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Review article

A review on antimicrobial activities of some culinary herbs and spices against *Staphylococcus aureus*

Didem Berber[*1], Orcun Toksoz[2], Ipek Turkmenoglu[2], Nuzhet Cenk Sesal[3]

[1] *Maltepe University, Fine and Arts Faculty, Gastronomy and Culinary Department, 34857, Istanbul, Türkiye*
[2] *Marmara University, Institute of Pure and Applied Sciences, Department of Biology, 34722, Istanbul, Türkiye*
[3] *Marmara University, Faculty of Arts and Sciences, Department of Biology, 34722, Istanbul, Türkiye*

Abstract

Food safety is of great importance all over the world as it concerns consumer health. All employees in the food chain must comply with the hygiene rules. One of the important issues that threaten food safety is contamination with microorganisms. Numerous people are affected by contaminated and/or poorly preserved food and outbreaks have occurred. The World Health Organization (WHO) draws attention to human health and economic losses in this respect. From ancient times, herbs and spices are utilized in Türkiye and various parts of world to enhance the flavor of food and their sensory properties. It is also possible to prevent the development of *Staphylococcus aureus*, which causes food poisoning, thanks to the antibacterial properties of culinary herbs or spices. Thus, using natural antimicrobial substances from spices and herbs may be an alternative for inhibition/elimination of growth of *S. aureus* extending the shelf life without synthetic preservatives. This review aims to explain foodborne diseases and their global burden, staphylococcal food poisoning, natural antimicrobials, some edible herbs in Türkiye: their culinary uses and antibacterial efficacy against *S. aureus.*

Keywords: *Antimicrobial; culinary herbs and spices; food poisoning; Staphylococcus aureus*

1. Introduction

The importance of foodborne diseases in terms of public health around the world has been emphasized in the literature. It is also known that the economic and social burden that arises especially for underdeveloped countries is remarkable when the morbidity and mortality rates are taken into account (Odeyemi, 2016; WHO, 2020, Pires et al., 2021). Different types of bacteria, viruses, parasites, prions, and fungi may cause foodborne diseases. Amongst them, bacteria have a major role in being the causative agent in foodborne diseases (Ishaq et al., 2021). As a result of burden assessments for foodborne diseases, the global importance of *Staphylococcus aureus* has been indicated (Fetsch and Johler, 2018). It is obvious that food safety should be handled carefully in the food chain from farm to table for human health (Sousa, 2008; Odeyemi, 2016). In this context, the standards ensure a strict controlling system with the traceability principle in every stage of food production. Unfortunately, developing countries face widespread food safety problems compared to industrialized countries. The reason for this can be explained simply by the use of traditional methods in marketing products (Sousa, 2008).

Staphylococcal intoxications are associated with enterotoxins, one of the virulence factors of this bacterium, which affect the digestive system of humans (CDC, 2018). The prevalence of food intoxication caused by *S. aureus* is reported to be at high rates worldwide (Fetsch and Johler, 2018). The relationship between *S. aureus* enterotoxins and food poisoning have been noted in individuals who ate a sponge cake infected with *S. aureus* and showed signs of food poisoning (Dack et al.,

[*] Corresponding author.
E-mail address: yazi47@hotmail.com (D. Berber).
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1930). Since then, there have been some food poisoning outbreaks caused by different foods depending on culturally eating habits that differ between countries (Hennekinne et al., 2012). 87% of vomiting cases by *S. aureus* outbreaks were reported in the U.S. between 1998 and 2008 (Bennet et al., 2013). In another study, *S. aureus* was detected in 102 of 971 food samples in Italy (Vitale et al., 2015).

