INDUS810). The mice aged 4 weeks have been consumed with a high-fat diet, and a normal diet together with or without of 200 mg/kg of INDUS810 by intraperitoneal injection twice/week to analyze the anti-obesity activity of fenugreek. It is reported that in high-fat diet-induced mice, the weight are decreased with INDUS810 in liver, epididymal white adipose tissue, interscapular brown adipose tissue. INDUS810 is able to reduce the serum cholesterol level, and low-density lipoprotein cholesterol, to maintain the insulin sensitivity in mice. INDUS810 is also able to retard the lipid deposition and to enhance the lipolysis activity in mature adipocytes. INDUS810 can enhance protein levels of sirtuin 1, peroxisome proliferator-activated receptor α, peroxisome-proliferator-activated receptor-gamma co-activator 1β, and sirtuin 3. It is capable to activate the adenosine monophosphate-activated protein kinase that may decrease the lipid levels within adipocytes. It is reported that INDUS810 is considered as a potential anti-obesity agent [196]

Gastrointestinal Activity Researchers have observed that the fenugreek seed exhibited anti-ulcer activity. Omeprazole, a well known proton pump blocker has been comparable to the effect of fenugreek. The drug is utilized to treat gastrointestinal disorders like gastritis, gastroesophageal reflux disorder, and duodenum and gastric ulcer. A gel fraction, and aqueous extract of fenugreek exhibited effective ulcer defensive activities, which may be characterized by its antisecretory activity and effectiveness over mucosal glycoproteins as reported by researchers in a ethanol-induced gastric ulcer in rats. It is reported that water extract of fenugreek has possessed antioxidant activity, which may retard the ethanol-induced gastric damage in the rats. In comparison with omeprazole, a better gastroprotective activity has been reported in insoluble gel fraction of fenugreek. This may be due to the presence of flavonoids and beneficial polysaccharides in fenugreek [338]. The defensive mechanism of flavonoids in the mucosa may be the reason for the gastrointestinal protective effect of fenugreek [991]

Antioxidant Activity Scholars have reported that the lipid peroxidation is enhanced, and the antioxidant molecules like α-tocopherol, glutathione, and β-carotene are altered with fenugreek in alloxan-diabetic rats. 2 g/kg BW of fenugreek powder supplementation has been given to alloxan-diabetic rats for 1 month to evaluate the antioxidant and lipid peroxidation capacity. The fenugreek powder is able to normalize the oxidative stress, and lipid peroxidation. It is reported that antioxidant activity has been found in insoluble part of fenugreek [888]

Cardiovascular Activity Researchers have investigated the cardioprotective activity of fenugreek, and garlic on hypercholesterolemic rats. For 8 weeks, the rats are given a high-cholesterol diet along with garlic (2%), and fenugreek (10%), and their combination. Myocardial infarction (MI) has been induced with isoproterenol. MI has been associated with enhancement of serum iron, circulatory troponin, disarrangement of activities of cardiac

ATPase, reduced ceruloplasmin. It is reported that isoproterenol-induced compromised antioxidant status is improved with garlic and fenugreek and the combination of both garlic and fenugreek [627]

Central Nervous System Activity Researchers have investigated the neuropharmacological effect of fenugreek. The neuropharmacological activity has been observed with petroleum ether extract (PE), total alcoholic extract (TA), total aqueous extract (TQ), total alkaloidal extract (TK), total glycoside extract (TG), fenugreek oil (FO) in diosgenin (DI), and trigonelline (TR)-induced albino Wistar rats. At the dose of 100 mg/kg BW of PE, TA, TQ, and FO have been given to rats. At the dose of 50 mg/kg BW of DI, TK, TG, and TR have been given to rats intraperitoneally. At a dose of 150 ug/kg of chlorpromazine hydrochloride (CP) and at a dose of 48 mg/kg of caffeine (CF) have been utilized as standard. It is reported that except TQ, all the other extracts are able to stimulate of the activity of central nervous system (CNS). While, TQ possessed CNS depressant activity. It is reported that fenugreek extracts contain bioactive components (isovitexin, and rhaponticin) that showed CNS depressant, and stimulant potential [641]

Ferula assafoetida (Asafoetida)

Anti-inflammatory Activity Researchers have evaluated the anti-inflammatory activity of asafoetida. Phenolic compound present in asafoetida is responsible for anti-inflammatory activity. 2.5 mg/kg of asafoetida has been administered to mouse to treat the carrageenan-induced paw edema. The bioactive compounds like sesquiterpene coumarins are present in asafoetida, which may retard the 5-lipoxygenase activity. Ferulic acid and flavonoid components derived from asafoetida possessed strong antioxidant potential and act as an anti-inflammatory agent [114]

Antimicrobial Activity Scholars have investigated the antimicrobial effect of ethanol, ethyl acetate, methanol, chloroform, and aqueous extracts of asafoetida. The antifungal effect against *Candida albicans* and *Aspergillus niger* and the antibacterial effect of asafoetida extracts against *Klebsiella pneumonia, Bacillus subtilis, Staphylococcus aureus,* and *E. coli* have been analyzed through well diffusion process and assessment has been done with the minimum inhibitory concentration (MIC). The inhibition zone has been compared with standards such as fluconazole (0.1 mg/ml) and ciprofloxacin (0.1 mg/ml). It is reported that antimicrobial activity has been found in methanol, ethyl acetate, and ethanol extracts. The highest inhibitory activity has been observed in methanol extract. The ethyl acetate, methanol, and ethanol extracts showed the MIC values of 1 mg/ml and 2 mg/ml, respectively, for the examined organisms [690]

Anti-diabetic Activity Scientists have analyzed the hypoglycemic effect of the asafoetida extract in streptozotocin-induced diabetic rats. Male Wistar rats have been divided into several groups like control groups, rats fed with 50, 100, and 300 mg/kg doses of asafoetida. Asafoetida extract has been administered regularly through drinking water to diabetic rats for 4 weeks. The serum glucose level is reduced in diabetic rats treated with 50 mg/kg of asafoetida extract in comparison with diabetic rats. It is reported that hypoglycemic activity has been found in streptozotocin-induced diabetic rats with asafoetida extract (50 mg/kg) after 2 weeks. Tannins and phenolic acids (ferulic acid) present in asafoetida are responsible for the anti-diabetic activity [38]

Anti-obesity Activity Researchers have identified the effectiveness of asafoetida over liver steatosis, weight enhancement, lipid deposition, and leptin level. Aqueous solution of fructose (10%) has been administered in a regular basis to both the control and treated rats. At the doses of 25 or 50 mg/kg (PO) of asafoetida oleo-gum resin has been administered to two treated groups. Tap water, and standard chow food have been given to the control group. It is reported that asafoetida is able to reduce the size of epididymal adipocytes, body weights, abdominal fat, and serum leptin levels. Researchers have observed that fat lowering and anti-obesity activity have been found in asafoetida that may also prevent liver steatosis in type 2 diabetic rats [106]

Gastrointestinal Activity Scholars have evaluated the effects of asafoetida oleo-gum resin on gastrointestinal diseases like digestion, parasite, bloating, and cancer [387]. Scholars have assessed the effectiveness of asafoetida in the prevention of dyspepsia. Asafoetida possessed anti-diarrhea, anti-parasite, anticancer, and liver defensive effects. Asafoetida is able to prevent gastrointestinal diseases [553]

Cardiovascular Activity Scientists have analyzed the effect of asafoetida essential oil (AEO) on ischemia–reperfusion-induced damage in isolated rat hearts. Forty-eight male Wistar rats have been separated into 6 groups: 1–3) AEO groups, 4) control groups, 5) vehicle groups, and 6) carvedilol groups. The hearts have been subjected to ischemia treatment (for 30 min) followed by reperfusion (120 min) for the control group. In other groups, hearts have been perfused with carvedilol (10 μM), vehicle (tween 0.1%), and AEO (0.125, 0.25, or 0.50 μL/g heart) for 5 min. The myocardial dysfunction has been significantly more acute only in group 3 in comparison with the control group. In group 3, the creatine kinase and lactate dehydrogenase activities are reported as the markers of myocardial damage. It is reported that the isolated rat hearts have been perfused with AEO (0.5 μl/g heart), which may spoil the myocardial ischemic-reperfusion damage [285]

Antioxidant Activity Researchers have reported that NO scavenging activity has been found in methanolic gum extract of asafoetida [235]. Researchers have revealed that the superoxide dismutase (SOD) enzyme activity are reduced in mouse brain tissue in the pentylenetetrazole (PTZ)-induced mouse [304]. The superoxide radical has been formed on the surface of the brain of mouse. The superoxide radical has not been scavenged with asafoetida by enhancing the superoxide dismutase enzyme. In the asafoetida treated groups, MDA (malondialdehyde) level is decreased in comparison with PTZ groups. Asafoetida gum extract is able to reduce the lipid peroxidation and oxidative destruction because of antioxidant activity [469]

Central Nervous System Activity Some studies proposed that asafoetida acts as a neuroprotective, and nerve stimulative agent [371]. Asafoetida oleo gum resin is able to increase the re-myelination and regeneration, and to reduce the rate of lymphocyte infiltration in the neuropathic tissue in mice. It is proved that monoamine oxidase B (MAO-B) are retarded with asafoetida resin. Asafoetida resin is able to treat the neurodegenerative diseases like Alzheimer's and Parkinson's diseases. Furthermore, it is noted that asafoetida showed acetylcholinesterase (AChE) retarding activity in the snail nervous system. It also possessed memory-enhancing activity [459]

Apium graveolens (Celery)

Anti-inflammatory Activity Researchers have proposed that isolated, and total fractions of celery seed may possess anti-inflammatory activity [524]. The aqueous extract of celery possessed flavonoids like apiin, apigenin, and phenolic acids are responsible for anti-inflammatory activity. It is evidenced that antioxidants like apigenin can reduce the generation of hydrogen peroxide and anti-immunoglobin E-induced histamine salvation. The flavonoids can retard the cyclooxygenase-2 (COX-2) activity. It is reported that coumarins, and phthalides are present in hexane extract of celery are responsible for the anti-inflammatory activity [742]

Antimicrobial Activity Researchers have evaluated the antimicrobial effect of methylated spirit, methanol, ethanol, and hexane extracts of celery against different bacterial strains like *Psteropseda aeruginosa, Staphylococcus aureus, E. coli, Salmonella typhi,* and *Bacillus subtilis* and fungal strains like *Candida glaberata, Trchophyton longifusus, Candida albicans, Fusarium solani,* and *Aspergillus flavus*. It is reported that *Salmonella typhi, E. coli, Staphylococcus aureus, Bacillus subtilis,* and *Psteropseda aeruginosa* are inhibited effectively by the different celery extracts. While the *B. subtilis,* and *S. typhi* are inhibited with the methanolic fraction. The methanolic fraction showed lower inhibitory activity against *E. coli. P. aeruginosa* is less inhibited with methylated spirit*A. flavus* is strongly inhibited with the ethanolic fraction of celery [480]

Antioxidant Activity Methanolic fractions of celery showed the highest antioxidant potential followed by methylated spirit, and ethanolic extract. It is reported that the highest ABTS radical scavenging activity has been possessed by ethanolic fraction followed by the methylated spirit and ethanolic extract [254, 480]

Anti-diabetic Activity Researchers have analyzed the anti-diabetic activity of celery extract with a few biochemical and hematological parameters in alloxan-induced diabetic rats. 50 adults albino rats have been divided into five equal groups: group 1—control groups (administered with normal saline of 0.5 ml/kg dose), group II—administered with 1 ml of the extract (425 mg/kg BW) for 1 month, group III—2 doses of alloxan (150 mg/kg), group IV—1 ml extract (425 mg/kg BW) injected to treat the diabetic rats for 30 successive days, and group V—14.2 mg/kg of metformin-treated diabetic rats (for 30 successive days). It is reported that the blood glucose level is decreased and insulin secretion, RBC, WBC count, PVC, and the neutrophil percentage are enhanced in diabetic rats with ethanol extract of celery after 1 month of treatment. Therefore, researchers have reported that the celery extract is able to reduce the WBC count, the average value of LDL-C, serum cholesterol, triglyceride, ESR, urea, uric acid, and creatinine in diabetic groups. The anti-diabetic activity of celery extract is similar to that of metformin (a standard drug for treatment of diabetes) [576]

Anti-obesity Activity Researchers have investigated the anti-obesity activities of celery. Celery seed ethyl acetate fraction (CSEA) (contains p-coumaric acid, and isoferulic acid) showed higher anti-adipogenesis in the 3T3-L1 cells in comparison with the ethanolic extract of celery seed. This may be due to the reduction in adipogenic hormones like adiponectin and leptin. The adipocyte-related transcription factors and gene expression levels including αp2, C/EBPα, and PPAR-gamma are reduced with CSEA [521]

Cardiovascular Activity Scholars have evaluated the effect of alcoholic, and water extracts of celery on the blood pressure of anesthetized rabbits [12]. It is proposed that the hypotensive effect has been higher in ethanol extract in comparison with aqueous extract. At a dose of 0.3 mg/kg of Atropine can block the hypotensive effect of ethanol extract [344]

Gastrointestinal Activity Scientists have proposed that the ethanol extract of celery is able to prevent the cytodestructive, and indomethacin agents (25% NaCl, 80% ethanol, and 0.2 M NaOH) induced gastric ulcer. Basal gastric secretion are reduced and gastric mucosa are protected with ethanol extract, which may be due to its antioxidant activity. Tannins, and flavonoids derived from celery are able to treat ulcer [42]

Central Nervous System Activity Researchers have analyzed the neuroprotective activity of celery. The insilico study has been considered to evaluate the neuroprotective activity of celery. It is reported that Choline present in celery is able to bind the acetylcholinesterase (Ache), Slc5a7, and choline acetyltransferase (Chat). The insilico research showed the activity in the neurotransmitter secretion process, neurotransmitter biosynthesis process, and neurotransmitter metabolic process. It is reported that neuroprotective activity has been found in celery by the interaction of Ache, Slc5a7, and Chat [555]

Capsicum frutescens **(Chili)**

Antimicrobial Activity Researchers have evaluated the effect of bell pepper on few food-borne bacteria*Salmonella typgimurium* is inhibited with bell pepper extract [174]. It is observed that *Listeria monocytogenes, Salmonella typhimurium, Staphylococcus aureus,* and *Bacillus cereus* are inhibited with bell pepper extract. The isopropanol, and water extracts of chili showed anti-bacterial effects, which may be due to the presence of capsaicin in bell pepper. It is recommended that *Pseudomonas aeruginosa,* and *Salmonella* found in beef meat are inhibited by isopropanol and aqueous extract of pepper*Clostridium, Bacillus,* and *Salmonella sp* are inhibited by an aqueous extract of pepper. The antibacterial activity has been found in isopropanol extract against *Salmonella typhimurium, Listeria monocytogenes, Staphylococcus aureus,* and *Bacillus cereus* [477]

Anti-inflammatory Activity At a range of 0–100 µg/mL concentration, the yellow, red, and green chili extracts exhibited anti-inflammatory activity. The anti-inflammatory activity of chili may be due to its free radicals scavenging property [719]

Antioxidant Activity Researchers have assessed the antioxidant potential of chili through different *in vitro* methods, namely ABTS, DPPH, and FRAP. The yellow and red chili have possessed the antioxidant potential of 5.18 µmol TE/g fw and 3.89 µmol TE/g fw, respectively, as assessed by ABTS method. The antioxidant activity of green chili (43.29 µmol TE/g fw) has been found greater than red chili (2.82 µmol TE/g fw) as assessed by DPPH method. Similar results have also been reported for green bell (46.36 μmol TE/g fw) and red chili (16.15 μmol TE/g fw) as assessed by FRAP method [719]

Anti-diabetic Activity Scholars have evaluated the anti-glycation properties of crude methanolic extract of chili. The anti-glycation capability of the water, ethyl acetate, n-hexane, and crude methanolic fractions of chili is higher than that of chloroform fraction. Scholars have proposed that the chili extracts are able to treat complications associated with diabetes [449]

Anti-obesity Activity Capsaicin derived from chili has been reported for its high-fat diet-induced chronic low-grade inflammation (CLGI) decreasing activity, which may be connected with anti-obesity activity. Capsaicin is able to reduce the amount of glycerol-3-phosphate dehydrogenase (GDPH) activity and intracellular triglyceride in 3T3-L1 adipocytes, to retard the leptin, PPAR-gamma, and C/EBPα expression. 0.075% capsaicin is able to reduce the lipid deposition in epididymal adipose tissue and mesenteric tissue in high-fat diet-induced obese mice. The serum level of glucose, triglycerides, and cholesterol levels are reduced with capsaicin [107]

Cardiovascular Activity Researchers have evaluated the cardioprotective activity of capsaicin in anesthetized dogs, and rabbits at a dose of 10–300 μg/kg. The induced hypertension is not affected with phentolamine, hexamethonium, and tolazoline in dogs and rabbits. In dogs, the hypotension has been reduced with atropine. The heart rate has not been affected or slightly enhanced in atropine-treated dogs with capsaicin. The contractile force or rate of atria of rabbit, and dog is not affected with capsaicin. In the dog, the constrictive activity of capsaicin is decreased slightly in upper mesenteric arteries. The capsaicin is able to contract the cerebral arterial strips [50]

Gastrointestinal Activity Researchers have investigated about the digestion provoking activity of chili may be due the presence of capsaicin. The activities of digestive enzymes in the small intestine and pancreas, stimulation of saliva, and secretion of bile have been connected to the digestive stimulatory activity of chili that also augmented the salivary amylase activity. Chili is able to increase the fat absorption, and digestion in high-fat-consumed rats, as reported by researchers. Capsaicin, chili extracts, and other phytochemicals are able to enhance the permeability of intestinal epithelial cells and the rate of gastric emptying. Chili can stimulate the acid secretion, and irritation character. The concentration-dependent cytopathic activity has been observed with chili extracts on oral mucosal fibroblasts. The defensive nature against gastric mucosa damages has been found with capsaicin, and chili extract. Chili is able to defend the gastric mucosa due to the activation of gastrointestinal transient receptor potential vanilloid subtype 1 (TRPV1), antioxidant enzymes, and retardation of inflammatory factors. Capsaicin is capable to treat ulcers by retarding acid secretion. The epigastric pain, fullness, dyspeptic symptoms, nausea, and heartburn are reduced by the administration of capsaicin, and red pepper in heartburn, and dyspeptic patients [784]

Central Nervous System Activity Scholars have investigated about the neuroprotective activity of phenolic extract of chili, and as an inhibitor of monoamine oxidase and cholinesterase activities. Scholars have evaluated the OH radicals scavenging capabilities, DPPH, and membrane-stabilizing activity of the phenolic extract of chili. The activities may take place may be due to the retardation of Fe^{2+}-induced lipid peroxidation in rat brain tissue. It is reported that the mitochondrial MAO, BChE, and AChE inhibitory activity are found in the phenolic extract of chili. Chili is able to control the neurodegenerative disease like Parkinson's disease [661]

Pimenta dioica (Allspice)

Anti-inflammatory Activity Researchers have evaluated the effect of allspice on anti-inflammatory activity. It is reported that the extract of *Pimenta dioica* (PD) is able to enhance the proinflammatory cytokines IL-6 and TNF-α by 150% and 166%, respectively. Eugenol derived from essential oil of PD is able to modulate the inflammatory response [540]

Antimicrobial Activity Scholars have examined the essential oil of PD against pathogenic fungi, and bacteria. It is reported that the five bacterial strains, namely *P. aeruginosa, E. coli, A. baumannii,* and *S. aureus,* and the yeast such as *C. albicans* are inhibited with EO extract of PD. The antibacterial effect has been found in EO of allspice against *P. aeruginosa* and *MRSA* [260]

Anti-diabetic Activity It has been reported by researchers that the protein glycation can be retarded with allspice. Therefore, allspice is utilized as a potential anti-diabetic agent [745]

Antioxidant Activity The antioxidant capacity for the aqueous soluble fraction, dichloromethane extract, and ethyl acetate soluble fraction of allspice has been evaluated through the oil stability index process, and ferric thiocyanate method. The free radical scavenging potential of allspice has been evaluated through DPPH assay [471]. Allspice is able to retard the xanthine oxidase activity by 74.83% [745]

Central Nervous System Activity The vaso relaxing, and hypotensive activity have been reported for water extract of allspice. The rodents have been considered to evaluate the hypotensive activity of water extract of allspice. It is reported that the aqueous extract of allspice is able to depress the CNS spontaneously in hypertensive rodents. The hypotensive action is not mediated by cholinergic or β-adrenergic ways [902]

Cardiovascular Activity Researchers have considered the anesthetized normotensive rats to evaluate the hypotensive effect of water, ethanolic extracts of allspice, and various fractions of the aqueous extract. At various doses (30, 70, and 100 mg/kg) of aqueous extracts of allspice have been given to the anesthetized normotensive rats intravenously. It is reported that allspices extracts are able to reduce the mean arterial blood pressure. A dose of 100 mg/kg of the aqueous extract showed the highest hypotensive effect in comparison with the ethanolic extract. The highest hypotensive effect has been reported in the aqueous fraction of allspice [893]