Antimicrobials are of great importance in controlling foodborne diseases caused by bacteria. In this respect, various food preservatives are currently used. However, due to the fact that natural components are preferred by consumers as preservatives in foods in the sector and the need to find some alternative antimicrobials, the interest in herbs and spices, which have been used for centuries, has intensified (Bondi et al., 2017). Various spices and herbs have been used as flavoring, fragrant, and coloring agents in foods for centuries. Furthermore, in the respect of ethnobotanical importance, local people utilize spices and herbs in folk medicine. In various studies, medicinal properties such as antimicrobial, antioxidant, antidiabetic, and anti-inflammatory activities, etc. of these spices and herbs have been reported. They are frequently used for microbial control in food products, especially due to its antimicrobial properties on microorganisms (Chakraborty et al., 2020; Karakol and Kapi, 2021). In recent years, the use of natural preservatives has been increasing day by day due to the natural antimicrobial properties of herbs and spices compared to many synthetic antimicrobial substances used in the food industry. The plant itself, extracts, and essential oils obtained from plants show antimicrobial effects in food products and can extend the shelf life of foods (Gyawali and Ibrahim, 2014). Researchers are interested in herbs and spices to preserve foods and extend product shelf-life in the last decades. Various studies show that herbs and spices have the potential to be used in some food processing stages such as maintenance and ensuring shelf life, prevention of microbial degradation and oxidation reactions (Babuskin et al., 2014; Márquez-Rodríguez et al., 2020; Pérez-Santaescolástica et al., 2022). With the emergence of some new technologies, natural antimicrobial compounds from herbs or spices may be utilized alternatively in the food industry.

2. Foodborne diseases and their global burden

Since food is a remarkable vehicle for pathogens of public health, it is the main cause of foodborne illness through microbial contamination. The World Health Organization (WHO) stated that foodborne diseases are one of the global healthcare challenges that cause many complications and deaths all over the world and the incidence of these diseases is increasing globally. Food safety, especially for food spoilage and food poisoning, has a pivotal concern around the world. The morbidity and mortality rates of foodborne diseases are notable in developing countries as well as in less developed countries (Odeyemi, 2016; WHO, 2020). Annually, more than 2 million deaths from foodborne diseases were reported in developed countries. Unfortunately, mostly affected patient groups from foodborne diseases are infants, children, elderly people, and immunocompromised patients. According to the WHO, 125.000 children die from foodborne illnesses each year, and unfortunately, children under the age of 5 are at potential risk (WHO, 2015). According to Centers for Disease Control and Prevention (CDC) estimation, 47.8 million people suffer from foodborne diseases, and amongst them, 128.000 hospitalization and 3.000 death are reported each year in the United States (CDC, 2018). On the other hand, foodborne diseases affect the socioeconomic development of countries leading to increased treatment costs, loss of work efficiency, tourism, and trade. Treatment costs were reported to be about $15.6 billion each year by the U.S. Department of Agriculture (USDA). Moreover, it was reported by WHO that these costs rise up to $110 billion higher each year when productivity and medical needs are deducted in low- and middle-income countries (WHO, 2020).

Due to the changing living conditions (increased eating out, consuming ready-made food, etc.) depending on the increasing industrialization and urbanization, great sensitivity is expected from each employee/individual in the food chain is in order to protect human health from farm to table within the scope of food safety. Despite the growth of the industry, sufficient practices of food handlers or the hygiene control of street food cannot be adequately controlled. Microorganism activity becomes inevitable due to reasons such as breaking the cold chain, not paying attention to the hygienic conditions of the personnel, the sanitation principles, the necessary storage, cooking, and heating temperatures in food and beverage enterprises. The incidence of foodborne infections and food poisoning considerably increased due to the consumption of food contaminated with pathogens or their toxins (Sousa, 2008; Odeyemi, 2016). Food safety problems are more common in developing countries than in industrialized countries, due to the use of traditional methods in the marketing of products. However, there are certain standards for every stage of the food process, handling and distribution in industrialized countries and applications are carried out with strict supervision and traceability principle. On the other hand, street foods are considerably popular in developing countries. In terms of food safety, this may affect the increase of biological, chemical, and physical hazards related to food quality (Sousa, 2008).