Garcinia indica (Kokum)

Anti-inflammatory Activity Researchers have evaluated the effect of water extract of *Garcinia indica* fruit rind (GIE) for anti-inflammatory activity in cotton pellet-induced granuloma, and carrageenan-induced paw edema in rats. The dose of 400 mg/kg, and 800 mg/kg of GIE have been administered to the Wistar rats orally. A dose of 10 mg/kg of diclofenac sodium has been considered as standard drug. Four sterile cotton pellets have been implanted in the ventral portion in the granuloma model in each rat. Pellet implanted rats are administered with diclofenac, and GIE orally for 8 days. The functions of the aspartate transaminase (AST), alkaline phosphatase (ALP), and alanine transaminase (ALT) have been examined from the serum. Rats, which are treated with GIE, decrease the cotton pellet granuloma, and paw edema in comparison with carrageenan treated and cotton pellet implanted rats, respectively. The ALP, AST, and ALT activities attenuated with the treatment of GIE. It has been reported that anti-inflammatory activity has been observed in GIE because of antioxidant potential, and lysosomal membrane stabilization through virtue of its phenolic compounds [677]

Antioxidant Activity Some investigations showed the effect of ethanolic, and water extracts of kokam for its antioxidant activity in Wistar albino rats. The biochemical parameters such as lipid peroxidation (LPO), sulfoxide dismutase (SOD), glutathione (GSH), and catalase (CAT) have been considered to analyze the antioxidant activity. It has been reported that the methanolic extract of kokam possessed free radical retardation activity. The β-carotene linoleate and DPPH methods have been considered to evaluate the free radical scavenging activity of chloroform extract of kokam. A strong antioxidant property has been found in methanolic extract of kokam in comparison with the standard ascorbic acid. The superoxide anion scavenging function has been reported for garcinol derived from kokum by phenazine methosulphate/ NADH nitroblue tetrazolium method [395]

Gastrointestinal Activity Researchers have suggested that the ethanolic, and water extracts of kokam possessed ulcer protective activity. It has been reported that the ethanolic and aqueous extracts of kokam possessed ulcer protective properties against HCl/ethanol-induced gastric damage and indomethacin-inducedulcerogenesis. At a dose of 500 mg/kg of ethanolic, aqueous extracts of kokam has been administered to rats orally. It has been reported the ethanolic, and aqueous extracts of kokum are able to decrease ulcer in the HCl/ethanol and indomethacin induced gastric damage in rats [678]

Anti-obesity Activity The hyperlipidemic effect has been found in methanolic extract of kokam as observed by the researchers in cholesterol-induced hyperlipidemic rat model. It has been reported that the methanolic extract of kokum is able to reduce the LDL-C, total cholesterol, triglycerides, VLDL-C, and to enhance HDL-C. It has been reported that hydroxy citric derived from kokam is able to decrease the body weight, appetite, and retard lipogenesis [557]

Anti-diabetic Activity Fasting blood glucose level is reduced with kokam extract in streptozotocin-induced hyperglycemic rats. At a dose of 400 mg/kg of water extract of kokum has been administered to rats. It has been reported that the water extract possessed anti-hyperglycemic effect and can enhance the oral glucose tolerance. Garcinol derived from

Kokam possessed strong glycation retarding effect as it can reduce the protein glycation in a bovine serum albumin/fructose process [395]

Central Nervous System Activity The neuroprotective activity has been found in methanolic extract of kokam against 6-hydroxydopamine (6-OHDA), which is an indicator for its anti-Parkinson's activity in rats. Lipopolysaccharide (LPS) induced anti-inflammatory mediators expression is decreased with garcinol. The anticholinesterase activity has been observed in kokam. The expression of neurofilament proteins and neurite outgrowth are inhibited with cyanidin-3-glucoside [81]

Antimicrobial Activity Researchers have evaluated the antibacterial effect of the crude methanolic extract of kokam. The doses of 500, and 1000 µg/mL of methanolic extract of kokum have been considered to analyze the antimicrobial activity. At a dose of 500 mg/mL of kokam extract exhibited the highest inhibition against *S. aureus,* and *P. aeruginosa* At a dose of 1000 mg/mL of kokam extract exhibited the highest inhibition against *S. aureus*, and *P. aeruginosa*. It is reported that the methanol extract of kokam cannot exert any inhibition against *E. coli* [930]

Cardiovascular Activity Scholars have studied about the effectiveness of kokum extract on cardiovascular diseases. The values of atherogenic coefficient (AC), atherogenic index of plasma (AIP), and cardiac risk ratio (CRR) have been significantly greater in the group of rats fed with Western diet in comparison with normal groups. The AC, AIP, and CRR levels are normalized with garcinol-enriched fraction (GEF) [532]

Alpinia galangal (Greater galangal)

Anti-inflammatory Activity Many researchers have evaluated the anti-inflammatory activity of galangal. The p-coumaryl alcohol-γ-O-methyl ether substantially, and selectively reduce the formation of interferon-gamma (IFN-γ) in CD4 + Th (T helper) cells. Hydroxychavicol acetate and acetoxychavicol derived from galangal are able to prevent the inflammatory immune diseases caused through indulgent activation. Galangal is able to reduce the granuloma weight in croton oil-induced granuloma pouch rat model and carrageenan-induced paw inflammation [205]

Anti-diabetic Activity Researchers have reported that aqueous, and methanolic extracts of galangal have been administered to normal rabbits to evaluate the anti-diabetic activity of galangal. It has been reported that galangal is able to reduce the blood glucose level [39]

Antimicrobial Activity Scholars have reported that the human immunodeficiency virus type-1 (HIV-1), and human cytomegalovirus (HCMV) are retarded potentially with methanolic extract of galangal. The antimicrobial activity has been observed in the essential oil of galangal. It is evidenced by scholars that ethyl acetate and ether extracts of galangal possessed antibacterial activity*Staphylococcus aureus* is inhibited by 1,8-cineole derived from galangal. It has been reported that the ethanol extract of galangal exhibited potential inhibitory activity as observed by the broth dilution method against *Staphylococcus aureus. Pseudomonas aeruginosa, Klebsiella pneumonia, E. coli, S. aureus,* and *Streptococcus pyogenes* are inhibited with water extract of galangal*Erysipelothrix rhusiopathiac,* *Staphylococcus aureus, Streptococcus suis, Pseudomonas aeruginosa, E. coli, Pasteurella multocida,* and *Arcanobacterium pyogenes* are inhibited by essential oil extracted from galangal. The combined effect of α-bisabolene, 1,8-cineole, and 4-allyphenyl acetate derived from galangal are responsible for the antimicrobial activity [744]

Gastrointestinal Activity The antiulcer activity has been found in galangal, which may be due to the action of cytoprotective, and antisecretory. At a dose of 500 mg/kg of ethanolic extract of galangal is able to decrease the gastric secretion in hypothermic restraint stressing, and pyrrolic ligation rats [53]

Antioxidant Activity Many studies have proposed that the antioxidant potential has been found in galangal and its isolates. A potential antioxidant property with an IC50 value of 550 μg/ml has been observed in the essential oil of galangal. It has been reported that the aqueous, methanolic extracts and volatile oils exhibited free radical scavenging activity significantly as appeared through the DPPH method. At neutral pH, galangal showed higher antioxidant capacity in comparison with the acidic pH. The reducing power, superoxide anion scavenging activity, and Fe^{2+} chelating activity have been found in ethanolic extract of galangal in a concentration-related manner. Furthermore, lipoxygenase inhibitor activity has been found in galangal. It is reported that the methanol and dichloromethane (DCM) of galangal possessed antioxidant activity [551]

Anti-obesity Activity Researchers have investigated the anti-obesity activity of ethanol extract of galangal in a cafeteria diet-fed obese rats. In albino rats, obesity has been induced with a cafeteria diet consumption regularly for 6 weeks. At a dose of 500 mg/kg of ethanol extract of galangal has been administered for 6 weeks regularly. It has been reported that the ethanol extract of galangal is able to reduce the parametrial adipose tissue weight, body weight, energy intake, deposition of hepatic triglycerides, liver weight, leptin, and serum lipid levels. The galangal extract is also able to retard the pancreatic lipase activity [850]

Cardiovascular Activity Scholars have found the bioactive constituents such as 5-hydroxy-7-(4″-hydroxy-3″-methoxyphenyl)-1-phenyl-3-heptanone, and galangin present in galangal which are capable to exert antioxidant, and anti-inflammatory effect through retarding the COX-2 activity, salvation of histamine, serotonin, and kinin. The LDL level is reduced in the blood with the extracts of galangal [13]. It is reported that galangin can control the cell membrane integrity, can decrease oxidative stress, and is able to improve cardiac systolic/diastolic dysfunction in the cardiac myocytes stressed with doxorubicin induced rats [752]. The galangal juice has been administered to broiler chicken. It has been reported that the galangal juice is able to decrease the level of triglyceride in the broiler bloodstream. For improving cardiovascular problems, the galangal extract has been mixed with *Phyllanthus embilica,* which is able to reduce the level of circulating LDL-C [224, 227]

Central Nervous System Activity Scientists have reported that the effectiveness of galangal to stimulate the cognitive activity and to enhance the antioxidant activity, and Na^+/K^+ATPase, simultaneously it can reduce acetylcholinesterase activity. Therefore, galangal is able to cure the neurodegenerative diseases such as Alzheimer's, and Parkinson's disorders [224, 227]

Acorus calamus (Sweet flag)

Central Nervous System Activity Researchers have evaluated the effect of ethanol extract of *Acorus calamus* (AC) on monoamine levels of the brain and unconditioned electrical function. It is reported that sweet flag is able to enhance α activity, serotonin level, and the norepinephrine level within the cerebral cortex in rats. Furthermore, sweet flag is able to enhance the dopamine level in the midbrain, and caudate nucleus. Sweet flag showed anti-depressive activity through changing the brain monoamine levels in various brain areas and through altering electrical action. Researchers have conducted a clinical investigation in 50 cases of depression. It is reported that the degree of acute depression is decreased with AC [626]

Anti-inflammatory Activity Scholars have investigated the anti-inflammatory effect of AC on severe, and chronic treated rat models. Croton oil granuloma pouch inflammatory response, carrageenan-induced paw edema, and cotton pellet granuloma production have been retarded with AC extract orally. The anti-inflammatory activity has been found with AC extract in severe, chronic, and immunologic rat models [976]

Antioxidant Activity The ethyl acetate extract of AC has been reported to possess anti-oxidant activity as reported through DPPH method [14]. It is reported that 0.2 g/mL of AC extract exhibited the highest antioxidant effect (86.43%). α-asarone is an active compound of AC has been administered peritoneally before the rats are going to be expressed to noise-stress for 1 month. It has been reported that α-asarone possessed antioxidant activity against sounding-stress-induced alterations in the rat brain [573]

Cardiovascular Activity Researchers have investigated the effectiveness of AC essential oil to reduce blood pressure. β-asarone and α-asarone derived from sweet flag possessed hypotensive effect as evaluated on the anesthetized dogs. The alcoholic extract of AC showed hypotensive activity on dog. 45 patients with ischemic heart disorders have been considered by researchers. They have been treated with AC extract. It has been reported that AC is able to decrease the body weight, serum cholesterol, SLDL (serum low-density lipoprotein), cure chest pain, improve ECG, and to enhance SHDL (serum high-density lipoproteins) [567]

Gastrointestinal Activity Scholars have reported that ethanol extract of AC has defended gastroduodenal mucosa and retarded gastric secretion in rats against the damages caused by reserpine, pyloric ligation, indomethacin, and cysteamine administration. A dose of 500 mg/kg of AC extract showed anti-ulcerogenic and anti-secretory effects in rats subjected to reserpine, indomethacin, pyloric ligation, and cysteamine administration. The AC extract possessed protective activity against cytodestructive agents. It is reported that AC is able to treat gastropathy [131]

Antimicrobial Activity Scientists have reported that *Bacillus subtilis, Staphylococcus aureus, E. coli, Bacillus megaterium, Salmonella paratyphi A* and *B, Salmonella marcescens, Proteus vulgaris, Staphylococcus citreus,* and *Shigella dysomei* have been inhibited with alcohol extract of AC*Staphylococcus aureus* has been inhibited with the acetate buffer, alcohol, ether, and dilute sulfuric acid extract of AC*Streptococcus viridans, Streptococcus* *pyogenes, Diplococcus pneumoniae, Corynebacterium diphtheriae, E. coli, Salmonella typhi, Salmonella paratyphi A* and *B, Staphylococcus aureus,* and *Shigella flexneri* have been inhibited with the extract of AC. Antifungal activity has been found in essential oil against *A. jumigatis, A. nidulans, Penicillium aculeatum, Phomopsis destuctum,* citrus decay pathogens *Penicillium digitatum, P. italicum, Diplodia natalensis, Altemaria tenuis, Candida albicans, Epidermophyton cresens, Aspergillus oryzae,* and *Microsporum gypseumPenicillium selenium, Aspergillus niger,* and *Saccharomyces* (yeast) have been inhibited with alcoholic extract. It is reported that antiviral activity has been observed in alcoholic extract of AC against Herpes simplex virus HSV-1, and HSV-2 [957]

Anti-diabetic Activity The methanolic extract of sweet flag showed α-glucosidase inhibitory activity. The α-glucosidase inhibitory activity has been measured with IC50 value at 54.90 µg/ml. Standard acarbose has been showed the IC50 value of 39.12 µg/ml for α-glucosidase inhibitory activity. The flavonoids and polyphenols present in the sweet flag are responsible for the anti-diabetic effect [185]

Anti-obesity Activity Researchers have evaluated the effectiveness of β-asarone in high-fat diet (HFD)-induced obese mice. The β-asarone is able to retard the metabolic transformations and glucose intolerance, to reduce the body weight, cholesterol level in adipose tissue in mice. The lipid-lowering effect has been observed with water extract of sweet flag [844, 845]

Food Industry Application of Selected Spices

Spices and herbs have been used in different food products either in the form of powder, extract, encapsulated material, or in raw form (Table 4). Figure 4 describes the application of spices and herbs in different food systems along with the methods of application

Meat-based Food Product Green and dried cardamom has been ground, dipped in water, and the hydrodistillation method with the help of clevenger type apparatus has been used to extract the EO. Thereafter, the EO has been applied to the chicken drumsticks to increase its shelf life by 2–3 days [464]. Cardamom seeds have been dried in shade and ground. 500 cc of 80% of ethanol has been added to 100 g of the dried powder and stored at room temperature (22^0 C) for 1 day. After filtration, the alcohol extract has been dried at 40^0 C temperature. The extract has been used on lamb meat to increase the quality in terms of flavor, taste, and enhance the shelf life of lamb meat [837]

EOs have been extracted from *Zataria Multiflora* and *Bunium persicum* The extracted EOs have been used to produce chitosan-loaded nanoemulsions. The nanoemulsion has been applied to turkey meat to enhance its shelf life up to 15–18 days and to improve its microbial quality [441]. To improve the cholesterol profile and nutrient digestibility of broiler chicks, the dried and milled seeds of *Zataria Multiflora* and *Bunium persicum* are used [852]. Nanocellulose, *Mentha piperita essential oil,* and *Bunium persicum* essential oil have been mixed at various percentages to prepare a biodegradable active poly-lactic acid composite films to enhance the shelf life of ground beef up to 4–7 days [911]. To improve the nutritional quality of boiler chicken meat, the chicks have been fed with different diet composition where corn-soybean meal-based diet has been taken as control. The other diet compositions are 10 ppm avilamycin + basal diet, 0.25% of cumin powder + basal diet, 0.75% of cumin powder + basal diet, 0.25% of black cumin powder + basal diet, and 0.75% black cumin powder + basal. It has been observed that the basal diet give satisfactory results [823]. The *Trachyspermum ammi* EO (NTEO), and *Bunium persicum* EO (NBPEO) have been used to prepare chitosan based nanoemulsions and chitosan based nanoemulsions have been applied to hamburgers to improve its microbial quality [875]. 1–2% of *Bunium persicum* EO along with tween 80 (emulsifier), and glycerol (plasticizer) have been used to make chitosan films and the films have been applied on chicken fillet to retard its chemical spoilage and to improve its microbial quality [425]

Lambs have been fed with 1.5% FSP (fennel seed powder) and diet without FSP (control) to improve the nutritional composition and to reduce the fat oxidation [351]. EO has been extracted from the fennel seed and applied to chicken thighs to extend its shelf life [417]. Different formulas have been considered with fennel and lettuce powders to reduce the bacterial growth, to improve the aroma and to replace the nitrite in sausage [726]

Dried and powdered poppy seeds have been used to decrease fat content and to improve the sensory scores, pungent flavor, textural attributes, and color feature of buffalo meat cookies [334]. Dried Poppy seeds have been used to prepare poppy paste, the paste has been applied to chevon nuggets to reduce the microbial activity, fat content, and to increase the protein percentage, sensory score, and shelf life [421]. Poppy seeds at different percentages (1, 3, and 5%) have been administered to chevon patties to reduce cholesterol and fat content and to increase the moisture, color, and mineral (Fe, K, Mn, Zn, Ca) profile [645]

Clove extract has been applied to cooked ground beef to decrease its lipid oxidation and to enhance the storage stability and flavor profile of the sample [1003]. The broiler chickens have been fed with diet enriched with clove to improve the physical sensory and microbial characteristics of carcass [899]. The tenderness, moisture content, water holding capacity, and sensory quality of chicken meat has been improved with the application of dried clove powder along with turmeric rhizome [801, 802]. EO derived from clove has been applied to frozen beef patties to improve its sensory quality and to improve oxidative stability [68]. Clove flower EOs and marjoram EOs have been applied to frozen beef patties to enhance oxidative stability, and quality [6]. At 1:5 proportion, clove extract has been applied to fresh beef patties to decrease the lipid, protein oxidation, and hue angle and to improve the quality attributes like elevated chroma value and redness value [90]. 400 mL of 95% of edible ethanol has been added into dried cloves. The mixture has been applied to Chinese-style sausages to retard protein and lipid oxidation, enhance the color, texture, flavor, acceptance, and quality [1013]

Cinnamon and sappan powders and thermoplastic starch have been mixed and extruded to produce active meat packaging film to extend its shelf life [467]. The shelf life of fresh beef has been extended up to15 days through the application of edible film comprised of 0.5, 1, 1.5, and 2% of cinnamon bark EO along with glycerol, and tapioca starch [953]. Nisin and cinnamon EO nanocapsules have been incorporated with sodium alginate coating. The mixture has been applied to beef slices to inhibit microbial growth, decrease lipid oxidation, prolong shelf life up to 15 days, enhance texture, color, odor, juicy characteristic, quality, antioxidant, and sensory properties [1014]. At 4:1 proportion, potassium chloride, carrageenan, and citric acid have been mixed with 0.05% cinnamon EO. The solution has been applied to chicken fillets to reduce the sensory score, and prolong shelf life [456]

0.5% of black pepper has been applied to buffalo meat steaks to increase quality and extend shelf life [575]

1.5% of EO of coriander seeds have been applied to chicken fillet to retard pathogen growth, enhance chemical quality and antioxidant capacity, and extend shelf life [430]

Table 4 Food application of different spices

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
cardamom	Meat product	Chicken drumsticks	Chitosan coating loaded with 1–2% essential oil	Proximate analysis, pH, peroxide value, TVN, TBARS, and sensory analysis	Shelf life increased by 2–3 days	[464]
		Lamb meat	Chitosan coating with 1%, and 2% of ethanol extract of cardamom	Flavonol, total flavonoid, antioxidant, MIC, MBC, pH, and sensory analysis	Increased the quality, flavor, taste, and shelf life	[837]
	Dairy product	Labneh	Powder	Microbiological, physiochemical, texture profile, and organoleptic properties evaluation	Increased the physicochemical, sensory properties, microbiological, and shelf life up to 30 days	[921]
Jeera	Meat product	Turkey meat	Chitosan-loaded nanoemulsion enriched with essential oil of *Bunium persicum,* and *zataria multiflora*	Microbial indicators and sensory analysis	Protected microbial quality and enhanced shelf life up to 15–18 days	[441]
		Broiler chicks	Dried jeera	Nutrient digestibility and metabolites	Enhanced the blood profile of cholesterol, and nutrient digestibility	[852]
		Ground beef	Poly-lactic acid film matrix with *Bunium persicum* essential oil (EO), *Mentha piperita* EO, and nanocellulose	Antibacterial, organoleptic, and sensory evaluation	Shelf life enhanced up to 4–7 days	[911]
		Broiler chicken	Jeera powder	Serum biochemical, nutrient digestibility, antibody-mediated immunity, and cell-mediated immunity estimated	Positive effects have not been found on these parameters	[823]
		Hamburger	Chitosan/cellulose nanofiber film coating with nanoemulsions of *Trachyspermum ammi* essential oil (EO), and *Bunium persicum* EO	Microbial evaluation	Increased microbial protection of perishable foods	[875]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Chicken fillet	Chitosan film with 0, 1, and 2% of *Bunium persicum* EO	Microbial and chemical analysis	Enhanced efficient factors connected with microbial, and chemical spoilage	[425]
	Dairy product	Gouda cheese	Edible coating with dried *Bunium persicum* EO and lactoperoxidase system	Bacteriological, chemical (pH, lipid extraction, thiobarbituric acid, free fatty acid, and peroxide value), and sensory evaluation	Reduced lipid oxidation, retarded gram-positive and gram-negative microorganisms, and enhanced shelf life	[806]
		Iranian white cheese	*Bunium persicum* EO	Phytochemical, antibacterial, antioxidant, and sensory analysis	Enhanced flavor, color, odor, and texture,	[266]
	Miscellaneous product	Mushroom	80% of ethanol extracts of aerial portions of *Marrubium vulgare, Physalis alkekengi, Alcea rosea,* and the seed of *Bunium persicum*	Enzyme kinetic parameters	Retarded mushroom tyrosinase	[638]
	Fruit and vegetable products	Corn starch	Dried jeera powder	Antibacterial activity analysis	Retarded food pathogens, enhanced protection of food products, and extended shelf life	[75]
Fennel	Meat product	Lambs meat	Powder	Quality, digestibility, and ruminal features evaluated	Enhanced ruminal nitrogen concentration, ammonia, acetate, improved fat oxidation, quality, and composition	[351]
		Poultry (broiler, laying hens, and Japanese quail)	Powder, EO, and extract	Body weight, carcass traits, egg quality, formation, immunity, the relative weight of lymphoid organs, antioxidant potential, and blood biochemistry analysis	Enhanced body weight, carcass traits, egg quality, formation, immunity, the relative weight of lymphoid organs, reduced antioxidant capacity, and improved blood biochemistry	[447, 448, 455]
		Chicken thighs	Dried EO	Microbiological evaluation	Extended shelf life	[417]
		Sausage	Powder of fennel, nitrite, and lettuce	Microbial property, physicochemical, and sensory properties assessed	Reduced bacterial growth, and aroma	[726]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
	Dairy product	Cottage cheese	Powder and phenolic-rich extract	Antioxidant activity, antimicrobial properties, color, and nutritional composition estimated	Enhanced antioxidant activity, and shelf life up to 14 days	[169]
		Yogurt	2.5, 5, and 7.5 µl of EO	Sensory, microbiological, and physicochemical properties analysis	Prolonged shelf life up to 29 days	[139]
		Processed cheese	Aqueous extract of fennel, and ajwain seed	Sensory, physicochemical (pH, free fatty acid, tyrosine value, UREA PAGA), and microbiological assessed	Enhanced microbial stability, shelf life, flavor, and acceptance	[577]
		Butter	*Plantago* major seed gum-based nanocomposite active films with fennel EO	Moisture absorption, water vapor permeability estimated	Improved shelf life	[578]
		Probiotic yogurt	Whole milk powder with water extract of dried fennel seed (2, 4, and 6%)	Physicochemical, antioxidant potential, total phenolic content, microbiological, and sensory analysis	Improved texture, flavor, enhanced protection, and bioactive components	[99]
		Steamed yoghurt	Fennel, and parsley EO	Proximate biochemical, microbiological, and sensory estimated	Enhanced nutritional qualities up to 29 days, durability biochemical and physicochemical characteristics, texture, acidity, taste, reduced total fat content, and prolonged shelf life	[356]
	Fruit and vegetable products	Pistachio	Potato starch-based films with 1, 3, and 5% of nano-ZnO, and 1, 2, and 3% of fennel EO	Microbiological activities, physicochemical, and sensory properties analysis	Enhanced fat, moisture, carbohydrate, and sensory properties (appearance, texture, flavor, acceptance), inhibited microbial formation, and propagation	[108]
	Miscellaneous product	Herbal candy	Powder	Proximate, physicochemical, and sensory analysis	Improved nutritional value, and acceptance of sensory and Physicochemical properties	[418]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
Poppy	Meat product	Buffalo meat cookies	Powder	Physicochemical, textural properties, color values, and sensory profile assessed	Decreased fat content, and improved sensory scores	[334]
		Chevon nuggets	Powder	Physicochemical evaluation	Decreased fat content, microbial activity enhanced protein, emulsion stability, sensory score, and storage quality	[421]
		Chevon patties	5% of Poppy seed	Physicochemical and sensory analysis	Reduced cholesterol, fat content, increased moisture, Fe, K, Ca, Mn, Zn, and color	[645]
		Beef	Seed EO	Proximate, lipid oxidation, texture profile, color, cholesterol, fatty acid, and sensory properties assessed	Reduced saturated fatty acid, cholesterol, cardiac arrhythmias, blood pressure, enhanced polyunsaturated fatty acid, and sensory acceptance	[330]
	Cereal-based product	Gluten-free bread	Seed flour	Spectroscopic and physicochemical properties evaluated	Useful in diabetes	[987]
		White chocolates	Poppy seed	Sensory properties estimated	Improved texture, and flavor	[1010]
Clove	Meat product	Ground beef	0.1% of clove powder, and 0.02% of BHT	pH, lipid oxidation, volatile compound, and color analysis	Decreased lipid oxidation, retarded volatile compound production, and enhanced product oxidative stability	[1003]
		Broiler chickens	1, 2, 3, 4, 5, and 6% of clove seed	Carcass and quality measured	Improved quality, sensory, carcass characteristic, and provided protective effect to antibiotics	[899]
		Indigenous chickens	Clove and turmeric powder	Physical and chemical, WAP, WHC, lipoprotein, cholesterol, triglyceride content, sensory, and color value analyzed	Reduced moisture content, HDL, enhanced acceptance, and tenderness	[801, 802]
		Hamburger	The bioactive coating based on chitosan with dried clove EO	Antimicrobial activity evaluated	Inhibited microbiological activities	[68]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Beef patties	Extract	Sensory characteristics and oxidative stability evaluated	Reduced hue angle, TBARS value, carbonyl content, lipid peroxidation, enhanced redness value, the durability of sensory characteristics, prolonged shelf life up to 10 days, and also quality	[1002]
		Frozen beef patties	Clove and marjoram EOs	pH, color, thiobarbituric acid-reactive substances, microbiological, and sensory properties assessed	Enhanced oxidative stability, and quality	[6]
		Chicken meat	LLDPE surface has been modified through chromic acid treatment and coated with clove EO	Antimicrobial activity analyzed	Promoted the yellow color, inhibited microbial activity, and improved packaging stability for 21 days	[628]
		Buffalo patty	0.1, and 0.2% of grape seed extract and 0.1% of clove EO	Lipid oxidation and microbial properties evaluated	Inhibited the microbial propagation, and reduced the lipid oxidation	[908]
		Goat meat balls	Hydroethanol, ethanol (1:1), and aqueous extract	Antimicrobial and antioxidant capacity analyzed	Inhibited microbial proliferation, and enhanced antioxidant activity, improved free fatty acid, pH, TBARS, total mesophilic count, sensory characteristics, extended shelf life	[864]
		Almond and walnut fortified chevon nuggets	EO	Sensory, oxidative stability and microbiological properties evaluated	Enhanced pH value, acceptance up to 14 days reduced TBARS, and microbial activity	[143]
		Chevon cutlets	2, 4, and 6% of sorghum flour with 100 ppm of clove EO	PH, proximate, thiobarbituric acid-reactive substances value, emulsion stability, microbiological profile, sensory properties, texture profile, and color value assessed	Reduced fat content, enhanced fiber, storage quality, acceptance, and nutritive value	[863]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Fresh beef patties	Extract powder	pH, TBARS value, carbonyl content, and color estimated	Reduced lipid oxidation, hue angle, protein oxidation, enhanced chroma value, redness, and improved quality	[90]
		Chinese-style sausages	Powder clove added with 400 mL of 95% edible ethanol	Protein carbonyl, color, texture profile, and sensory properties analyzed	Retarded protein and lipid oxidation, enhanced color, texture, flavor, acceptance, and quality	[1013]
		Raw chicken sausage	500 ppm of Clove powder extract and 700 ppm of green tea extract	Chemical, physical parameters, sensory quality, and bacteriological status estimated	Reduced microbiological, chemical parameters, physical parameters, sensory attributes, increased antioxidant activity, inhibited lipid oxidation, and prolonged shelf life up to 3–6 days	[424]
		Beef sucuks	Deboned chicken meat protein coating containing thyme or clove EO	Microbial, physical, and chemical parameters evaluated	Enhanced thiobarbituric acid reactive substances, weight loss, pH, reduced water activity, and prolonged shelf life	[808]
	Dairy product	Soft cheese	Thyme, ginger, and clove EO	Sensory attributes and microbial protection measured	Provided protection, and enhanced sensory scores	[30]
		Mayonnaise	Eugenol-lean fraction of clove extract	Sensory, pH, color, non-thermal and thermal creaming value, rheological, and phytochemical properties analyzed	Reduced thermal and non-thermal creaming, and enhanced color intensity	[190]
		Probiotic yoghurt	0.1, 0.3, and 1% of clove, and 0.03% of propolis	Sensory, microbiological, and chemical parameters evaluated	Altered sensory, microbiological, and chemical properties	[343]
	Fruit and vegetable	Strawberries	Mustard, and clove EO	Antifungal activity of EO vapors estimated	Retarded fungal growth	[24]
		Banana varieties	Cassava starch films with clove EO	Solubility, moisture, thickness, WVP, biodegradability, color, and antifungal activity assessed	Enhanced film thickness, decreased moisture content, solubility, TTA, mass loss, Improved antifungal activity, quality, and prolonged shelf life	[67]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
Cassia bark	Meat product	Meat	Thermoplastic cassava starch with cinnamon, and sappan powder extract	Microbial count and appearance identified	Reduced total microbial count, extended shelf life, and formed active packaging	[467]
		Chevon rolls	0.25% of ethanolic cinnamon bark extract, and 0.40% of ethanolic aloe vera extract	pH, oxidative stability, microbial quality, and sensory properties evaluated	Improved acceptance, color, odor, and prolonged shelf life	[750]
		Fresh beef	0, 0.5, 1, 1.5, and 2% of EO	Shelf life estimated	Prolonged shelf life up to 15 days	[953]
		Beef slices	Sodium alginate coating with cinnamon essential oil nanocapsules, and nisin	Physicochemical parameters (TVB-N, pH value, weight loss), antimicrobial activity, sensory characteristics, and color parameters estimated	Inhibited microbial growth, decreased lipid oxidation, prolonged shelf life up to 15 days, enhanced texture, color, odor, juicy characteristic, quality, antioxidant, and sensory properties	[1014]
		Chicken meat	Edible coating of Rosemary, and cinnamon EO with alginate coating	Antioxidant potential, chemical quality, and sensory properties analyzed	Improved antioxidant activity, sensory characteristic, quality, decreased lipid oxidation, and extended shelf life	[724]
		Chicken fillets	Edible coating of carrageenan and cinnamon EO	TBA, drip loss, pH, TV, ERV, WBSFV, color, microbiological, and sensory attributes evaluated	Increased sensory score, and prolonged shelf life	[456]
	Dairy product	Butter	Extract	Sensory, proximate, chemical, phytochemical, and microbiological activity estimated	Improved physiochemical properties, inhibited microbial propagation, and spoilage	[966]
		Eastern European curd cheese	Liquid whey protein concentrate-based edible coating with 0.3% of Chinese cinnamon bark CO_2 extract	Microbiological, physicochemical (protein, pH, lactic acid, fat, moisture, color, rheological, and sensory attributes) assessed	Inhibited microbial growth and prolonged shelf life	[597]
		African yogurt	Cinnamon bark and black pepper seed powder extract	Antimicrobial potential and pH value evaluated	Inhibited bacterial propagation	[662]
		Yogurt	0, 0.1, 0.2, 0.3, and 0.4 mL of cinnamon oleoresin	Sensory, quality and shelf life analyzed	Enhanced microbial count and obtained shelf life up to 10 days	[442]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
	Cereal-based product	Bread	0, 1, 2, 3, and 4% of powder	Antioxidant potential, total phenol content, sensory quality, texture, and microbial properties estimated	Enhanced loaf volume by 2%, acceptability, phenol content, antioxidant potential, inhibited mold growth, and extended shelf life up to 6 days	[251]
		Cake	3% of cinnamon	Proximate, and sensory attributes analyzed	Enhanced protein, carbohydrate, crude fiber, Ca, Fe, Zn, reduced total energy, and fat content	[259]
		Sponge cake	0, 1, 2, 3, and 4% of powder	Quality and sensory attributes measured	Reduced volume, pH, moisture content, color, lightness, yellowness, enhanced stiffness, and acceptability with 1% powder	[522]
		Spanish bread	Mustard, and cinnamon EO	Antifungal activity and shelf life evaluated	Control fungal growth, enhanced acceptability	[208]
		Cookies	4% of Powder	Antioxidant potential and quality analyzed	Reduced loss ratio, moisture content, spread rate, yellowness, lightness, enhanced stiffness, redness, antioxidant capacity, and acceptability	[879]
	Fruit and vegetable products	Processed apple	Nutmeg and cassia bark EOs in alginate-based edible coatings	Shelf life and sensory attributes estimated	Inhibited microbial growth, reduced flavor, consistency, aroma, and extended shelf life up to 15 days	[800]
		"Thomson navel" orange fruit	Shellac edible coating with cinnamon EO	Ascorbic acid, fruit spoilage, weight loss, consistency, and sensory attributes assessed	Decreased weight loss, consistency loss, and improved quality	[463]
		Mango	Bees wax-based edible coatings with bark EO and hexanal	Quality, physicochemical, sugar, organic acid, internal gas, volatile compound, and sensory attributes evaluated	Improved quality, physicochemical, and flavor	[342]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Fresh cut fruits (Grapes, pears, raspberries, strawberries, gala apples, Valencia, Hamlin orange, fuji apples, flor de Invierno pears, granny smith apples, golden delicious apples)	Vanilla, *Cinnamomum zeylanicum,* and *Cinnamommum cassia*	Shelf life analyzed	Inhibited pathogenic propagation, extended shelf life	[619]
	Miscellaneous product	Mushrooms	cinnamon EO	Browning, weight loss, antioxidant activity, and volatile oils evaluated	Neglected browning, and weight loss	[264]
		Chocolates	Cinnamon, shellac, and xanthan extract	Antioxidant potential and physicochemical parameters analyzed	Prolonged bioactive profile, enhanced antioxidant capacity, phenolic content, acceptability, and flavor	[622]
Black pepper	Meat product	Buffalo meat steaks	Carrageenan edible film with 0.5% of oleoresins of black pepper	Physicochemical characteristics, microbiological properties, proximate, and sensory attributes estimated	Increased quality and extended shelf life	[575]
		Chicken meat	Hot red pepper, garlic, and black pepper powder	Proximate composition, cholesterol level, and TBARS assessed	Enhanced composition, protein, antioxidant capacity, quality reduced lipid oxidation, and cholesterol level	[718]
	Dairy product	Paneer	0.50% of cardamom, and 0.25% of black pepper powder	Sensory, proximate, and physicochemical parameters evaluated	Enhanced phenolic compound, and extended shelf life	[112]
		Burfi	0.5,1, and 1.5% of turmeric, and 0.6, 0.8, and 1% of black pepper powder	Sensory, and textural profiles analyzed	Improved texture, flavor, color, appearance, acceptance, and nutritional value	[501]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
	Fruit and vegetable	Pineapple	Chitosan and alginate-based edible coatings with black pepper, and *Schinus terebinthifolia* EO	Microbiological activity and shelf life estimated	Retarded microorganism, and extended shelf life up to 45 days	[229]
	Cereal-based product	Snack like pastry	Tigernut, black pepper, and plantain flour	Proximate composition, mineral, vitamin, vitamin C, and sensory characteristics evaluated	Increased protein, fat, dietary fiber, mineral, vitamin, flavor, and taste	[17]
Coriander	Meat product	Chicken fillet	The bioactive edible coating is based on sodium alginate with coriander EO in 650 mL of aqueous extract	MBC, MIC, antimicrobial activity, TBARS, TVBN, peroxide value, and sensory attributes evaluated	Retarded pathogen growth, enhanced chemical quality, antioxidant capacity, and extended shelf life	[430]
		Quails meat	Coriander, and black cumin seed	Feed conversion, BW (Body Weight) gain, carcass attributes, organ production, and fatty acid composition analyzed	Reduced BW, enhanced fatty acid composition	[428]
		Lambs meat	5% of powder	Digestibility, blood metabolites, immune system, rumen, and chemical composition estimated	Exhibited important effect on blood cells, and blood metabolite concentration	[446]
		Porcine meat	Meat and bone meal protein films with coriander EO	Moisture content, mechanical parameters, water vapor permeability, and optical properties assessed	Enhanced antimicrobial food packaging capacity	[520]
		Broiler chicken	*Cichorium intybus,* and coriander water extract	Antioxidant potential, phytochemicals, minerals, carcass traits, blood parameters, and growth examined	Enhanced total phenolic acid, flavonoid content, Na, Fe, K, lipid profile, carcass attributes, liver activity, and antioxidant capacity	[316]
	Dairy product	Ghee	Coriander steam distilled to extract	Antioxidant activity evaluated	Enhanced antioxidant capacity	[688]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
	Cereal-based product	Wheat and wheat product	Coriander, thyme, and oregano essential oils	Antifungal activity, phytotoxicity effect, antimicotoxigenic capacity, and sensory properties evaluated	Inhibited fungal growth	[160]
	Fruit and vegetable products	Stick carrots	Seed EO, extract, and hydrosol	MBC, MIC, inactivation, growth kinetics, chemical properties, and sensory attributes analyzed	Inhibited microorganisms, enhanced sensory characteristics, and color	[697]
Nutmeg	Meat product	Beef	The edible coating is based on sage seed mucilage with nutmeg EO	Shelf life and quality estimated	Reduced microbial count, lipid oxidation, enhanced stiffness, acceptability, color stability, and sensory attributes	[468]
		Bovine loins	Active films formulated with polyvinyl alcohol, various oleoresin concentration, and gelatin of nutmeg	Physicochemical characterization assessed	Reduced pH, humidity percentage, TVB-N, and prolonged the shelf life	[305]
	Dairy product	Fresh Baladi cheese	Nutmeg and cinnamon EO	MIC and inhibition zone diameter evaluated	Provided less safety to the fresh Baladi cheese against *Brucella*	[46]
Black mustard	Meat product	Normal ground beef, and lean ground beef	Cellulose acetate film with ground mustard seed	Moisture absorption, sinigrin content, allyl isothiocyanate, AITC, microbiological, and shelf life analyzed	Decreased moisture absorption, and extended shelf life up to 3.68 days	[118]
Turmeric	Meat product	Chicken breast, fresh pork loin, and beef loin	The edible alginate-based film with turmeric	Structural, physical properties, thickness, WS, MC, antioxidant activity, color, transparency, WVP, OP, mechanical properties, infrared spectroscopy, pH, and lipid oxidation evaluated	Enhanced antioxidant activity, decreased lipid oxidation, improved quality, and shelf life	[155]
		Chicken meatballs	0.5 and 1% of powder	Quality analyzed	Prolonged lipid oxidation	[472]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Beef burger, and minced beef	Turmeric and marjoram ethanolic extract	The bacterial pathogen, AST, molecular, and antimicrobial activity estimated	could not provide any microbial effect	[783]
		Broiler chicken	Powder	Antibacterial property, body weight gain, FCR, and quality assessed	Increased palatability, flavor, crude protein, digestion absorption, decreased saturated fatty acid, and triglycerides	[508]
		Sausages	Edible hydrogel coatings with turmeric residue and gelatin hydrogels or cassava starch and gelatin hydrogel	Microbial culture and antimicrobial activity measured	Retarded microbial growth	[941]
		Chicken breast fillets	Carboxymethyl cellulose solution with turmeric, and black pepper seed extract	Quality, microbiological property, total lipid extraction, FFA, PV, TBA, TVB-N, and sensory attributes evaluated	Reduced lipid oxidation, proteolysis, controlled bacterial count, and extended shelf life up to 16 days	[218]
		Chicken, and fish meat	Film-based curcumin with rice starch	MC, WAC, WS, biodegradability, color, pH, temperature, and storage stability analyzed	Altered color from yellow to reddish-brown, decreased water solubility, and water absorptivity	[283]
	Dairy product	yogurt	Gel-like stable suspension using cellulose nanofibers with turmeric	Titratable acidity, pH, syneresis, color, rheology, and sensory attributes evaluated	Enhanced syneresis, provided yellow color, and improved sensory characteristic	[341]
		Whole, skim, and low-fat milk	Encapsulated curcumin	Physical stability, bioaccesability, and antioxidant activity analyzed	Enhanced chemical stability, bioaccesibility, and bioactivity	[309]
		Buffalo milk ghee	0.5, 1, and 1.5% of powder	Sensory attributes estimated	Enhanced acceptability	[72]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Stirred yoghurt	Ethanol, and aqueous extracts	Proximate composition, total carbohydrate content, moisture content, fat, crude protein, digestion, distillation, titration, micronutrients, physicochemical, microbial, and sensory attributes assessed	Enhanced nutrient composition, pH, vitamins, minerals, quality, acceptance altered color from white to yellowish-orange, reduced carbohydrate, protein content, and inhibited microbial activity	[580]
		Dairy yogurt	Turmeric, and cinnamon oleoresins	Sensory attributes, proximate composition, shelf life, microbial, physicochemical parameters, and glycemic impact examined	Enhanced acceptability, quality, decreased blood glucose level, postprandial blood glucose level, and chances of type 2 diabetes	[696]
		Pasteurized milk	Turmeric, ginger oleoresins, and pomegranate peel ethanolic extract	GCMS, sensory, proximate composition, color, antioxidant, TPC, microbial count, and antimicrobial potential measured	Inhibited gram-positive, gram-negative bacteria, fungi, enhanced TPC, and antioxidant capacity	[407]
		Buffalo milk paneer	Raw turmeric powder aqueous extract	Sensory properties evaluated	Increased nutritional, and quality	[884]
		Herbal milk	0.1% of turmeric powder, 25% of tulsi juice, and 3% of ginger juice	Physicochemical, sensory, and microbiological properties analyzed	Enhanced nutritional value, acceptance, sensory attributes, TPC, antioxidant activity, and flavor	[314]
		Custard	Paw-paw and turmeric powder	Proximate composition, functional parameter, microbiological, and sensory attributes estimated	Reduced sensory acceptance	[660]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Functional kulfi	Curcumin encapsulated in calcium alginate	Morphology, color, encapsulation efficiency, FTIR, SEM, release behavior, physical characteristic, microbiological properties, and sensory attributes assessed	Enhanced sensory characteristics (flavor, color, appearance, taste), acceptance, and lower microbial load	[841, 843]
		Herbal lassi	Turmeric extract	Sensory, and TPC measured	Enhanced sensory attributes, TPC, and extended shelf life up to 9 days	[558]
		Paneer	Fresh raw turmeric powder aqueous extract, and buffalo milk	Hardness, cohesiveness, elasticity, gumminess, and chewiness evaluated	Improved hardness, cohesiveness, elasticity, gumminess, and chewiness	[461]
		Fresh shanklish cheese	Extract and kefir	Chemical properties analyzed	No effect on the physical–chemical composition	[856]
		Manchego-type cheese	Nanoemulsified curcumin	Sensory and physicochemical properties estimated	Enhanced antioxidant potential, TPC, improved appearance, color, and odor	[807]
		Cokelek cheese	The edible film with 0.5% of alginate, 1.5% of sorbitol, 5% of egg white protein powder, and 2% of turmeric EO	Volatile compounds, EOs, physical–chemical properties, and microbiological properties assessed	Enhanced EO, inhibited water vapor transmission, microbial growth, and reduced weight loss	[437]
		Pineapple ice cream	Curcumin-loaded nanoemulsions	Sensory and technological parameters measured	Decreased application of artificial dyes	[158]
		Dairy product	Plantain syrup and turmeric powder	Oxidation, color, water activity, titratable acidity, pH, syneresis, WRC, total soluble solids, carotenoids, antioxidant potential, TPC, mineral contents, and microbiological quality-examined	Reduced yellow color, enhanced oxidation value, syneresis ratio, WRC, TPC, antioxidant capacity, Ca content, and extended shelf life	[164]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
	Cereal-based product	Bread	4% of Powder	Proximate composition, physical attributes, curcumin content, TPC, and sensory properties evaluated	Enhanced antioxidant capacity, curcumin content, and TPC	[531]
		Yellow layer cake	Powder	Quality, physicochemical, and sensory attributes analyzed	Enhanced crumb color, the viscosity of cake batter, cake volume, crude fiber, curcuminoid content, TPC, reduced density, water activity, stiffness, improved antioxidant potential, and physicochemical properties	[530]
		Functional biscuits	Turmeric powder, wheat flour, and soya bean flour	Proximate composition, TPC, reducing power, color, and sensory attributes estimated	Enhanced nutritional quality, protein content, and antioxidant activity	[16]
		Moin-Moin	2.5 g of Powder	Proximate, mineral content, physical, microbiological, and sensory attributes assessed	Lowered microbial count	[34]
		Gluten-free cracknel biscuits	Turmeric rhizome, and chia seed powder	Sensory attributes measured	Inhibited microbial growth	[507]
		Wheat flour dough, and cake	0, 2, 4, 6, and 8% of powder	Rheological, physical properties, curcumin content, and sensory attributes examined	Enhanced antioxidant capacity, and curcumin content	[683]
		Breakfast cereal	Encapsulated turmeric extract (5%)	Physical attributes, TPC, curcuminoid content, antioxidant potential, and consumer acceptability evaluated	Enhanced antioxidant capacity, curcuminoid content, and TPC	[516]
		Biscuits	Turmeric, carrot water extracts, and grape leaves ethanol extract	Antioxidant activity, chemical, and physical properties estimated	Improved antioxidant capacity	[362]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Cake	Enriched cornstarch with curcumin-loaded lyophilized liposomes and the enriched cornstarch	Water absorption, water activity, moisture content, bulk properties, flowability, and wetting time assessed	Reduced acute, homogeneous yellow color, stiffness, and chewiness	[296]
		Snacks	Turmeric powder, and broken rice grains	Sensory, physicochemical, microbiological properties, chemical composition, phenolic compound, and antioxidant activity measured	Improved sensory and nutritional properties	[666]
		Corn snacks	Turmeric, ginger, and bay leaves powder	Organoleptic, proximate, minerals, vitamins, functional properties, TPC, TFC, polyphenolic compounds, physical properties, color, texture, and microbial properties examined	Enhanced vitamins, mineral content, phytochemical content, improved rheological properties, and extended shelf life	[74]
	Fruit and vegetable products	Pumpkin	EO	Microbial activity and quality parameters evaluated	Retarded microbial growth, improved quality, extended shelf life up to 15 days	[171]
Bay leaves	Meat product	Meatballs	Whey protein edible films with bay leaves, and sage	Antioxidant potential, TPC, PV, CD, thiobarbituric acid value, color, and sensory attributes evaluated	Reduced CD, peroxide value, enhanced sensory characteristic, acceptance, and extended shelf life	[37]
		Minced beef	Encapsulation of bay leaves extract (hydroalcoholic, water, and alcoholic) with nano-liposome	Antioxidant, phenolic, flavonoid content, antimicrobial activity, shelf life, and chemical properties analyzed	Enhanced antioxidant activity, inhibited microbial load, oxidation, and extended shelf life	[940]
		Minced maronesa beef	Rosemary, and bay leaves EO	Volatile composition, microbiological activity, color, and pH estimated	Enhanced pH, decreased microbial load, improved color, and extended shelf life	[970]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Dry fermented game sausages	Bay leaves EO	Technological traits, sensory acceptability, TBARS, pH, and water activity assessed	Reduced pH, TBARS, water activity value, and enhanced acceptance	[482]
	Dairy product	Domiati cheese	Mint, bay leaves, and dill EO extract	Sensory, and fungal evaluated	Reduced total count of fungi, and contamination	[389]
	Cereal-based product	Meat bread	Bay and oregano	Shelf life, storage stability, oxidation parameters, microbiological, color, and sensorial profile evaluated	Extended shelf life	[945]
		Cookies	6% of powder	Palatability, postprandial glycemia, appetite, and gastrointestinal problem analyzed	Decreased blood glucose level and enhanced applicability	[450]
		Rice	Clove leaf and bay leaf EO	Chemical composition and antifungal activity	Prolonged shelf life	[702]
	Fruit and vegetable	Fried potatoes	Multilayer food packaging films with bay leaves, Algerian sage leaves ethanol, and aqueous extract	Bioactive molecules, packaging color, tangible migration, and lipid oxidation evaluated	Improved antioxidant activity, extended shelf life	[670]
		Fresh cut muskmelons	Bay leaves EO nanoemulsion	Physicochemical properties, and microbiological analyzed	Inhibited TA level, oxidative browning, improved TPC, retarded spoilage microorganisms, and improved physiological quality	[770]
Saffron	Meat product	Poultry	Saffron	Growth, and feed additive parameters evaluated	Improved antioxidant activity, protection, and quality	[159]
	Cereal-based product	Wheat flour pasta	Powder	Characterization, moisture content, water activity, antioxidant potential, TPC, HPLC, TPA, color, and sensory attributes evaluated	Enhanced sensory properties	[85]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Functional cookies	50 mg of aqueous extract	Proximate composition, sensory, physical, texture, color, TPC, antioxidant activity, and lipid peroxidation analyzed	Improved antioxidant activity, enhanced sensory properties, increased acceptance, and shelf life	[144]
	Fruit and vegetable products	Fresh cut cucumber	Edible film with saffron petal alcoholic extract	Physical parameters, moisture content, transparency, water vapor permeability, antibacterial activity, TPC, antimicrobial activity, and total soluble solids evaluated	Enhanced physical properties, quality, reduced spoilage, and extended shelf life	[359]
		Salad dressings	Pomegranate juice and saffron powder	Rheology, storage stability, color, and sensory attributes analyzed	Reduced viscosity, structured emulsion, improved rheological properties, enhanced color, and taste	[420]
Star anise	Meat product	Yao meat	Nanoemulsion-based active coating with star anise EO, nisin, and polylysine	Shelf life, quality, sensory, physicochemical, and microbial properties evaluated	Improved stability, inhibited microbial growth, decreased total volatile, pH, improved acceptability, color, odor, quality, and extended shelf life from 8 to 16 days	[537]
	Dairy product	Milk	Ethanol and aqueous extracts of star anise powder	MICs inhibition evaluated	Retarded bacterial growth, delayed spoilage, improved protection level, and reduced health problems	[727]
	Fruit and vegetable products	Strawberry	Edible film from the base formulation with star anise EO, and cinnamon extract	Quality and shelf life evaluated	Reduced titratable acidity, pH, extended shelf life up to 41 days	[77]
Onion	Meat product	Beef burger patties	Edible onion film	Shelf life, sensory, and quality parameters evaluated	Enhanced chrome, redness, yellowness, reduced pH, increased chewing property, flavor, texture, color, odor, and appearance	[872]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Ground beef meat	Water extract	Phenolic compounds, MIC, antibacterial activity, microbiological property, physicochemical, and sensory attributes analyzed	Enhanced meat protection, delayed protein, lipid oxidation, and inhibited pathogens propagation	[618]
	Cereal-based product	Fermented millet-based porridge	*Alliam cepa,* and *Allium parvum* extracts	Antibiotic susceptibility, MIC, and FTIR evaluated	Improved food protection	[286]
		Wheat pasta	Powder	Chemical composition, antioxidant activity, quality, color, and sensory attributes analyzed	Enhanced nutritional value, flavonoids, total dietary fiber, TPC, and antioxidant activity	[596]
	Fruit and vegetable products	Pesticide-treated vegetables (tomato, beet, cucumber, cherry tomato, lettuce, round aubergine, and pepper), and grapes	Onion	Genotoxicity and toxicity evaluated	Enhanced mutagenicity and micronucleus frequency	[294]
Dill	Meat product	Beef	Plantago major seed mucilage edible coating with dill seed EO	Antioxidant activity, TPC, antimicrobial activity, sensory, and chemical properties evaluated	Prolonged shelf life up to 9 days	[137]
		Meat	A water-soluble polysaccharide (AGP1) of dill seed	AGP1 characterization analyzed	Good thermal stability, lower lipid peroxidation, and enhanced bacterial stability	[353]
		Broiler chicks meat	Dill seed and dietary hemp	Quality, physicochemical properties, lipid peroxidation, oxidative stability, and sensory attributes estimated	Decreased lipid peroxidation, enhanced sensory characteristics, lipid profile, and oxidative stability	[975]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
	Dairy product	Probiotic yogurt	100 ppm of EO	Sensory and physicochemical properties evaluated	Enhanced probiotic bacteria, titratable, reduced pH, increased sensory scores, and physicochemical properties	[590]
		Yogurt	Aqueous extract of dill seed powder	Physicochemical, textural, colorimetric, and sensory attributes analyzed	Enhanced antioxidant capacity, TPC, acidity, lower water content, increased acceptability, nutritional value, and taste	[938]
	Fruit and vegetable product	Tomato pomace	Dill seed, and *Mentha piperita*	Shelf life stability and physicochemical properties evaluated	Extended shelf life	[98]
		Dried fruit	Methanol; a fraction, EO fraction, and aqueous fraction	Bacterial cultures, antibacterial effect, antioxidant potential, and TPC analyzed	Enhance antioxidant capacity and TPC	[918]
Fenugreek	Meat product	Meat with olive oil	2 and 4% of Powder	Emulsion stability, lipid oxidation degree, water salvation, fat released, TPA characteristic, and color evaluated	Reduced fluid salvation, fat released, gumminess, stiffness, chewiness, and increased quality	[303]
		Ground beef patties	Extract	Storage stability analyzed	Reduced thiobarbituric acid value, delayed bringing stage of oxidative rancidity, improved oxidative stability, and antioxidant capacity	[369]
		Tunisian beef sausage	Water-soluble polysaccharide of fenugreek seed	Functional parameters, and oxidative method estimated	Retarded myoglobin, lipid oxidation, and improved storage stability	[490]
		Beef burger	3, 6, 9, and 12% of seed flour	Antimicrobial and antioxidant activity assessed	Enhanced microbiological quality, essential amino acid, physicochemical quality, improved acceptance, and sensory attributes	[363]
		Hen meat patties	Powder	pH, proximate composition, TBARS value, microbiological quality, and sensory attributes measured	Enhanced sensory properties	[720]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Rabbit sausage	5, 10, and 15% of powder	Physical, color, TBARS, and sensory properties examined	Lower lipid oxidation and improved antioxidant capacity	[1006]
	Dairy product	Buffalo yogurt	*Moringa oleifera* and fenugreek seed flours	Proximate, polyphenols, AOA, TPC, physicochemical, mineral content, microbiological properties, antibacterial activity, and sensory attributes evaluated	Enhanced viability of yogurt culture, AOA, TPC, antibacterial effect, mineral, functional properties, and nutritional value	[250]
		Milk	Sprouted	Dairy and growth performance analyzed	Enhanced dairy performance, improved regular weight gain, and increased growth ratio	[161]
	Cereal-based product	Rice and chickpea	15% of fenugreek polysaccharide flour	Moisture obtained, expansion rate, WAI, color, texture, sensory, and glycemic index evaluated	Reduced GI, improved sensory, and physical properties	[849]
		Dark wheat flour	2, 5, and 8% of the flour	Proximate composition, baking, antioxidant activity, TPC, texture, sensory, and microbiological properties estimated	Enhanced acceptance, and improved quality	[568]
		Brabari, and lavash flatbreads with wheat doughs	4.93% of seed gum	Quality assessed	Higher water absorption, improvement, extensibility, less tendering degree, and optimum amounts of retardation to stretch	[728]
		Muffins	Seed husk	Rheological, chemical properties, color, dietary fiber, tangible gravity, viscosity, sensory, physical, texture, and composition measured	Enhanced fiber content, improved quality, volume, and tender texture	[889]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Biscuits and bread	Wheat and fenugreek flour	Proximate composition, functional characteristic, physicochemical, microbiological properties, and sensory attributes examined	Improved flour quality, reduced gluten content, enhanced protein, fiber, mineral, and acceptability	[915]
		Oat	Powder	Bulk density, stiffness, storage stability, and shelf life evaluated	Reduced stiffness, bulk density, and extended shelf life	[986]
		Legumes, and millets (laddu, dhokla, and uppuma)	Seed	Hypoglycemic effect analyzed	Improved acceptability and maintained diabetes	[689]
		Bread	5% of the fenugreek powder	Carbohydrate metabolism, taste, acceptance, insulin, blood glucose, nutrient composition, and sensory characteristic estimated	Reduced insulin, glucose, controlled functional property, decreased insulin resistance, and type 2 diabetes	[541]
		Flatbreads and buns	10% of fenugreek powder	GI, and glycemic response assessed	Reduced glucose curve, GI, glycemic response, and postprandial glycemia	[767]
		Wheat biscuits	Fenugreek powder	Thickness and sensory attributes measured	Enhanced thickness, quality, acceptability, dietary fiber, protein content, lysine, total Ca, and total Fe	[372]
		Pea and oat	Seed powder and leaf powder	Barrel temperature and stiffness examined	Improved quality	[985]
		Injera	Fenugreek powder	Mineral, proximate composition, total microbial load, and sensory properties evaluated	Enhanced crude fiber, crude protein, mineral, lower microbial growth, increased crude fat content, and nutritional value	[327]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Pearl millet	EO	Amylose content, solubility, moisture content, film thickness, opacity, water solubility, tensile properties, SEM, and antimicrobial activity analyzed	Enhanced tendril break, tensile power, melting enthalpy, thermal transition temperature, morphological properties, surface softness, retarded microbial growth, increased mechanical, obstacle properties, quality, and prolonged shelf life	[253]
		Biscuit and wheat flour	10% of fenugreek powder	Physical properties, sensory, chemical, and rheological properties analyzed	Enhanced sensory, chemical properties, and prevented degenerative disorders	[268]
		Whole wheat flour	5, 10, 15, and 20% of fenugreek powder	Rheological, functional, and thermal characteristics estimated	Developed yellowish color, enhanced bulk density, emulsion potentiality, water retention capacity, lower melting enthalpies, increased viscosities, consistency, power-law firmness coefficient values, and functional properties	[780]
		Gluten-free fresh pasta	Fenugreek, tiger nut, and chickpea powder	Chemical properties, water activity, glycemic index, rheological, color, and sensory attributes assessed	Enhanced nutritional value, protein content, soluble, insoluble fiber, health benefits, reduced glycemic response, slow down starch enzymatic digestion, increased texture, developed more reddish color, and improved sensory acceptability	[539]
		Semolina-based upma	Raw, soaked, and germinated chickpea, and fenugreek seed powder	Sensory and nutritive value examined	Enhanced acceptability, dietary fiber, protein, fat, Fe, Ca, moisture content, reduced calories, carbohydrates, GI, and improved nutritional value	[503]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
		Wheat flour rusk	Fenugreek powder	Mineral, proximate composition, dietary fiber, functional, physical parameters, stiffness, color, antioxidant activity, and sensory attributes evaluated	Improved antioxidant, nutritional properties, reduced sensory characteristic, enhanced mineral, fiber, phytochemical properties, stiffness, loaf weight, quality, acceptability, lower loaf volume, and developed dark color	[252]
		Mungbean	Fenugreek	Soil pathogenic fungi analyzed	Lower frequency of soil pathogenic fungi, enhanced percent pollen fertility, chlorophyll content, and nitrate reductase activity	[937]
Asafoetida	Dairy product	Milk dessert	*Lactobacillus reuteri* encapsulated with sodium alginate with zedo, and asafoetida gum	Sensory, physicochemical, microbiological, and bacterial survival evaluated	Enhancement in MLR survival	[431]
Celery	Cereal-based product	Wheat flour and bread	Powder	Chemical, Physical parameters, antioxidant potential, TPC, starch digestibility, and sensory attributes evaluated	Enhanced antioxidant capacity, phenolics content, crumb stiffness, sensory characteristic reduced GI, starch digestibility, and bread volume,	[982]
		Biscuits	Oleoresin and EO	Microstructural and physicochemical properties analyzed	Enhanced hydration properties of fiber, stiffness, and quality	[882]
Chili	Meat product	Hubbard broiler	Powder	Physicochemical, biochemical, and hematological parameters evaluated	Decreased blood glucose level	[258]
		Vietnamese fermented pork roll (nem chua)	Powder	TBA, Enterobacteriaceae load, pH, TVB-N, sensory attributes analyzed	Reduced Enterobacteriaceae load, pH, TVB-N, TBA, enhanced sensory score, and maintained physicochemical	[598]
		Broiler chickens	Chili, and turmeric powder	Proximate composition, quality, refrigeration loss, water absorptive capability, pH, lipid profile, TBARS, and sensory attributes estimated	Reduced lipid oxidation, enhanced flavor, and storage stability	[801, 802]