Foodborne diseases are mainly observed as infections or intoxications caused by ingestion of food that contain microbiological or chemical agents which occurs via contamination of food during food production, food transfer, and food chain. The source of foodborne pathogens is indicated as water, contact with infected farm animals, pets and humans. WHO reported more than 200 diseases caused by insecure foods with harmful bacteria, viruses, parasites or chemical substances (WHO, 2020). Mostly gastrointestinal problems and also neurological, gynecological, and immunological symptoms are seen in foodborne diseases. Foodborne pathogens may cause severe diarrhea which is a major problem worldwide. Thirty one foodborne pathogens are known to cause foodborne illness. According to CDC, thirty one known pathogens affects 9.4 million (6.6-2.7 million) people. Top five pathogens contributing to domestically acquired foodborne illnesses are declared as *Norovirus, Salmonella nontyphoidal, Clostridium perfringens, Campylobacter* spp., and *S. aureus* (CDC, 2018).

3. Staphylococcal food poisoning

Staphylococcus belongs to the family of *Micrococcaceae* according to Bergey's Manual of Determinative Bacteriology. The genus includes more than 30 species with a wide range of distribution in nature. Approximately 241.000 cases are reported annually due to *S. aureus* which is a Gram-positive, facultative anaerobe, and salt-tolerant (up to 20% NaCl) bacterium with an ability to resist drying and heat (Bhunia, 2018). *S. aureus* is commonly found in the skin and mucosal membranes of humans which the persistent and intermittent colonization ratios have been reported to be 20-30% and 60%, respectively. *S. aureus* can also grow in animals such as dairy cattle, sheep, goats, etc. Unfortunately, the development of mastitis in these animals causes contamination in milk. Furthermore, *S. aureus* can contaminate foods via air, dust, and surfaces (Argudín et al., 2010).

The potential danger of this bacterium is associated with its virulence factors such as adhesion proteins, enterotoxins, superantigens, toxic shock syndrome toxins, exfoliative toxins (ETs), pore-forming hemolysins, ADP-ribosylating toxins, and proteases. Food poisoning is related to a superfamily of secreted virulence factors called staphylococcal enterotoxins (SEs), SE-like toxins (SEls) and toxins. *S. aureus* toxins are structurally similar, resistant to heat and proteolytic enzymes, having a property of superantigenicity causing disruptions in adaptive immunity, and having emetic activity (Bhunia, 2018).

Staphylococcal intoxications occur after intake of enterotoxins produced by enterotoxigenic staphylococci and act on the digestion system (Fig. 1). *S. aureus* generally localizes on human nasopharynx mucous membranes and skins of animals. Especially employee hygiene in food and beverage enterprises plays important role in food contamination with *S. aureus.* Any career that includes enterotoxin-producing staphylococci, transfer of bacteria to food, optimal growth conditions for *S. aureus*, and food with a sufficient amount of toxins are indispensable for these diseases. Therefore, hand washing has great importance because the bacteria can multiply on food contaminated with *S. aureus* and produce toxins. The contamination of food with *S. aureus* toxin does not show itself by spoilage or bad odor. The symptoms of food poisoning associated with *S. aureus* are generally characterized by severe vomiting, cramping, and sometimes diarrhea. Symptoms are generally observed within 30 minutes to 8 hours after ingestion of *S. aureus* toxin (CDC, 2018). Staphylococcal food poisoning may be related to meat and meat products such as sausage, poultry, and egg products, dairy products, raw milk, salads, ready-to-eat foods like bakery products such as cream-filled pastries, cakes, and sandwich paddings (Argudín et al., 2010).

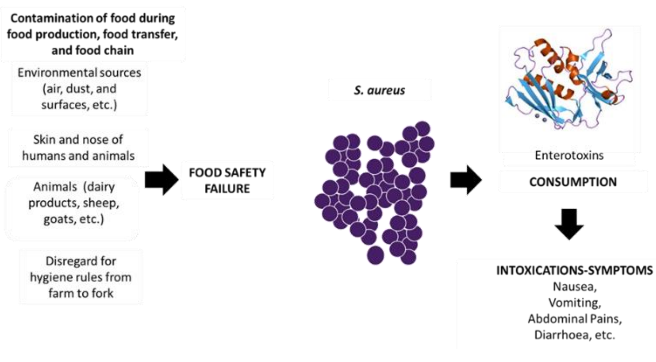

Fig. 1. *S. aureus* and their enterotoxins causes intoxications with several symptoms. The figure is adapted from Smith, 2015; Fetsch and Johler, 2018.