Table 4 (continued)

Spices	Food system	Food product	Method of application	Tests conducted	Key results	Reference
	Dairy product	Gouda cheese	Microencapsulation of chili pepper powder extract added with olive oil	Quality, pH, amino acid content, texture, and sensory attributes assessed	Enhanced quality, reduced stiffness, and extended utilization	[474]
		Yogurt	Encapsulate chilli waste bioactives	Physicochemical and sensory attributes measured	Improved solubility, water activity, moisture content, flowing, color, polyphenol retention, acceptance, sensory properties, controlled lactic acid bacteria, enhanced bioactive, nutritional, and color parameters	[819]
Allspice	Fruit and vegetable product	Tomato	Oregano, allspice, and garlic EO	Antimicrobial and physical properties evaluated	Decreased viscosity, enhanced elongation, developed dark color, and improved physical parameters	[261]
Kokam	Dairy product	Cocoa butter	Phulwara butter and kokum fat fraction	Physical and chemical parameters evaluated	Improved triacylglycerol, fatty acids composition, solidification properties, and low melting limits	[755]
	Cereal-based product	Rice extrudates	Encapsulated fruit powder	Proximate composition, nutritional value, starch, protein, lipids, vitamins, phytochemicals, moisture, color, relative humidity, antioxidant potential, breaking strength, texture, TPC, and bulk density analyzed	Improved color, reduced loss of antioxidant capacity, TPC, and enhanced bulk density	[366]
	Miscellaneous product	Chocolate	Cocoa butter, and 5% of kokam powder	Triglyceride composition, rheology, and stiffness evaluated	Enhanced stiffness, solids fat content, physical parameters, and heat resistance properties	[556]

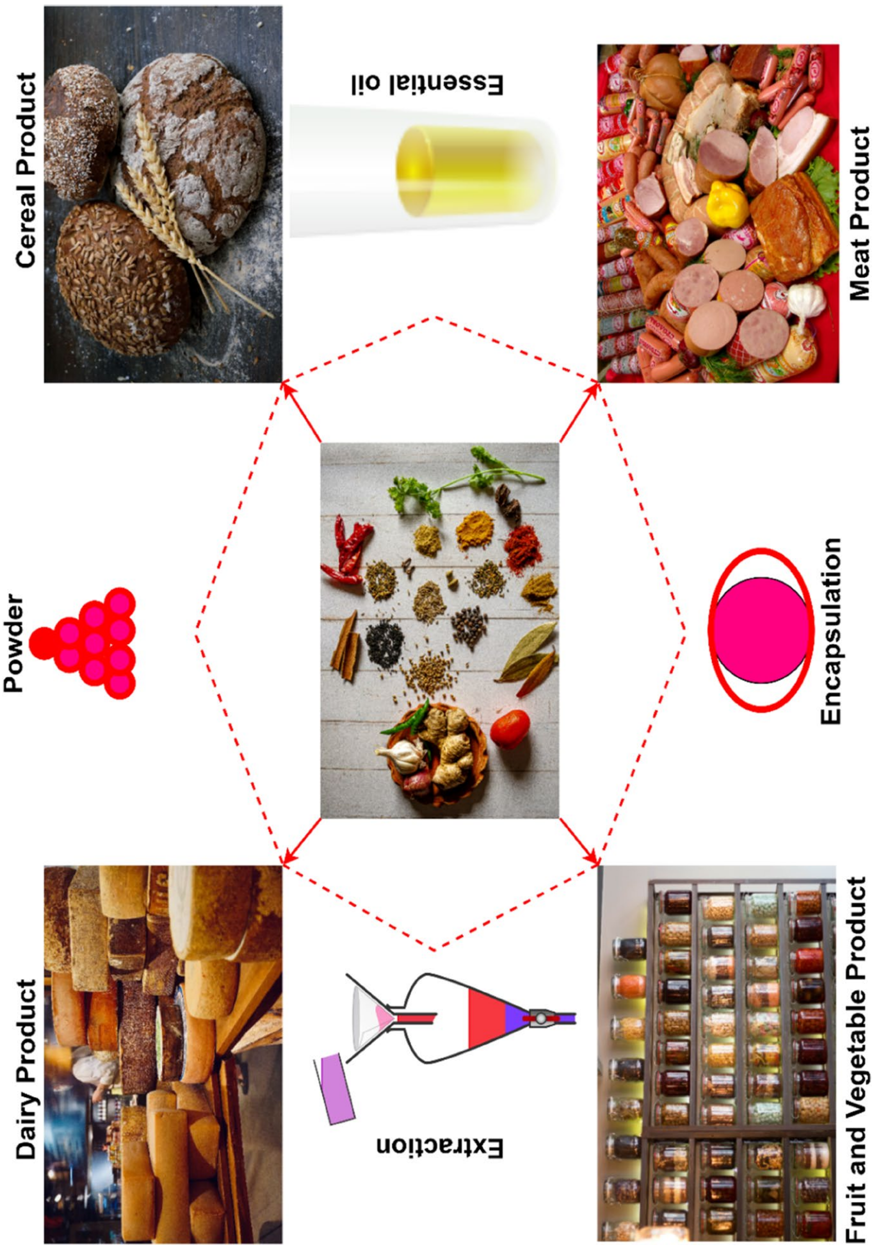


Fig. 4 Food application of spices and herbs

Cellulose acetate film with 500 mg of powdered mustard seeds has been applied to meat product to form moisture-activated antimicrobial film, decrease moisture absorption, and extend shelf life of meat up to 3.68 days [118]

Turmeric and alginate have been applied to chicken, pork, and beef to enhance its storage stability, quality, and to decrease the lipid oxidation. The mixture has improved the shelf life for chicken, and pork up to 12 days, while the shelf life of beef has been extended to 16 days [155]. Dried turmeric rhizomes powder has been applied to broiler chicks to enhance its quality, and marketability [612]. Turmeric and black pepper extracts have been applied to chicken breast fillet to reduce lipid oxidation and proteolysis, to control bacterial count, and to extend shelf life up to 16 days [218]. Acetone solution has been applied to extract curcumin. 200 mL of acetone has been added to10 g of turmeric powder. The solution has been applied to chicken and fish meat to alter color from yellow to reddish brown, to decrease water solubility, and to improve the water absorptivity [283]

Powder of sage and laurel leaves have been applied to cooked meatballs to reduce peroxide value, to enhance sensory characteristic and acceptance, and to extend shelf life [37]. Hydrodistillation by Clevenger-type apparatus has been used to extract EOs from rosemary and bay leaves. The EOs have been applied to minced maronesa beef to enhance pH, decrease microbial load, improve color, and extend the shelf life [970]

Onion peel extract has been applied to ground beef meat to delay protein and lipid oxidation and to inhibit the growth of pathogenic bacteria [618]

The fenugreek seed powder has been applied to rabbit sausage to lower lipid oxidation and to improve antioxidant capacity [1006]

Dairy Based Food Product Raw bay leaves and cardamom powder have been applied to labneh to increase the physiochemical, sensory, and microbiological properties and shelf life up to 30 days [921]

100 g of dried *Bunium persicum* seed EOs has been applied to gouda cheese to reduce lipid oxidation, to retard the growth of gram-positive and gram-negative microorganisms, and to enhance shelf life [806]

Phenolic-enriched extracts of dried fennel seeds have been applied to cottage cheese to enhance antioxidant activity and shelf life up to 14 days [169]. 250 g of aqueous extract of ajwain and fennel seeds has been applied to processed cheese to enhance microbial stability, shelf life, flavor, and acceptance [577]. The water extract of dried fennel seeds has been applied to probiotic yogurt to improve texture, flavor, enhance protection, and bioactive components [99]. EOs have been extracted from *Petroselinum crispum* and fennel; the EOs have been applied to steamed yogurts to improve its nutritional qualities, physicochemical characteristics, texture, acidity, and taste and to extend the shelf life up to 29 days [356]

The eugenol-lean fraction of clove buds has been applied to mayonnaise to reduce thermal and non-thermal creaming, homogenous, enhance color intensity, reduce power, and enhance antioxidant potential and phenolic content [190]

The EOs of cinnamon bark and black pepper have been applied to traditional African yoghurt to inhibit bacterial propagation [662]

Cardamom and black pepper powder have been applied to paneer to enrich its phenolic profile and to extend shelf life [112]

0.9 wt.% of cellulose nanofibers (CNFs) and 30wt.% of turmeric have been mixed together. The solution has been applied to yoghurt to enhance the color quality and sensory characteristics and to reduce the syneresis [341]. Aqueous extract of curcumin has been applied to milk food product to enhance chemical stability, bioaccessibility, and bioactivity and improve human health [309]. Water extract of turmeric has been applied to yoghurt to enhance nutrient composition, pH, alter color from white to yellowish-orange, reduce carbohydrate, protein content, increase vitamins, minerals, inhibit microbial activity, and acceptance of the product [580]. Water extract of raw turmeric slices have been applied to buffalo milk paneer to increase nutritional, health properties, and quality of the product [884]. In distilled water, 0.50% of lecithin, 4% of curcumin, and an emulsifier have been dissolved to formulate thick emulsion. The emulsion has been applied to kulfi to enhance sensory characteristics (flavor, color, appearance, taste), acceptance, and lower microbial load [841, 843]. Water extract of 5% raw turmeric has been applied to paneer to improve the hardness, cohesiveness, elasticity, gumminess, and chewiness [461]. Nanoemulsified curcumin has been applied to Pelibuey sheep milk to enhance antioxidant potential, TPC, appearance, color, odor, beneficial health effect [807]. The EOs extracted from turmeric has been applied to Cokelek Cheese to inhibit microbial growth, and to reduce the weight loss [437]

Water–ethanol extract of 100 g of star anise has been applied to milk to inhibit bacterial growth, delay spoilage, and to improve the keeping quality of the final product [727]

At the 1:10 proportion, water extract of dill has been applied to yogurt to enhance antioxidant capacity, TPC, acidity, acceptability, nutritional value, and taste, and to lower the water content of the product [938]

The *Moringa oleifera* and fenugreek seed flours have been applied to buffalo yogurt to enhance the viability of yogurt culture, TPC, antibacterial effect, minerals, functional properties, and nutritional value [250]

At the proportion of 1:5, the olive oil has been added into chili pepper powder; the prepared extract has been applied to Gouda cheese to enhance its quality, to reduce stiffness, and to extend its shelf life [474]

Cereal-based Food Product The hydro-distillation process with the help of Clevenger-type apparatus has been operated for 3 h at 100^0 C to extract EOs of thyme flower shoots, and black cumin seeds. The extracted oils have been applied to corn starch to retard the propagation of food pathogens, and to extend its shelf life [75]

Cinnamon powder has been applied to bread to enhance loaf volume by 2%, acceptability, phenolic content, antioxidant potential, to inhibit mold growth, and to extend shelf life up to 6 days [251]

Black pepper flour has been applied to snack food product to increase the nutritional profile, flavor profile, mineral profile, and the marketability product [17]

Coriander EOs have been applied to wheat, and wheat product to inhibit fungal growth [160]

Turmeric rhizome powder has been applied to biscuits to enhance the nutritional quality, protein content, and antioxidant activity [16]. Turmeric rhizome powder has been applied to Moin-Moin to lower the microbial count [34]. Korean turmeric rhizomes powder has been applied to cake, and wheat flour dough to enhance the antioxidant capacity, and curcumin content [683]. 0.35 g of turmeric extract has been applied to breakfast cereal to enhance antioxidant capacity, curcuminoid content, and TPC [516]

Water extract of 1 g of saffron has been applied to cookies to improve antioxidant activity, enhance sensory properties, increase acceptance, and shelf life [144] onion powder has been applied to wheat pasta to enhance nutritional value, flavonoids, total dietary fiber, TPC, and antioxidant activity [596]

Germinated fenugreek seed powder has been applied to bread, and biscuits to improve flour quality, nutritional quality, mineral content, acceptability, to reduce gluten content [915]. Water extract of fenugreek seed has been applied to Injera to enhance crude fiber, crude protein, minerals, crude fat content, and to lower the microbial growth [327]. Fenugreek EO has been applied to pearl millet to enhance tendril break, tensile power, melting enthalpy, thermal transition temperatures, morphological properties, surface softness, to retard microbial growth, to increase mechanical, obstacle properties, quality, and prolonged shelf life [253]. Water extract of germinated fenugreek seed has been applied to wheat flour, and biscuits to enhance sensory, chemical properties, and to prevent degenerative disorders [268]

Fruit and Vegetable-based Food Product Clove EO, and mustard EO have been applied to strawberries to retard fungal growth [24]

Hexane extract of sage, and bay leaves has been applied to fried potato to improve antioxidant activity, and to extend shelf life [670]

Ethanol extract of 40 g of saffron petals has been applied to fresh-cut cucumber to enhance physical properties, quality, to reduce spoilage, and to extend the shelf life [359]

The methanol fraction of dill has been applied to dried fruit extracts to enhance antioxidant capacity, TPC [918]

Miscellaneous Food Product 80% of ethanol extracts of *Marrubium vulgare, Physalis alkekengi, Alcea rosea,* and *Bunium persicum* seeds have been applied to mushroom tyrosinase to retard mushroom tyrosinase [638]

Fennel seed powder has been applied to herbal candy to improve the nutritional value, acceptance, and other physicochemical properties [418]

Nanotechnology Application of Spices

Different types of spices like cardamom, black jeera, fennel, poppy, clove, turmeric, bay leaves, fenugreek, etc. are along with some specific solvent such as zinc acetate solution, silver nitrate solution, chitosan solution, etc. are the key elements to synthesize metal, and polymer nanoparticles, zinc oxide nanoparticles, silver nanoparticles, gold nanoparticles, selenium nanoparticles, and polymer nanoparticles which have several health benefits like antioxidant, anti-carcinogenic, anti-diabetic, cytotoxicity activity, enzyme retardation effect, antimicrobial activity, dye decolorization effect, and catalytic activity. A complete discussion on nanoparticles synthesis with the help of different types of spices using various methods and its beneficial applications are portrayed in Fig. 5 and Table 5

Zinc Oxide Nanoparticles

The pure green cardamoms have been cleaned many times and air dried. To produce ZnONPs, 0.2 M zinc acetate solution has been added to 2.2 g of cardamom powder dissolved in 50 ml deionized water and stirred on a magnetic stirrer till dissolve. At 80^0 C, 5 g of green cardamoms have been boiled in deionized water for 20 min to obtain the purified extract. The produced nanoparticle has been analyzed for its antimicrobial, and anticancer activity [676]

10 mg of fennel seed powder has been soaked in 50 mL of deionized water for 24 h. To the extract 250 mL of deionized water, 41.3 mg of ZnO has been added, the mixture has been placed in an incubator at 99^0 C. Dark yellow-colored ZnONPs has been formed. The purified ZnONPs has been analyzed for its cytotoxic activity and antimicrobial activity [61]*P. anisum* and fennel seeds powdered have been dissolved in 800 mL of distilled water and stored in a refrigerator for 1 day. The extract has been used to assess the liver functionality test [127]

5 g of coriander seeds or leaves have been mixed with zinc acetate solution to synthesize ZnO-NPs. The ZnO-NPs have been evaluated for its TFC and TPC content [867]. 90 mL, 1 mM zinc oxide solution has been added into 10 mL of *Coriander* oleoresin extract to produce ZnO-NPs. The ZnO-NPs have been analyzed for its antibacterial effect, and cytotoxic activity [695]. Water extract of turmeric rhizome has been mixed with Zn acetate solution to prepare ZnONPs. The ZnONPs have been assessed for its antioxidant potential, anti-carcinogenic effect, trypan blue dye exclusion, colony developing, nitrite, and caspase effects [393]

To synthesize ZnONPs, NH_4OH, and zinc acetate dehydrates have been added to fenugreek seeds. The prepared ZnONPs have been measured for its capability of seedling growth [192]

The Pure sweet flag rhizome has been mixed with 0.1% of mercuric chloride, and 1 mM of zinc acetate solution to form ZnONPs. The ZnONPs have been estimated for its antimicrobial effect, and cytotoxicity activity [954]

Gold Nanoparticles

To prepare AuNPs, 30 mL of 2.5×10^{-4} M boiling $HAuCl_4$ solution was mixed with 1 mL cardamom seed extract. The synthesized AuNPs have been evaluated for their anticarcinogenic effect, antioxidant, and antibacterial activities [733]

To synthesize Au-NPs, methanol, and alcoholic extracts of black cumin have been mixed with various proportions of 1 mM $HAuCl_4$ The prepared Au-NPs have been analyzed for its urease retardation activity, enzyme retardation, antifungal, antibacterial activities, xanthine oxidase effect, and carbonic anhydrase function [117]

Water extract of 25 mg of cinnamon has been added to 100 µL of 0.1 M $NaAuCl_4$ solution to synthesize AuNPs. The AuNPs have been assessed for their cytotoxicity activity and prostate cancer diminishing activity [186]

30 mg of turmeric rhizome has been added with 2 mL of 10 mM NaOH solution and 1 mL of 1 mM $HAuCl_4$ solution to produce AuNPs. The AuNPs have been measured for their cytotoxic activity [886]

The water extract of fenugreek seeds has been mixed with 2.5 mg of $HAuCl_4$ solution to form AuNPs. The AuNPs have been evaluated for their antioxidant activity [324]

The water extract of sweet flag rhizomes has been mixed with gold chloride solution to synthesize the greenish-yellow to pale pink *Acorus calamus* gold nanoparticles. The *Acorus calamus* gold nanoparticles have been evaluated for its antimicrobial activity [820]

Silver Nanoparticles

40 mL of aqueous silver nitrate solution (0.14, 0.16, 0.18, 0.20, and 0.22 g) have been mixed with 10 ml of cardamom seed extract to synthesize the AgNPs. The AgNPs have been evaluated for their antibacterial effects [835]

90 ml of silver nitrate has been mixed with 10 ml of fennel seed extract to produce AgNPs, which have been analyzed for its antibacterial effect [409]

Clove extract- AgNPs have been synthesized with clove bud powder and aqueous 1 mM $AgNO_3$ solution. The Clove extract- AgNPs have been assessed for its antiviral effect, micro hemagglutination, and cytotoxicity activity [592]

10 ml of the fennel seed extract has been mixed with 90 ml of 1 mM silver nitrate solution to prepare AgNPs. The AgNPs have been measured for its anti-viral activity against influenza virus subtype H7N3 and cytotoxicity [292]

To synthesize of AgNPs, $AgNO_3$ has been mixed with 100 mL cassia bark aqueous extract. The AgNPs have been estimated for its capacity to reduce blood glucose level, improve the histopathology of the liver, and kidney tissue conditions [483]

10 ml of black pepper has been mixed with 90 ml of 1 mM silver nitrate solution to form AgNPs. The AgNPs have been evaluated for its anti-carcinogenic effect [486]

To synthesize silver nanoparticles, 100 ml of 0.1 N $AgNO_3$ solution has been mixed with 50 ml of coriander seed extract to evaluate the antimicrobial effects of AgNPs [648]. 10 mL of 0.5 M of aqueous $AgNO_3$ solution has been added into coriander extract to synthesize AgNPs to observe its antibacterial activity [543]. 100 ml of 1 mM $AgNO_3$ solution has been mixed with 20 ml of coriander seed extract to synthesize AgNPs for its antibacterial activity [813]. 99.5 ml of water and 0.5 ml of *Coriander* oleoresin have been mixed with 1 M of silver nitrate solution to synthesize AgNPs, which have been evaluated for its antioxidant potential [319]. 10 g of coriander seed powder has been mixed with 45 mL of 1×10^{-3} M of $AgNO_3$ solution to synthesize AgNPs to observe its antimicrobial effect, antibiofilm activity and plasmid curing effect [349]