4. Natural antimicrobials from plants

Plants, including herbs and spices, have various phytochemicals which are, bioactive chemicals derived from plants that have potential effects against different diseases. These compounds are produced by a secondary metabolism of the plants. It has been reported that plants produce phenolics, phenolic acids, sulfur-containing compounds, quinones, flavonoids, alkaloids, phenolic diterpenes, and vitamins, especially flavonoids and polyphenols, and tannins by their secondary metabolism. Plants produce these metabolites to protect themselves against biotic or abiotic stress conditions. The secondary metabolites with antimicrobial activity are reported from fruits, vegetables, seeds, herbs and spices, animal tissues, bacteria, and fungi to ensure food security (Argudín et al., 2010).

5. Herbs and spices: the role in the food industry

During food processes, different chemical additives with various biological activities such as protection against microbial activities, coloring, giving pungency, and preventing oxidation reactions are added into foods and beverages. However, there is controversy about the advantages and disadvantages of these artificial chemicals in terms of safety and efficacy. Nowadays, consumer trends have turned to all-natural products, or at least to foods and beverages containing extracts or chemicals from ethnobotanically valuable herbs or spices. Depending on the demand of these customers, manufacturers give more importance to the use of natural food products compared to previous years in the food industry. For this purpose, many studies focusing on various natural resources approved as GRAS (Generally Recognized As Safe) for use in foods have been performed and also are still being conducted (Bondi et al., 2017). The major issue in this perspective for the food manufacturers is to provide expected shelf life and quality. Spices, herbs, and their chemicals are utilized especially for their properties of antibacterial, antifungal, and antiviral activities.

6. Some edible herbs in Türkiye and their antibacterial efficacy against *S. aureus*

Medicinally important plants have been used for the treatment of diseases among the people for centuries in Türkiye as well as all over the world. Edible herbs are grown according to the local climate and geographical features, and people transfer this knowledge from generation to generation in their own traditions and customs (Ceylan and Akar Sahingoz, 2019). It is estimated that about five hundred plants are used in Turkish folk medicine. Some of them are locally utilized as tea, poultice or tinctures for their therapeutic efficacies. On the other hand, their culinary usage is very common between local people.

Spices and herbs have been investigated in the literature for their antibacterial effects against *S. aureus*. Some of these spices and herbs are given below.

6.1. Falcaria vulgaris Bernh.

F. vulgaris (with the local name of Kazayağı, Pekaz) belongs to the Apiaceae family. It is an annual, biannual, or perennial highly branched, dull plant. The stem is flat, rounded and striated. It can be grown up to 25-100 cm. This plant is generally consumed as salad (Iğdır, Van), pickle (Erzurum, Iğdır, Van), or as a spice in cheese (Van), either prepared as a meal after boiled in milk (Iğdır) cooked as a vegetable (Erzurum, Van), or consumed fresh (Iğdır) in Türkiye. In general, young stems of plants are utilized for culinary purposes (Dogan et al., 2014). This plant has ethnomedicinal properties and it has been reported to be used traditionally for skin ulcers, stomach and liver ailments, kidney and bladder stones since ancient times. Furthermore, there are several studies in the literature showing antibacterial and antioxidant activities of *F. vulgaris* against several bacteria including *S. aureus*. Based on the results of detailed studies, it has been suggested that the potential for such biological activities is probably due to the high carvacrol content (about 30%) (Jaberian et al., 2013; Kohsari et al., 2019). Recently, the potential efficacy of silver nanoparticles synthesized by *F. vulgaris* aqueous extract was determined against multidrug-resistant *S. aureus* (Kohsari et al., 2019). Moreover, Hekmati et al. (2020) reported the antibacterial potential of essential oils from the flower, leaf, and stem parts of *F. vulgaris* against several bacteria including *S. aureus.* Shahbazi (2017) also reported the antibacterial efficacy of methanol extracts for *F. vulgaris* leaves with small inhibition zones.