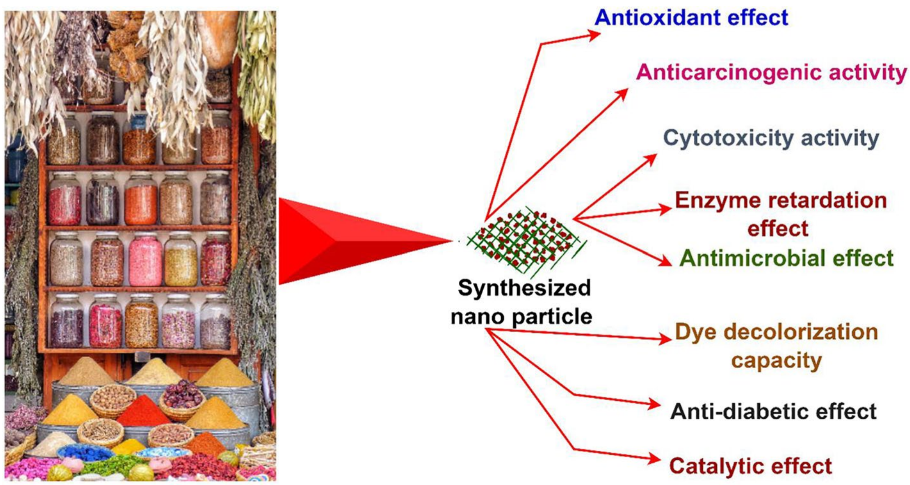


Fig. 5 Nanoparticles from spices and herbs and their application

Table 5 Nanotechnology application of spices

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
Cardamom	Zinc oxide nanoparticles (ZnONPs)	Ultraviolet–visible (UV–Vis), spectroscopy, X-ray powder diffraction (XRD), SEM, and FTIR	Zn acetate solution with green cardamom solution	Antimicrobial effects, anticancer activity	[676]
	Gold (Au NP)	SAED pattern, PerkinElmer Lambda-35 spectrophotometer, TEM, XRD, FTIR, and IR prestige-21 Shimadzu spectrometer	2.5 × 10–4 M Chloroauric acid with water extract of cardamom (2 g sample in 100 ml)	Anticarcinogenic effect, antioxidant, and antibacterial activities	[733]
	AuNP	XRD, SEM, TEM and UV–Vis spectra	Green synthesis	NA	[694]
	Silver NPs (AgNPs)	FTIR, UV–visible spectroscopy	Green synthesis	Cytotoxic effect, anti-carcinogenic activity	[487]
	AgNPs	EDAX, XRD, FTIR and SEM	Green synthesis	Antimicrobial effects	[326]
	AgNPs	SEM, UV–Vis absorbance spectroscopy, and XRD	Green synthesis	Antibacterial effects	[835]
	Gelatin NPs (GNPs)	Zeta potential, encapsulation efficacy, average particle size, DLS, UV–Vis spectrophotometry, DSC, XRD, SEM, and FE-SEM	Cardamom extract-loaded gelatin NPs with Water extract of green cardamom	Glioblastoma treatment	[649]
	ZnO-NPs	FTIR, UV–Vis, XRD, SEM, and TEM	Biogenic synthesis	Antibiofilm function, antibacterial, and mosquito larvicidal effect	[972]
Black jeera	Ag-NPs	FE-SEM, FTIR, XRD, EDS, TEM, and TG–DTA	Green synthesis	Catalytic decreased of organic dyes	[769]
	Ag-NPs	SEM, UV–Vis spectrometer, FTIR, EDX	Sodium chloride solution with alcoholic extract of black cumin	Pharmacological activities, antibacterial activity, sedative, analgesic, hypertensive, and bronchodilator activities	[447, 448, 455]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Au-NPs	SEM, UV–Vis spectroscopy, FTIR, EDX, and XRD	1 mM hot Au solution with methanol or alcoholic extract of black jeera seed	Urease retardation activity, enzyme retardation, antifungal, antibacterial activities, xanthine oxidase effect, and carbonic anhydrase function	[117]
	Encapsulation of black cumin EO	FTIR, SEM, AFM, and XRD	Chitosan nanopolymer	Free radical scavenging activity, antifungal, and aflatoxin B_1 retardation activity	[990]
	Cellulose NPs	GC–MS	*Mentha pepperita,* and black cumin EO with polylactic acid solution	Antibacterial effect	[912]
Fennel	Au-NPs	UV–Vis absorption spectra, TEM, XRD, and FTIR,	A biomimetic synthesis	Catalytic activity	[200]
	Ag-NPs	XRD, UV–Vis spectrophotometer, FTIR, SEM, and EDS	Rapid green synthesis	Antibacterial effect	[409]
	Selenium NPs (Se-NPs)	XRD, UV–Vis, FTIR, SEM, and EDS	173 mg of sodium selenite salt solution with fennel seed extract	Toxicity evaluation, arthritis treatment	[84]
	Au-NPs	UV–Vis, FTIR, TEM, and FE-SEM	Green synthesis	Antioxidant potential, anti-human breast cancer, and qualitative evaluation	[194]
	Chitosan nanocomposite	XRD, SEM, and FTIR	Chitosan-based nano-encapsulated fennel EO	Aflatoxin B_1, antifungal retardation activities	[497]
	ZnO-NPs	FTIR, UV–Vis, XRD, TEM, and EDX	Green synthesis	Cytotoxicity evaluation, cell treatment, and antimicrobial activity	[61]
	Ag-NPs	UV–Vis spectral	Methylene blue dye solution with fennel seed extract	Phytochemical evaluation, and catalytic activity	[603]
	Ag-NPs	Viability	Ag-NPs dilutions with 100 g fennel seed EO	Scolicidal effect for protoscoleces of hydatid cyst	[517]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Chitosan NPs	CNPs	Chitosan solution with fennel seed EO	Fish trail, peroxide value, total volatile base nitrogen evaluation, microbial activity, and sensorial attributes	[549]
	ZnO-NPs	DLS	ZnO dispersion with water extract of anise, and fennel seed	Liver enzyme evaluation, MDA, immunohistochemistry of interleukin 6 analysis, and histopathological assessment	[127]
	ZnO-NPs	EXD, FTIR, SEM, and XRD	Green synthesis	Antioxidant activity, biological, and antibacterial activity	[465]
	ZnO-NPs	XRD, UV–Vis spectrophotometry, and SEM	Green synthesis	Antimicrobial activity, pharmaceutical products development, agricultural area improvement	[895]
	Titanium dioxide NPs (TiO_2-NPs)	Response surface methodology	2% of TiO_2 and 2% of fennel EO	Antibacterial activity, packaging film production	[562]
	Mono-disperse carbon quantum dots (C-QDs)	NMF-ARD-SO, PCA, MCR-ALS, UV–Vis absorption spectroscopy, TEM, EDS, FTIR, and TLC	Purified C-QDs with fennel seed	Photoluminescence evaluation	[214]
	Transdermal nanoemulsions	HPLC	68% of Smix, 2% of fennel EO, and 5.6% of oleic acid	Anti-diabetic activity evaluated	[616]
	TiO_2-NPs	TEM	TiO_2-NPs with fennel	Chemical evaluation, heavy elements analysis	[458]
	Nano-chitosan	FTIR	Nano-chitosan, pectin with fennel EO, and potato peel extract	Antimicrobial activity, antioxidant activity, mechanical, thickness, optical parameter, total soluble matter, and morphological evaluation	[774]
	Oil in water nano-emulsions	Ultrasonic emulsification	Nano-emulsions with 0.05, and 0.01wt% of fennel seed EO	Herbicidal capacity evaluated	[435, 436]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
Poppy	Au-NPs	FTIR, UV–Vis spectrophotometer, and SEM	Green synthesis	NA	[624]
	Lead oxide NPs (PbO-NPs), and Fe2O3-NPs	EDX, XRD, FTIR, and SEM	Green synthesis	Antifungal, antibacterial activity, antioxidant activity, reducing capacity, free radical scavenging activity, and anti-carcinogenic effect	[625]
	Mesostructured silica-coated magnetic NPs	EDS, SEM, and XRD	Fe3O4 solution with solid–liquid extract of poppy seeds	Na	[176]
Clove	ZnO-NPs	TEM and SEM	Zinc nitrate solution with a clove flower solution	Anti-mycotoxin, antifungal effect, lipid peroxidation evaluation, and ergosterol content analysis	[511]
	Ag-NPs	UV–Vis spectroscopy, and FTIR	Biomimetic synthesis	Antifungal, antibacterial effect	[36]
	Ag-NPs	HR-TEM, FTIR, UV–visible spectroscopy and EDAX	Green synthesis	Cytotoxic activity, and anti-carcinogenic effect	[964]
	FeO-NPs	UV–Visible spectral, SEM, EDAX, and FTIR	Bee venom with water extract of clove	Anti-carcinogenic effect	[116]
	Ag-NPs	TEM, FTIR, UV–Vis spectroscopy, and XRD	Green synthesis	Antiviral effect, micro haemagglutination evaluation, cytotoxic activity	[592]
	Pt and Au/Pt bimetallic NPs	FTIR, UV–visible spectra, XRD, XPS, cyclic voltammetry, zeta potential	Phyto-mediated synthesis	Antioxidant activity, antibacterial, and catalytic efficacy evaluated	[841, 843]
	PVP/clay nanocomposites	DSC, XRD, SAXS, SEM, and FTIR	Clove EO	*Aedes aegypti larvae* management	[799]
	Fe-NPs	XRD, TGA, and XPS	Green synthesis	NA	[497]
	Chitosan NPs	TEM, UV–Vis spectra, IR, and XRD	Chitosan solution with 1 ml of clove EO	Biochemical evaluation and insecticidal effect	[271]
	Fe2O3-NPs	Microscopic and spectroscopic	Biogenic green synthesis	Methylene blue dispelled	[397]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	ZnO-NPs	SEM and XRD	Green hydrothermal synthesis	Physicochemical evaluation, and bactericidal activity	[82]
	Ag-NPs	UV–visible spectra, SEM, and FTIR	Silver solution with methanolic extract of clove flower	Antifungal, and antibacterial effect	[547]
	Ag-NPs	Analytical	Ag solution with water extract of clove	Oxidative stress, biochemical, hematological evaluation, testis, liver histological analysis, anti-fungal effect, anti-inflammatory, and antioxidant activity	[162]
	Zn-NPs	UV–visible spectroscopy	Green synthesis	Antibacterial effect	[405]
	Carbon dots	XPS, FTIR, and UV–visible spectrometer	Hydrothermal synthesis	Antioxidant effect, catalytic, and cytotoxic effect	[495, 498]
Cassia bark	Ag-NPs	FTIR, UV–Vis absorption spec-troscopy, and SEM	Silver nitrate solution with water extract of cassia bark	Pathogenic avian influenza virus subtype H7N3 effect, and cyto-toxicity evaluation	[292]
	Au-NPs	TEM, and UV–Vis spectroscopy	Green synthesis	Fluorescence activity	[275]
	Colloidal NPs	Cryo-SEM	Shellac solution with polyphenol-rich extract of cassia bark	Encapsulation efficacy, loading potential, TPC, antioxidant activity, pH, and stability evalu-ation	[623]
	Cobalt aluminate NPs (CoAl2O4-NPs)	TEM, XRD, SEM, XPS, IR, and UV–Vis spectroscopy	Cobalt aluminate solution with cassia bark extract	NA	[325]
	Ag-NPs	UV–Vis spectra, FTIR, TEM, and XRD	$AgNO_3$ with water extract of cassia bark	Blood glucose assessment, histo-pathological evaluation of liver, and kidney tissue	[483]
	Cinnamon NPs	UV–Vis spectrophotometer, FTIR, SAED, BIO-TEM, HRTEM, EDX, and DLSLC-MS	Pulse laser ablation in liquid with the cinnamon stick	Antibacterial effect	[787]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Ag-NPs	FTIR, ATR, TEM, and SAED	$AgNO_3$ water solution with water extract of cassia bark	Type 2 diabetes treatment	[484]
	Ag-NPs	FESEM, UV–Vis spectrophotometer, XRD, EDAX, and FTIR	Green synthesis	Antibacterial activity	[715]
	TiO_2 /cellulose nanocomposite	EDX, FTIR, XRD, and FE-SEM	Green synthesis	Decreased toxic organic compounds	[65]
	Se-NPs	FTIR and SEM	Green biosynthesis	Antibacterial activity	[57]
	Cinnamon NPs (CN-NPs)	UV–Vis absorption, TEM, EDX, PL emission, and FTIR-ATR	Methanol media and green pulsed laser ablation in liquid	NA	[785, 787, 788]
	Cinnamon NPs	SAED, TEM, HRTEM, FTIR, UV–Vis, and photoluminescence	4 ml of Citric acid, olive oil, and ethanolic extract of cinnamon	Antioxidant, and antimicrobial activities	[786]
	AuNPs	TEM, and UV–Vis spectrophotometer	Starch solution with alcoholic extract of cinnamon	Cytotoxicity, and prostate cancer treatment	[186]
	Nickel NPs (Ni-NPs)	XRD, FTIR, and SEM	Nickel solution with a methanol solution of cassia bark	Serum, blood biomarker evaluation, oxidative stress, and histological assessment	[386]
	Nanoemulsion	TEM	Bacterial nanocrystals with cinnamon EO	Surfactant effect of gelatin evaluation	[753]
	CNPs	TEM, and EDX spectra	Citric acid medium applying pulse laser ablation in liquid	NA	[785, 787, 788]
	AuNPs	FTIR, UV–visible spectroscopy, XRD, and TEM	Green synthesis	Antibacterial effect	[337]
	Amorphous cinnamon NPs	TEM, XRD, FTIR, and photoluminescence spectra	Ethanol solution with nanosecond-pulse laser ablation in liquid technique	Biomedicine utilization	[790]
	Mg-NPs	TEM and UV–visible spectroscopy	MgCl solution with cassia bark oleoresin	NA	[80]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	CNPs	XRD, UV–Vis, FTIR, TEM, HRTEM, SAED, EDX, DLS, and HPLC	Cinnamon stick with 5 mL of liquid methanol	Antibacterial effect	[789]
	Core/shell NPs	ZP, DLS, and PDI	1% of acetic acid solution with ethanol extract of oregano leaves, and cassia bark	Cytotoxic effect, and mitochondrial transmembrane capacity evaluation	[423]
	TiO_2-NPs	ZP	Green synthesis	Antioxidant activity, oxidative stress, and histological evaluation	[791]
	Ag-NPs	DLS, UV spectroscopy, STEM, and ZP	Pectin films with cinnamon bark, and garlic extract	Antibacterial activity	[340]
	Cinnamon-loaded poly-NPs	TEM, FTIR, and XRD	50 mg of PLGA with 10 mg of methanolic extract of dried cinnamon bark	Antimicrobial effect	[971]
	Edible coatings of nanostructures chitosan	ZP, FTIR, DLS, and TEM	Chitosan solution with cinnamon EO	Quality of cucumber fruits, total chlorophylls content evaluation, and microbiological analysis	[390]
Black pepper	Au-NPs	UV–visible spectroscopy, EDX, SEM, and FTIR	Green synthesis	Catalytic effect, antibacterial, antifungal effect, urease inhibitory, xanthine oxidase effect, carbonic anhydrase-II effect, sedative, oedema evaluation, and severe toxicity analysis	[136]
	Ag-NPs	UV–visible spectroscopy, FTIR, HR-TEM,	Green synthesis	Anti-carcinogenic effect	[486]
	Ag-NPs	SEM, UV–Vis spectroscopy, XRD, TEM, and FTIR	Green synthesis	Phytochemical constituents, antibacterial effect, cytotoxic activity	[427]
	Ag-NPs	XRD, UV–Vis spectrophotometer, TEM, and FTIR	Rapid green biogenic synthesis	NA	[312]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Chitosan NP	XRD, UV–Vis spectrophotometry, and ZP	Chitosan solution with black pepper EO	Insecticidal effect, toxicity, neurotransmitter evaluation, and pest control	[739]
	Copper NPs	XRD, UV–visible spectroscopy, FTIR, FEG-SEM, EDS, and HR-TEM	Green synthesis	Antibacterial effect	[824, 825]
	Ag-NPs	UV–Vis spectra, XRD, SEM, EDX, and FTIR	Phyto-synthesis	Antibacterial effect	[406]
	Undoped cobalt oxide, and cerium ion-doped cobalt oxide NPs	AFM, UV–Vis, and FTIR	Green synthesis	Photocatalytic effect	[805]
Coriander	Ag-NPs	TEM, UV spectroscopy, XRD, SEM	Situ green synthesis	Antimicrobial effect	[648]
	Ag-NPs	FTIR, UV–visible spectroscopy, PXRD, DLS, ZP, XRD, FESEM, and EDAX	Green synthesis	Antibacterial effect	[818]
	Ag-NPs	UV spectral, SEM, and FTIR	Biogenic synthesis	Antimicrobial effect	[574]
	ZnO-NPs	SEM and PSA	Zn acetate solution with coriander seed, and leaves extract	Free radical scavenging activity, TPC, TFC evaluation	[867]
	Cu-NPs	XRF	Cu solution with coriander	Phytotoxic, and genotoxic activities	[60]
	ZnO-NPs	SAED, TEM, and HRTEM	Zinc-based solution, $ZnSO_4$ with coriander seeds	Carotenoid, chlorophyll pigment content evaluation, and antioxidant enzyme function	[771]
	ZnO-NPs	TEM	Photo-synthesis	Carotenoid content, malondialdehyde content evaluation	[758]
	ZnO-NPs	FTIR, UV–Vis spectroscopy, XRD, SEM, and EDS	Green synthesis	Proline, chlorophyll content evaluation, and lipid peroxidation analysis	[451, 454]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	CdS-NPs, and CuO-NPs	XRD, UV–Vis, FTIR, DLS, and FESEM	Ammonium hydroxide solution mixed with copper chloride solution, and coriander	Endogenous H_2O_2 evaluation, antioxidant enzyme activity, and genotoxicity analysis	[713]
	CdS-NPs and CuO-NPs	FESEM, XRD, and DLS	Ammonium hydroxide solution into copper chloride and sodium dodecyl sulfate solution with coriander seed	Mitotic evaluation	[712]
	Ag-based hybrid nanostructures	FTIR	Bio-synthesis	Antibacterial activity	[543]
	Si-NPs	UV–Vis spectrophotometer	Silicon dioxide solution and salicylic acid with coriander	TPC and TFC evaluation	[19]
	Ag-NPs	EDX, UV–visible spectrophotometry, SEM, XRD, and FTIR	$AgNO_3$ solution with coriander seed extract	Antibacterial activity	[813]
	ZnO-NPs	UV–visible spectroscopy	Green synthesis	Antibacterial effect, cytotoxic assay	[695]
	Ag-NPs	TEM and UV–visible spectroscopy	Green synthesis	Antioxidant potential	[319]
Nutmeg	Ag-NPs	TEM, atomic absorption spectroscopy, XRD, FTIR and UV–visible	Green synthesis	Antimicrobial effect	[842]
	TiO_2-NPs	UV–Vis spectroscopy, XRD, FTIR, FESEM, and EDX	Green synthesis	Photocatalytic effect, morphological, physicochemical parameters, and antibacterial effect	[776]
	Ag-NPs	UV–Vis absorption spectrum, FTIR, XRD, TEM, and SEM–EDS	Bio-synthesis	Antibacterial effect, and cytotoxic activity	[120]
	Ag-NPs	UV–visible spectroscopy, SEM, EDX, XRD, FTIR, and ZP	$AgNO_3$ solution with hydroethanolic extract of nutmeg seed	Anti-diabetic activity	[698]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Chitosan nano-matrix	XRD, SEM, and FTIR	Bio-synthesis	Antimicrobial effect, aflatoxin inhibitory capacity, and lipid peroxidation	[224, 227]
	Ag-NPs	UV spectrophotometer, FTIR, and AFM	$AgNO_3$ solution with nutmeg seed powder	Antimicrobial effect, biofilm activity, and plasmid curing evaluation	[349]
	Ag-NPs	FTIR, SEM, and EDX	Green synthesis	Antibacterial effect	[935]
	Ag-NPs	SEM, UV–Vis spectrophotometer, XRD, EDAX, and FTIR	Green synthesis	Antibacterial activity	[408]
	Ag-NPs	XRD, UV–visible, FTIR, SEM, TEM, and AFM	Green synthesis	Antibacterial effect	[564]
	Ag-NPs	UV–Vis spectrophotometry, DLS, TEM, FTIR, and EDX	450 ml of 1 mM $AgNO_3$ solution with water extract of nutmeg seed	Antibacterial, antifungal, and cytotoxic activity	[766]
Black mustard	Ag-NPs	FTIR and ZP	Green synthesis	Antimicrobial effect	[680]
Turmeric	Ag-NPs	XRD, UV–visible spectroscopy, FTIR, TEM, and SEM	Green synthesis	Anti-carcinogenic effect	[963]
	Cu-NPs	TEM, UV–visible spectroscopy, and FTIR	Biochemical synthesis	Antibacterial effect	[959]
	Ag-NPs	UV–visible spectra, TEM, and FTIR	Bio-synthesis	Antibacterial effect	[505]
	Magnetic NPs	TEM	$NaBH_4$ solution in ammonia with rhizome of turmeric	Curcuminoids and free phenolic acids evaluation	[550]
	Nickel oxide NPs, CuO-NPs, and Cu-Ni biometallic hybrid NPs	EDX, UV spectroscopy, FTIR, XRD, SEM, TEM, and TGA	Biosynthesis	Antibacterial activity, anti-leishmanial evaluation, protein kinase retardation, cytotoxic activity, anti-diabetic activity, anti-Alzheimer's activity, and antioxidant potential	[289]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Curcumin NPs	XRD, FTIR, TEM, and SEM	Crude curcuminoid powder with ethanol extract of turmeric powder	NA	[368]
	Ag-NPs, and Au-NPs	TEM and UV–Vis spectroscopy	Au, Ag solution with turmeric rhizome extract	Antimicrobial, and anticancer activities	[844, 845]
	Fe-NPs, Ag-NPs, and Cu-NPs	EDAX spectroscopy, UV–visible spectrophotometry, SEM, DLS, FTIR, and XRD	Facile-synthesis	Physicochemical parameter	[795]
	Ag-NPs	FTIR, UV–vis spectroscopy, XRD, TEM, EDX, DLS, and fluorescence spectroscopy	Ag solution with extract of turmeric rhizome	Antibacterial effect	[318]
	Curcumin NPs	SEM, and XRD	Green synthesis	Antibacterial effect and antifungal effect	[451, 454]
	Ag-NPs	XRD, UV–visible spectroscopy, TEM, and FTIR	Bio-synthesis	Antibacterial effect	[295]
	Nano-ZnO, and nano-*Curcuma longa*	SEM, and FTIR	In deionized water, 200 ml solution of each 0.25 M Zn $(CH_3COO)_2 2H_2O$ and 0.5 M NaOH have been added with turmeric rhizome	Third-degree burn treatment	[152]
	Au-NPs	TEM, FTIR, and UV–Visible spectroscopy	Green synthesis	Antioxidant activity	[650]
	Ag/CS nanocomposite	UV–visible spectrum, TEM, SAED, SEM, FTIR, and XRD	100 ml of 1 mM $AgNO_3$ solution with turmeric extract	COVID-19 treatment	[263]
	Ag-NPs	XRD, UV–Vis spectroscopy, FTIR, EDX, and TEM	$AgNO_3$ solution with turmeric powder	Antibacterial effect	[943]
	Ag-NPs	AFM, and UV–Vis spectrophotometer	90 ml of 5 mM aqueous of Ag(NO3)2 with turmeric rhizome extract	Antimicrobial effect	[894]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Ag-NPs	FTIR, UV–visible spectroscopy, XRD, and ZP	Green synthesis	Antimicrobial effect, anti-carcinogenic, and cytotoxic activity	[308]
	Ag-NPs	DSC, ZP, AFM, XRD, and FTIR	100 ml of 1 mM of silver nitrate solution with ethanol extract of turmeric rhizome	Cytotoxic activity	[313]
	Ag-NPs	TEM, UV–visible spectrophotometer, and SEM	10 µl of $AgNO_3$ solution with turmeric extract	Cytotoxic activity	[847]
	Ag-NPs	XRD, SEM, UV–visible spectroscopy, FTIR, and HPLC	Green synthesis	Antimicrobial effect	[315]
	Silver-curcumin nanoconjugates (Ag-CurNCs)	UV irradiation	Green synthesis	Cytotoxic activity, antibacterial, and photostability evaluation	[7]
	Curcumin NPs	TEM, UV spectra, SEM, and DLS	1 mL of dichloromethane and curcumin solution	MIC value, zone of inhibition evaluation	[150]
	Au-NPs	FTIR, UV–Vis spectroscopy, and TEM	Green synthesis	Cytotoxic activity, and stability evaluation	[886]
	Magnetic NPs	HRTEM, Mossbauer spectroscopy, FTIR spectroscopy, XRD, and magnetization measurement	$NaBH_4$ solution in ammonia with turmeric rhizomes	NA	[297]
	Polymeric NPs	DLS, FTIR, and TEM	Curcumin–nanocurcumin with micellar aggregates of cross-linked and random copolymers of N-isopropyl acrylamide and N-vinyl-2-pyrrolidone and poly-monoacrylate	Cancer treatment	[154]
	Silk fibroin NPs (SFNs)	ZP, DLS, FESEM, TEM, ATR-FTIR, fluorescence spectroscopy, and UV–Vis spectrophotometric	SF-ionic liquid solution with curcumin	Free radical scavenging activity, and cytotoxic activity	[613]
	Nano silver	XRD, DLS, SEM, EDX, and TEM	Green synthesis	Antibacterial activity	[272]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	InP/ZnS quantum dots embedded mesoporous NPs	GC–MS, and CLSM	InP/ZnS quantum dots with turmeric crude extract	NA	[376]
	Nanocurcumin	TEM, DLS, and SLS	Ethanolic extract of curcumin powder solution	Antimicrobial effect	[833]
	Ag-NPs	TEM, UV–vis spectroscopy, FTIR, SEM, and EDS	Green synthesis	Antibacterial effect	[62]
	Biopolymer core–shell NPs	DSC, and FTIR	Curcumin with hydrophobic protein like zein and hydrophilic polysaccharide like pectin	NA	[375, 377]
	Curcumin NPs	PL, IR, FL, FTIR and FE-SEM	Polymer solution with ethanol solution of curcumin	Anti-carcinogenic effect	[348]
	Ag-NPs	UV–Vis spectroscopy	Extracellular biosynthesis	Antimicrobial effect	[608]
	Nano-encapsulated curcuminoids	Photoacoustic spectroscopy (PAS)	Polyvinyl pyrrolidone with curcuminoids	Anti-inflammatory activity, oxidative stress evaluation	[534]
	Goldmag NPs (CD-GMNs)	XRD, FTIR, TGA, DLS, TEM, and VSM	Hydroxypropyl-β-cyclodextrin with turmeric	NA	[526]
	Polymeric NPs	Liquid chromatography-tandem mass spectrometry (LC–MS/MS)	N-isopropyl acrylamide, acrylic acid, vinylpyrrolidone with curcumin solution	Tumor, and metastases treatment	[153]
	Garlic, turmeric, and zedoary NPs	SEM	Garlic, turmeric, and zedoary added to the water	Antibiotic, and antibacterial activities	[355]
	PLA-TPGS NPs	DLS, FTIR, UV–vis spectrophotometer and FESEM	100 ml water solution of copolymer PLA-TPGS with 10 mg of curcumin	NA	[651]
	Cu-NPs	TEM, FTIR, SEM, and XRD	Copper solution with curcumin	Antifungal activity	[811]
	Ag-NPs	UV–visible spectroscopy	90 mL of 1 mM silver nitrate distilled water with turmeric EO	Anti-inflammatory effect	[223]
	Poly-l-lysine mediated NP	Fluorescence microscope	Silica, trisodium citrate solution with curcumin	NA	[692]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Au-NPs	FTIR, UV–Visible spectroscopy, and TEM	Rapid bio-synthesis	Radical scavenging activity, TPC, and TFC	[246]
	Chitosan phosphate NPs	TEM, and DLS	6 g of orthophosphoric acid, 2 g of chitosan powder, 100 mL of 2% of acetic acid solution with curcumin solution	Antimicrobial effect, and cyto-toxic activity	[236]
	ZnO-NPs	UV–visible spectroscopy, FTIR, XRD, and electron microscopy	Green synthesis	Antioxidant potential, anti-carcinogenic effect, trypan blue dye exclusion evaluation, MTT, LDH leakage analysis, colony developing, nitrite assessment, and caspase effects	[393]
	Ag-NPs	Fluorescence life time, UV–Vis-ible absorption spectroscopy, and fluorescence emission spectroscopy	Ag solution with curcumin dye solution	NA	[291]
	ZnO-NPs	TEM, and XRD	Zinc solution with turmeric rhizome	Antibacterial effect, antifungal effect, antioxidant potential, and hydrogen peroxide evaluation	[392]
	Curcuma longa NPs	FTIR, XRD, SEM, and PL	Turmeric powder	Physicochemical, morphological, and optical parameters	[71]
	Nanocurcumin	TEM, FTIR, and SEM	*Myristica acid,* chitosan solution with curcumin	Cell viability	[466]
	Ag-NPs	FESEM, UV–Vis spectroscopy, PXRD, HRTEM, SAED, and ZP	Rapid green synthesis	NA	[452]
	Curcumin PLGA-encapsulated NPs	ZP, SEM, XRD, and DSC	50 mg of PLGA with 5 mg of curcumin	Anti-plasmodial, toxicity evalua-tion, and cytotoxic activity	[167]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Ag-NPs	UV–vis absorption spectrum, SEM, TEM, FTIR, X-ray photo-electron spectrometer, and DLS	10 mM $AgNO_3$ solution with 250 µl of 20 mM curcumin	Antiviral effect	[996]
	Apotransferrin NPs	Electron and atomic force microscopy, SEM, and TEM	10 mg of apotransferrin in 100 µl of phosphate-buffered saline with 3.6 mg of curcumin	HIV-1 neutralization	[306]
	Au-NPs	UV–Vis spectroscopy, TEM, and DLS	Green synthesis	Anti-carcinogenic activity, cytotoxic activity, and anti-tumor effect	[273]
	Alginate-chitosan-pluronic composite NPs	SEM, AFM, and FTIR	Pluronic, alginate, chitosan with curcumin	Cytotoxic activity	[225]
	Niosomes NPs	TEM, and DLS	Niosomes solution with curcumin	Physical attributes, encapsulation efficiency, and drug release	[659]
	Ag-NPs	TLC, and HPLC	Silver salts with ethanol extract of turmeric rhizome	Anti-carcinogenic effect	[365]
	Ag-NPs	UV–Vis spectroscopy	Bio-synthesis	Antifungal activity	[1019]
	Curcumin niosomal NPs	ZP, PCS, and FTIR	Cholesterol, tween 60, span 60 with 50 mg of curcumin	NA	[1020]
	Au-NPs	UV–visible spectrophotometer	Bio-synthesis	TPC	[247]
	Curcumin loaded chitosan-alginate-sTPP NPs	AFM, and FESEM	Ultrasonic-mediated synthesis	Adsorption isotherm evaluation, cell culture analysis	[26]
	Chitosan NPs	PCS, and DLS	Chitosan solution with curcumin	Stability, and hemocompatibility evaluation	[960]
	Ag-NPs	TEM, and DLS	Green synthesis	Human pterygium-derived keratinocytes treatment	[890]
	Silica NPs	N_2adsorption-desorption measurement, TEM, SEM, TGA, XRD,IR, FTIR, ZP, and DLS	PEGylated KIT-6 suspension with curcumin solution	Cytotoxic activity, and apoptosis evaluation	[546]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	PEG-albumin-curcumin NPs	FTIR, SEM, ZP, and DSC	Polymeric solution with curcumin	Breast cancer treatment	[927]
	Cassava starch NPs	DSC, TEM, FTIR, SEM, XRD, and fluorescence spectra	5 g of cassava starch solution with curcumin	DPPH, cytotoxic activity, and cellular absorption evaluation	[96]
	Au-nonaspheres	FTIR, UV–VIS spectrophotometer, and TEM	500 µl of 10 mM of Au solution with 46 mg of curcumin	Cytotoxic activity, superoxide anion development evaluation, nitric oxide release, MPO release analysis, SOD, GSH, and catalase assessment	[860, 862]
	ZnO-NPs, and Ag-NPs	UV–VIS spectrophotometry, FTIR, XRD, SEM, TEM, fluorescence spectra, DLS, ZP, EDX, and HRTEM	Zinc chloride solution, $AgNO_3$ solution with curcumin solution	Antibacterial activity	[913]
	Ag-NPs	EDS, UV–visible spectrum, SEM, zeta sizer, FTIR, and TEM	Green synthesis	Antibacterial activity	[48]
	Ag-NPs	TEM, UV–visible spectroscopy, DLS, EDX, XRD, ZP, FESEM,EDAX, and FTIR	Green synthesis	Cytotoxic activity	[629]
	Poly-magnetic FeO-NPs	TEM	Polymer templated iron oxide solution with curcumin	Morphogenesis, and synergistic free radical scavenging activity	[478]
	Polycaprolactone (PCL) NPs	DSC, HPLC, and ZP	PCL solution with curcumin	NA	[936]
	Curcumin NPs	ESEM	Curcumin	Anticarcinogenic effect, and antibacterial activity	[15]
	Silica NPs	FTIR, XRD, UV–visible, HPLC, TEM, XRF, XRD, and AFM	40 g of rice husk with turmeric powder	Anti-carcinogenic effect	[763]
	Ag-NPs	HPLC, tandem mass spectra	Pulse with dried rhizome of turmeric	Anti-carcinogenic activity	[602]
	Ag-NPs	UV absorption spectrometry, SEM, TEM, spectrofluorimetry, and Z scan	$AgNO_3$ solution with curcumin	NA	[245]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Ag-NPs	TEM, and UV–visible absorption spectroscopy	75 ml of 1 mM of silver nitrate solution with 10 mM of curcumin	Antibacterial effect	[249]
	Au-NPs	Surface plasmon resonance spectrum, and SEM	Green synthesis	Nucleic acid evaluation	[691]
	Au-NPs	FTIR, UV–visible spectroscopy, and TEM	PVP with curcumin	Cytotoxic activity	[929]
	Starch NPs	TEM, SEM, UV–Vis spectrophotometer, and LSM	Starch solution with curcumin	Swelling evaluation	[198]
	Silver/silver chloride NPs	XRD, UV–vis, FTIR, SANS, SAXS, AFM, SEM, ZP, SAS, and EDS	Green synthesis	Antioxidant potential, antibacterial activity, cell viability, and hemocompatibility	[128]
	Curcumin-PBCANPs	TEM, DLS, ZP, fluorescence spectra, and HPLC	Chitosan solution, PBCA solution with curcumin	Anti-tumor activity	[262]
	PLGA-PEG-Fe3O4 NPs	VSM, SEM, and FTIR	Fe_3O_4 and curcumin encapsulated in PLGA-PEG co-polymer	Cytotoxic activity	[775]
	Au-NPs	TEM, and UV–Vis	100 mL of miliq water solution with curcumin	Antimicrobial effect	[210]
	Polymeric NPs	SEM, UV–vis, and ZP	PVA solution with curcumin	Cellular toxicity evaluation	[779]
	Ag-NPs	FTIR, XRD, and SEM	Silver nitrate solution with curcumin	NA	[18]
	Chitosan tripolyphosphate NPs	ZP, PCS, AFM, TEM, FTIR, and UV spectrophotometer	TPP salt with curcumin	Antibiotic activity	[396]
	Fluorescent carbon dots	Fluorescence spectra, UV–spectrophotometer, TEM, and FTIR	Facile synthesis	NA	[848]
	Nitrogen-doped fluorescence carbon dots	Fluorescence spectra, TEM, XPS, XRD, UV–vis absorption spectra, and FTIR	Nitrogen-doped carbon dots powder with curcumin	NA	[916]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Carbon nanodots	TEM, FTIR, EDAX and FESEM	Carbon soot with turmeric rhizome	Antibacterial activity, cell compatibility, and anti-carcinogenic effect	[206]
	Curcumin quantum dots	CLSM, TEM, SEM, UV–VIS, fluorescence, Raman spectroscopy, and ZP	60 g of zirconia beads with curcumin solution	Antibiofilm effect	[860, 862]
	Curcumin quantum dots	TEM, and DLS	Curcumin quantum dots solution	Antimicrobial activity	[764]
Bay leaves	FeO-NPs	XRD, UV–Visible, FTIR, SEM, TEM, and EDS	Green synthesis	Antimicrobial effect	[401]
	ZnO-NPs	XRD, UV–Vis spectroscopy, FTIR, TEM, SEM, and EDX	Green synthesis	Antibacterial effect, cytotoxic activity	[968]
	TiO_2-NPs	FTIR, UV–visible absorption spectroscopy, XRD, SEM, particle size, and ZP	Green synthesis	Antimicrobial effect, and antioxidant activity	[738]
	Zirconia NPs	XRD, UV–visible absorption spectrophotometer, FTIR, SEM, and DLS	Green biogenic synthesis	Antimicrobial activity	[191]
	Ag-NPs	XRD, UV–Visible spectroscopy, FTIR, SEM, and TEM	Green synthesis	TPC, TFC, and radical scavenging activity	[433]
	CuO-NPs	UV–vis spectroscopy, FTIR, SEM, and TEM	Green synthesis	Antioxidant activity, antibacterial effect, and dye decolorization capacity	[166]
	Ag-NPs	XRD, UV–visible spectroscopy, FTIR, SEM–EDX, and TEM	Green synthesis	Antimicrobial effect, and catalytic effect	[43]
	PLGA-NPs	SEM, UV–Vis spectrometry, DLS, and ZP	Polylactic-co-glycolic acid solution with bay leaves EO	Cancer treatment	[280]
	Ag-NPs	UV–Visible spectroscopy, SEM, ZSP, and FTIR	Green synthesis	Antimicrobial activity	[103]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
Saffron	Au-NPs	UV–vis spectroscopy, FTIR, SEM, EDX, AFM, and XRD	Green synthesis	Catalytic effect, antibacterial effect, enzyme retardation effect, sedative effect, carrageenan-induced paw edema evaluation, and severe toxicity analysis	[58]
	ZnO-NPs, and CuO-NPs	UV–visible spectroscopy, SEM, XRD, EDS, and FTIR	Green synthesis	NA	[846]
	Ag-NPs	XRD, UV–vis spectrum, HRTEM, and FTIR	Green synthesis	Antibacterial activity	[115]
	Exogenous calcium NP	HPLC	Copper sulfate fungicide + acaricide with saffron	TFC, and antioxidant enzyme activity	[111]
	Ag-NPs	FESEM, UV–Vis, and FTIR	Green synthesis	Antibacterial effect	[1021]
	Ag-NPs	XRD, FESEM, EDX, and FTIR	Green synthesis	Antimicrobial effect	[462]
	Ag-NPs, and Au-NPs	XRD, UV–Vis spectroscopy, and TEM	Phyto-synthesis	NA	[105]
	Nano-bimetallic Ag/Pt alloy	Electron microscopy, UV–visible, infrared spectroscopy, FTIR, and XRD	Bio-synthesis	Antioxidant activity, antimicrobial, cytotoxic activity, and catalytic effect	[995]
	FeO-NPs	EDX, UV–visible spectroscopy, FTIR, XRD, and SEM	Biogenic synthesis	Antifungal activity	[54]
	Chitosan NPs	SEM, FTIR, XRD, WAXD, and DLS	Chitosan solution with water extract of saffron	Cytotoxic activity	[657]
	Nano-silica	HPLC	2 mM of silica solution with corms of saffron	Antioxidant enzymes evaluation	[920]
	Chitosan-gum Arabic complex nanocarriers	FTIR, XRD, TEM, and ZP	Chitosan, gum Arabic solution with saffron extract	NA	[731]
	Cu-NPs	ZP, UV–visible absorption spectroscopy, particle size, FTIR, and electron microscope	Cu solution with ethanolic extract of saffron	Oxidative stress, and antioxidant activity	[97]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
Star anise	Ag-NPs	XRD, UV–Vis, FTIR, SEM, TEM, AFM, and particle size distribution	Green synthesis	Anti-diatom effect	[510]
	Ag-NPs	XRD, TEM, SAED, EDS, UV–visible absorption spectra, FTIR, and Raman spectroscopy	Silver nitrate solution with star anise seed extract	NA	[544]
	PLGA-NPs	TEM, and SEM	Polylactic-co-glycolic acid with star anise	NA	[504]
Onion	Ag-NPs	TEM, UV–vis spectroscopy, and SEM	Green synthesis	NA	[364]
	Ag-NPs	UV–Vis spectral, EDS, and FTIR	Green synthesis	Cytotoxic activity	[646]
	ZnO-NPs	TEM, and SEM	ZnO solution with onion root	NA	[502]
	Au-NPs, and Ag-NPs	TEM, UV–Vis spectrophotometer, SEM–EDX, and XRD	$AgNO_3$, and Au solution with dried onion root	NA	[233]
	Ag-NPs	ZP, TEM, DLS, LIBS, and ICP/OES	Silver solution with onion root	Cytotoxic, and genotoxic activities	[814]
	Ag-NPs	TEM, AFM, XRD, and FTIR	Biogenic synthesis	NA	[777]
	Cu-NPs	UV–Visible spectrum, ZP, TEM, and SAED	Bioinspired synthesis	NA	[635]
	Ag-NPs	UV–visible spectrophotometer, FTIR, TEM, and EDX	Green synthesis	NA	[998]
	Al_2O_3-NPs	FTIR, and CLSM	Al_2O_3 solution with onion root	Oxidative stress evaluation	[734]
	Cr_2O_3-NPs	CLSM	The water solution of Cr_2O_3 with onion root	Cytogenetic evaluation	[499]
	WO_3-NPs	EDX, and TEM	Tungsten solution with onion	Cytotoxic activity, and genotoxic evaluation	[535]
	Ag-NPs	TEM	Silver ions, PVP with onion root	Cytological evaluation	[300]
	Ag-NPs	TEM, ZP, UV–vis	200 mg/mL of the silver ion with onion root	Antioxidant activity, and LPO evaluation	[177]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	MgO-NPs	TEM, FESEM, DLS, and LDV	MgO solution with onion bulbs	ROS, H_2O_2 evaluation, hydroxyl radical, and lipid peroxidation analysis	[571]
	Au-NPs	TEM, UV–Vis spectroscopy, XRD, and SEM	Green synthesis	NA	[682]
	Au-nanorods	ZP, and electron microscopic	Au capped with CTAB or PEG, and onion	Cytogenetic analysis	
	Zn-NPs, and Ag-NPs	EDX, UV–vis spectra, TEM, particle size, PDI, and ZP	Silver ion, Zn solution with onion root tip	Genotoxicity evaluation	[9]
	Au-NPs	DLS, and TEM	Au solution with onion root	Toxicity analysis	[735, 736]
	TiO_2-NPs	Optical, fluorescence, and confocal laser scanning microscopy	12.5, 25, 50, and 100 µg/mL of TiO_2 solution with onion root tip	Genotoxicity evaluation	[674]
	ZnO-NPs	UV–visible, XRD, FTIR, SEM–EDX and TEM	ZnO solution, ZnO bulk, zinc ions with onion root	NA	[28]
	TiO_2-NPs, and ZnO-NPs	TEM, DLS, and LDV	$TiO_{2,}$ ZnO solution with onion root	Cell viability evaluation	[237]
	Chitosan capped Ag-NPs	AFM, and SEM	Chitosan coated $AgNO_3$ solution with onion bulbs	NA	[699]
	ZnO-NPs	TEM, and ZP	Stock solution with onion bulbs	Cytotoxic activity, ROS generation, and genotoxicity evaluation	[900]
	Ag-NPs	FTIR, SEM/EDS, AFM, and ZP	Green synthesis	Anti-corrosion activity	[391]
	ZnO-NPs	FTIR, DLS, and FESEM	Green synthesis	Phytotoxicity evaluation	[604]
	TiO_2-NPs, Al_2O_3-NPs, and CuO-NPs	UV–visible spectrophotometer, FTIR, XRD, SEM, EDX, and TEM	CuO, $Al_2O_{3,}$ TiO_2 solution with onion bulbs	Superoxide radicals, ROS formation, and SOD, CAT activities evaluation	[29]
	Ag-NPs	TEM	Ag stock solution with onion bulbs	Cytological, comet evaluation, lipid peroxidation, and hydrogen peroxide analysis	[350]
	Ag-NPs	SEM	Green synthesis	NA	[740]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	ZnO-NPs	UV–visible spectroscopy, XRD, FTIR, TEM, SEM, and EDAX	90 ml of 1 mM zinc nitrate solution with onion bulbs extract	Cell viability, antioxidant activity, and TBARS evaluation	[988]
	Ag-NPs	UV–Visible spectra, FTIR, and SEM	Rapid green synthesis	Antioxidant machinery evaluation	[874]
	Ag-NPs	UV–Vis spectroscopy, and XRD	Green synthesis	NA	[796]
	Ag-NPs	FTIR, DLS, XRD, TEM, SAED, XPS, and UV–VIS	Green synthesis	Antibacterial, and cytotoxic activity	[834]
	Ag-NPs	UV–Visible spectroscopy, FTIR, and SEM	Green synthesis	Antioxidant potential, cell viability, and physical stability evaluation	[8]
Dill	Chitosan nanomatrix	SEM, XRD, and FTIR	1.5 g of chitosan solution with dill seed EO	TPC, and phytotoxicity evaluation	[226]
	Nanosilver	UV–visible spectroscopy, XRD, FTIR, and SEM	Green synthesis	NA	[595]
Fenugreek	Au-NPs	UV–Visible spectroscopy, TEM, XRD, FTIR, and SAED	Green synthesis	Catalytic effect	[95]
	Ag-NPs	UV–vis spectroscopy, and SEM	Biogenic synthesis	Photocatalytic, and antibacterial effect	[100]
	Fe-NPs	UV–visible spectrometry, XRD, TGA/DTG, FTIR, and TEM	Bio-synthesis	Photocatalytic methyl orange dye degradation, and antibacterial activity	[722]
	TiO_2-NPs	FTIR, UV, XRD, HRTEM, XRD, and HRSEM	Green synthesis	Antimicrobial activity	[896]
	ZnO-NPs	UV–Vis spectroscopy, UV–Visible diffuse reflectance spectroscopy, FTIR, XRD, SEM, PL, and EDX	Bio-synthesis	Photocatalytic activity	[63]
	Ag-NPs	UV–Vis spectroscopy, FTIR, SEM, HRTEM, and EDS	Bio-synthesis	NA	[404]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Au-NPs	UV–Vis spectra, fluorescence, DLS, and TEM	2.5 mg of $HAuCl_4$ with water extract of fenugreek seed	Antioxidant activity	[324]
	Lanthanum NPs	SEM, and FTIR	Green synthesis	NA	[184]
	Ag-NPs	UV–VIS spectra, SEM, and XRD	1 mM $AgNO_3$ solution with aqueous extract of fenugreek seed	Antimicrobial activity	[708]
	Ag-NPs, and Au-NPs	TEM, and SEM	Green synthesis	Anti-diabetic effect	[974]
	Au-NPs	UV–Vis spectra, fluorescence, DLS, and TEM	Green synthesis	NA	[1000]
	ZnO-NPs	DLS, XRD, FTIR, SEM, and TEM	50 mL of NH_4OH solution with fenugreek seed	NA	[192]
	SnO_2-NPs	XRD, SEM, TEM, FTIR, and UV–Visible spectrometer	Biogenic synthesis	Photocatalytic, and antimicrobial effect	[339]
	MnO-NPs	SEM, XRD, TEM, FTIR, EDX, and UV–Vis spectroscopy	Green synthesis	NA	[765]
	Organic–inorganic hybrid nano-flower	SEM, XRD, EDX, and FTIR	Green synthesis	Antimicrobial potential	[66]
	Fe-NPs, and Ag-NPs	TEM, XRD, EDX, and FTIR	Green synthesis	Antibacterial, and antioxidant potential	[241]
	Ag-NPs	TLC, and HPLC	Aqueous $AgNO_3$ solution with methanolic extract of fenugreek seed	TFC, metal chelating evaluation, FRAP, α-amylase inhibition analysis, anti-inflammatory effect, antimicrobial activity assessment	[255]
	Au-NPs	UV–Vis spectrophotometry, and SEM	Bio-synthesis	NA	[302]
	Fe-NPs	XRD, TEM, UV–Visible spectroscopy, and FTIR	Green synthesis	NA	[78]
	ZnO-NPs	XRD, and TEM	Zinc acetate, citric acid with fenugreek seed	Seed germination, and seedling growth evaluation	[855]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Ag-NPs	XRD, UV–Vis spectra, FTIR, and SEM	$AgNO_3$ solution with water extract of fenugreek seed	Optical parameters evaluation	[588]
	Ag-NPs	XRD, and SEM	Green synthesis	Antibacterial activity	[31]
	Magnetic Fe-NPs	XRD, FTIR, SEM, and EDX	Green synthesis	NA	[883]
	Au-NPs	UV–Vis spectrophotometry, EDX, XRD, and FTIR	Bio-synthesis	NA	[301]
	Nano-hydroxyapatite chitosan	SEM	Chitosan solution with fenugreek seed polysaccharide	Bone tissue engineering evaluation	[1018]
	Lanthanum NPs	FTIR and SEM	100 mg/ml of lanthanum solution with fenugreek seed extract	Osteosarcoma treatment	[219]
	Pd-NPs	SAED, UV–Visible spectroscopy, SEM, FTIR, and XRD	Green synthesis	Catalytic activity	[565]
	Ag-NPs	Particle size analyzer, UV–Visible spectroscopy, and XRD	Green synthesis	NA	[215]
	TiO_2-NPs	XRD	TiO_2 solution with alcoholic extract of fenugreek seed	NA	[358]
	Ag-NPs	SEM	Green synthesis	Antifungal activity	[277]
	Au-NPs	XRD, fluorescence spectra, SEM, TEM, EDAX, and FTIR	Facile green synthesis	NA	[79]
	Ag-NPs	FTIR, UV–Visible spectroscopy, and TEM	Green synthesis	Antibacterial, and antifungal effects	[69]
	ZnO-NPs	XRD, SEM, EDX, UV–V spectroscopy, and TEM	Biogenic synthesis	Anti-tumor capacity evaluation	[723]
	Nanosized TiO_2	DLS, FTIR, and infrared spectra	6 µL of TiO_2 stock suspension with fenugreek seed powder	NA	[600]
	Ag-NPs	XRD, and HRTEM	Green synthesis	NA	[380]
	Se-NPs	TEM, DLS, and FTIR	1 mM of selenium dioxide with water extract of fenugreek seed	Tumoricidal activity evaluation	[267]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
	Au–Pd bimetallic NPs	UV–Vis, SEM, TEM, XRD, XPS, and FTIR	Green synthesis	Catalytic evaluation	[566]
	ZnO-NPs, Pd-NPs, Cd-NPs, Ni-NPs, and Ag-NPs	EDS, UV, SEM, and FTIR	Green synthesis	Antimicrobial activity	[1007]
	Au-NPs	UV–Vis absorption spectroscopy, FTIR, and SEM	Green synthesis	NA	[276]
	Carbon quantum dots	SEM, UV–Vis absorption spectroscopy, TEM, TLC, Raman spectroscopy, EDS, FTIR, and XRP	Ultrafast synthesis	NA	[213]
	Nanosized TiO_2	XRD, FTIR, and SEM	Photo-synthesis	Seedling growth, biomass, TFC evaluation, TPC, total soluble protein content analysis, antioxidant enzyme activity, and lipid peroxidation assessment	[601]
	Carbon nanodots	Fluorescence spectroscopy, and CFM	Carbon synthesis	NA	[978]
	CeO_2-NPs	SEM, XRD, FTIR, TEM, Raman spectroscopy, and XRP	Sol–gel solution with fenugreek extract	Fluorescence sensing of picric acid evaluation	[759]
	Au-NPs	TEM	Au solution with fenugreek hydrogel-agarose matrix	Carbamates evaluation	[440]
	Graphene quantum dots	FTIR, SEM, AFM, and fluorescence microscopy	Fenugreek β-amylase with aminopropyltriethoxysilane, and glutaraldehyde	Biochemical, thermodynamic, and kinetic evaluation	[23]
Asafoetida	Ag-NPs	FTIR, and TEM	Bio-synthesis	NA	[793]
	Ag-NPs	SEM, FTIR, and XRD	Green synthesis	Larvicidal effect	[804]
	Ag-NPs	EDX, FESEM, XRD, UV–visible spectroscopy, and FTIR	Green synthesis	Antibacterial activity	[11]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
Chili	Ag-NPs	TEM, UV–Vis spectroscopy, SEM, EDX, XRD, and FTIR	0.1 M silver nitrate solution with water extract of chili, garlic, and ginger	Antimicrobial activity, and antioxidant activity	[668]
Allspice	Au-NPs	TEM, UV–Vis absorption spectroscopy, FTIR, and XRD	Green synthesis	Antibacterial activity, photocatalyst, and antioxidant activity evaluation	[288]
	Ag-NPs	AFM, UV–Vis spectroscopy	Green synthesis	NA	[317]
	CuO-NPs	XRD, UV–Visible, FTIR, SEM–EDS, TEM, and TGA-DTA	Green synthesis	Cytotoxicity, anti-carcinogenic activity, antioxidant potential, and anti-diabetic effect evaluation	[703]
	Au-NPs	FTIR, XRD, UV–Vis absorption spectroscopy, Raman spectroscopy, and electron microscopy	Green synthesis	NA	[457]
	Ag-NPs	UV–visible spectroscopy, XRD, SEM, TEM, EDX, GC–MS, FTIR and LC–MS	Green synthesis	Larvicidal activity evaluation	[495, 498]
Kokam	Ag-NPs	FESEM, UV–vis absorption spectroscopy, FTIR, EDS, XRD, TEM, and SAED	Biogenic synthesis	Antioxidant, and antibacterial effect	[792]
	Au-NPs	UV–Vis spectroscopy, XRD, FESEM, and FTIR	Bio-synthesis	NA	[488]
	Au-NPs	TEM, UV–spectroscopy, and SEM	Biogenic synthesis	Anti-carcinogenic effect	[132]
	Au-NPs	FTIR, UV–visible spectroscopy, EDS, XRD, SAED, and TEM	Green synthesis	Antioxidant potential, photoluminescent, and photocatalytic effect evaluation	[240]
	Ag-NPs	UV–visible spectroscopy, FTIR, XRD, and TEM	Phytobiological synthesis	Antibacterial activity	[905]
	Au-NPs	UV–Vis spectroscopy, and FESEM	Au solution with kokum fruit extract	NA	[489]

Table 5 (continued)

Spices	NP synthesized	Characterization	NP synthesis technique used	Application	Reference
Greater galangal	Ag-NPs	XRD, FTIR, UV–vis spectroscopy, SEM, TEM, SAED, and EDX	Bio-synthesis	Antibacterial effect	[384]
Sweet flag	BFNPs	XRD, SEM, Raman spectroscopy, and IR	Green synthesis	Antifungal activity	[928]
	Au-NPs	UV–Visible spectral, XRD, FTIR, SEM, HRTEM, and EDAX	Green synthesis	UV-blocking and antibacterial activity	[307]
	ZnONPs	XRD, SEM, and FTIR	Green synthesis	Antioxidant activity	[717]
	CeO_2-NPs	Confocal, light, and electron microscopy	Green synthesis	Antibiofilm effect	[64]
	ZnONPs	EDX, UV spectrophotometer, SEM, FTIR, and TEM	1 mM of zinc acetate solution with aqueous extract of sweet flag	Antimicrobial effect, and cytotoxic activity	[954]
	Ag-NPs	UV–Visible spectra	1 mm of $AgNO_3$ solution with methanolic extract of *Agaricus bisporus,* and sweet flag rhizome	Antibacterial activity	[704]
	Cu-NPs	FTIR, UV–Visible absorption spectrometer, SEM, and TEM	Green synthesis	NA	[869]
	Ag-NPs	TEM, FESEM, EDAX, and FTIR	Green synthesis	Antibacterial activity, and cytotoxic activity	[10]
	Ag-NPs	TEM, UV spectrophotometer, and SEM	Green synthesis	Antioxidant potential	[705]
	Au-NPs	UV spectroscopic, FTIR, SEM, and TEM	3 mM of gold chloride solution with water extract of sweet flag	Antimicrobial activity	[820]
	Ag-NPs	DLS, UV–visible spectroscopy, SEM, EDX, and FTIR	Green synthesis	Antioxidant activity, antibacterial effect, and cytotoxic activity	[637]
	ZnO-NPs	UV–visible spectrophotometric	Biogenical synthesis	Sun protection factor evaluation	[299]
	Hydroxyapatite NPs	TEM, XRD, SEM, and HRTEM	0.6 M Na_2HPO_4, 1 M $CaCl_2$ with water extract of sweet flag rhizome	Anti-acetylcholinesterase retardation, computational pharmacokinetics evaluation	[711]

Nutmeg seed and bark were cleaned continuously with deionized water, dried, and powdered. For biosynthesis of silver nanoparticles, 1 mM of silver nitrate solution has been mixed with 10 g of nutmeg seed powder, which has been done to evaluate the antibacterial activity of AgNPs [408]

Water extract obtained from 5 g of black mustard seed has been mixed with 1 mM of silver nitrate solution. The AgNPs have been evaluated for its antimicrobial effect [680]

$AgNO_3$ solution has been added to turmeric powder to prepare AgNPs and then the AgNPs have been evaluated for its antibacterial effect [943]. 10 ml of curcumin extract has been added to 100 ml of 1 mM silver nitrate to synthesize yellow to yellowish-brown color silver nanoparticles. The nanoparticles have been evaluated for its cytotoxic activity [313]. 6.8 g of curcumin powder or organic turmeric powder has been added to 100 mL of Milli-Q water to make water extract of turmeric powder. To synthesize AgNPs, 2 mL of aqueous extract of turmeric powder has been added to 8 mL of 1 mM $AgNO_3$ solution. The AgNPs have been evaluated for its antibacterial effect [62]. To prepare AgNPs, 1 mM of silver nitrate has been mixed with turmeric rhizome extract. The nanoparticles have been evaluated for its antimicrobial effects [608]. 250 μL of 20 mM curcumin has been dissolved in DMSO, and 2.5 mL $AgNO_3$ to synthesize cAgNPs. The cAgNPs have been evaluated for its antiviral activities [996]. To decrease the curcumin particle size, the filtrate was sonicated in ultrasonicator at 20 kHz frequency for around 20 min. To prepare silver nanoparticles, 20 g of the turmeric powder has been mixed with silver salts. The synthesized AgNPs has been estimated for its anti-carcinogenic effect of AgNPs [365]. Curcumin solution has been added to 75 ml of 1 mM of silver nitrate solution to synthesize AgNPs to observe its antibacterial effect [249]. 1 mL of turmeric extract has been added to 100 mL of 1 mM $AgNO_3$ water solution to produce AgNPs, which have been evaluated for their antioxidant potential, antibacterial activity, cell viability, and hemocompatibility [128]

10 mL of the water extract of bay leaves has been mixed with 50 mL solution of $AgNO_3$ to prepare AgNPs. The AgNPs have been analyzed for its radical scavenging activity [433]

1 mM $AgNO_3$ has been added to 10 ml of the water extract of fenugreek seed to prepare silver nanoparticles, and its antimicrobial activity has been measured [708]

Selenium Nanoparticles 173 mg of sodium selenite salt has been homogenized in 90 mL of deionized water. The mixture has been mixed with 10 mL of fennel seed extract to synthesize 100 mL of selenium nanoparticles to observe its toxicity, and the capability to prevent arthritis [84]

Water extract of fenugreek seed has been added with 1 mM selenium dioxide solution to synthesize SeNPs. The SeNPs have been evaluated for their tumoricidal activity [267]

Carbon Dots Nanoparticles

0.5 g of fine clove powder has been dissolved in 30 mL of water (hydrothermal synthesis) to synthesize carbon dot nanoparticles. The nanoparticles have been evaluated for its antioxidant effect, catalytic, and cytotoxicity effect [495, 498]

Quantum Dot Nanoparticles

600 mg of curcumin has been added to 10 g of zirconia beads in 15 ml of ethanol to synthesis curcumin quantum dots and then tested it for its antimicrobial activity [764]

Fennel seed has been passed through single-step thermal decomposition method to prepare mono-disperse carbon quantum dots. The quantum dots have been analyzed for its photoluminescence [214]

To synthesize graphene quantum dots, fenugreek β-amylase, glutaraldehyde, and aminopropyltriethoxysilane have been used. The graphene quantum dots have been assessed for its biochemical, thermodynamic, and kinetic properties [23]

Polymeric Nanoparticles

To synthesize gelatin nanoparticles, 200–500 mg of gelatin has been mixed with 150 g of cardamom powder. The gelatin nanoparticles have been evaluated to observe its capacity to prevent Glioblastoma disease [649]

The equal amounts of aqueous tripolyphosphate solution and chitosan solution have been added together to ethanol extract of 50 g of fennel seed to synthesize chitosan nanoparticles and then the nanoparticles are tested for its peroxide value, total volatile nitrogen, microbial activity, and sensory attributes [549]

To synthesize chitosan nanoparticles, the water extract of 30 g of clove has been mixed with 1 gm of chitosan solution. After that, 0.5 g of sodium tripolyphosphate has been poured into the solution. The chitosan nanoparticles have been analyzed for its biochemical, and insecticidal effect [271]

2% of shellac powder has been mixed with ethanol extract of 10 g of cassia bark to synthesize colloidal nanoparticles and then the nanoparticles have been tested for its encapsulation efficiency, loading potential, TPC, antioxidant activity [623]. Ethanol extract of 100 g of oregano and cassia bark have been mixed with chitosan solution to synthesize core/shell nanoparticles and then the nanoparticles have been examined for its cytotoxic effect, and mitochondrial transmembrane capacity [423]

$NaBH_4$ solution has been mixed with turmeric powder to synthesize magnetic nanoparticles and then the nanoparticles have been tested for its capacity to obtain curcuminoids, and free phenolic acids [550]. To synthesize curcumin silk fibroin nanoparticles, 0.5 g of silk fibroin (SF) has been mixed with an SF-ionic liquid solution. The curcumin silk fibroin nanoparticles have been evaluated for its free radical scavenging activity and cytotoxic activity [613]. To synthesize nanocurcumin, ethanol extract of curcumin powder has been dissolved into water. The nanocurcumin has been assessed for its antimicrobial effect [833]. To prepare curcumin-loaded chitosan phosphate nanoparticles, the curcumin has been mixed with chitosan solution. The antimicrobial effect, and cytotoxic activity of curcumin-loaded chitosan phosphate nanoparticles have been analyzed [236]. To synthesize curcumin-encapsulated nanoparticles, chitosan solution, curcumin, and TPP have been mixed together. The curcumin-encapsulated nanoparticles have been measured for their stability and hemocompatibility [960]. 5 g of cassava starch has been mixed with 50 mL of 3.16 M sulphuric acid solution to produce starch nanoparticles. The cytotoxic activity, antioxidant activity, and cellular absorption of the synthesized nanoparticles have been observed [96]. To synthesize PBCANPs, 0.1% of chitosan has been dissolved in HCl,0.01% of curcumin powder and 100 μL of BCA monomer have been added to the solution. The PBCANPs have been evaluated for their anti-tumor activity [262]

Conclusion

Spices are gaining interest in terms of functional food formulation, as a source of new drug molecule, in biotechnological industries as a source of novel bioactive components and effective source of functional nanoparticles. Phenolic acids, flavonoids, organic acids, alkaloids, tannins, and health-beneficial pigments are found in spices abundantly. Synthetic antioxidants may possess detrimental health effect, which can be replaced with natural antioxidants that are present in different spices. The application of synthetic and costly antioxidants is reduced which provides health problems and toxicity. Spices are produced mostly in the economically backward countries or in the developing countries; therefore, it is obvious that spices are not only significant in terms of human health development, or in the field of biotechnology, it is also an aid to improve the economy of the countries. The 24 spices expressed in this article are achieving worth financially and improving the lifestyle of the stakeholders associated with the harvesting and post-harvest administration of the spices. In this article, 24 spices have been covered; it has been found that most of the spices have been explored for their bioactive, health-beneficial effects, and functional food development potential, whereas some of them are yet to be searched for their food fortification potential, e.g., sweet flag and galangal have not been explored for their food fortification potential. Most of the spices considered in this article are seasonal in nature. Therefore, adequate preservation methods need to be searched to overcome the issue of seasonal availability of spices described. Spices may be used for a source of natural food pigment. The inedible portions of the spices may be utilized as a source of natural colorant and novel bioactive compounds. Therefore, the wastage parts or inedible portions of the spices can be utilized as a source of natural pigment, and bioactive extraction. Carbon dot-, quantum dot-, metal-, and polymer-based nanoparticles are prepared with several spices like asafoetida, cardamom, black jeera, fennel, fenugreek, poppy, clove, turmeric, bay leaves, sweet flag, etc., using different methods such as green or biogenic synthesis. These nanoparticles possess different health-beneficial potentials like antioxidant, anti-carcinogenic, anti-diabetic, enzyme retardation effect, and antimicrobial activity. The nanoparticles have also been analyzed for their cytotoxic effect. The synthesized nanoparticles possess a significant role in environmental pollution management as some of the nanoparticles hold dye decolorization activity

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Declarations

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