6.2. Urtica dioica L.

U. dioica L. (with the local name of Isırgan Otu/nettle) belongs to the Urticaceae family. The members of *Urtica* are perennial plants with oppositely arranged serrated and hairy and stinging leaves and small greenish-white flowers (Kregiel et al., 2018). *U. dioica* L. is consumed both raw and cooked. Young branches and especially the upper parts are used in soups, salads, pastries, meatballs, mixed herb roasts, bulgur, and rice pilafs (Karaca et al., 2015). In Erzurum, this plant is used in several ways such as ingredients in soups, or boiled, or fried with ingredients such as eggs and onions (Cetinkaya and Yildiz, 2018). *U. dioica* L. has also ethnobotanical value and has been utilized in Turkish folk medicine for years especially in gastric and rheumatic pains, liver insufficiencies, and also in colds. Furthermore, its medicinal efficacy in rheumatism, eczema, urinary tract infections, arthritis, anemia, hay fever, diuretic, astringents, skin complaints, gout, sciatica, neuralgia, hemorrhoids, and hair problems has been emphasized in the literature (Gulcin et al., 2004). The potential antibacterial effect of *U. dioica* L. against *S. aureus* has been examined in some studies. Also, Gulcin et al. (2004) reported the potency of water extracts of *U. dioica* L. for this bacterium. In another study conducted by Zenão et al. (2017), the ethanol extracts of *U. dioica* L. leaves were found to be successful against methicillin-sensitive and methicillin-resistant strains of *S. aureus*. Salehzadeh et al. (2014) investigated *U. dioica* L. methanol extracts against sixteen isolates of methicillin-resistant *S. aureus* and antibacterial efficiency was demonstrated with inhibition zones ranging between 10-21 mm except one isolate.

6.3. The genus Rumex

Rumex (with the local name of Labada, Evelik Otu, Carşaf, Efelek, Efelik, Labada, Lapaza, Mancar, Mancarotu, Pancarotu, Yapalak, Tırşık) belongs to the Polygonaceae family. *Rumex* genus has been recorded to have nearly 200 species distributed worldwide (Vasas et al., 2015). It is one of the oldest known herbs of Türkiye. It resembles spinach in structure. This plant is encountered in all areas of Türkiye but especially in Eastern Anatolia. In the region of Erzurum, Kars, Ardahan and Bingöl, this herb is cooked as stuff, soup, and beetroot (Cetinkaya and Yildiz, 2018). Twenty-eight species belonging to *Rumex* genus have healing properties in various diseases such as bacteria-related dermatologic conditions, dysentery, and enteritis. Different parts of this herb including roots, leaves, flowers, tubers, aerial parts, stems or whole plant were investigated in many studies for their chemical compounds (Vasas et al., 2015). The fruit parts of *R. pulcher* L. is reported to be generally utilized in coughs as decoctions or internal use. There are several studies examining the antibacterial efficacy of some *Rumex* species against various bacteria. Tamokou et al. (2013) reported the antibacterial activity of *R. abyssinicus* Jacq. against *S. aureus*. Furthermore, the inhibitory effect of the ether and ethanol extracts of *R. crispus* L. has been indicated on the growth of *S. aureus* (Yildirim et al., 2001). In another study, Tukappa and Londonkar (2013) demonstrated that extracts from leaves of *R. vesicarius* L. had significant efficacy against *S. aureus*. In a study testing several extracts prepared with different solvents and various parts of *R. vesicarius* L. including whole plant, leaves, stems, flowers, roots, and fruits, ether extract of roots has been found to be considerably effective to inhibit the growth of this bacterium (Mostafa et al., 2011).

6.4. Capsicum annuum L.

It is one of the most economically important genera in the Solanaceae family. It contains more than twenty five known species. Among these species, the most common and most economically used are *C. annuum, C. baccatum, C. chinensis, C. frutescens* and *C. pubescens* (Aguilar-Melendez et al., 2009). Especially *C. annuum* L. (red pepper) is grinded to obtain spice to give flavor and bitterness to the dishes. It is grown in the Mediterranean, Aegean, Marmara, and Southeastern Anatolia regions of Türkiye. In addition to being used as a spice since ancient times, red pepper types can be either consumed fresh or used in industry as canned, tomato paste, pickles, hot sauce, dried, powdered and chili peppers in processed meat products. With its high antioxidant activity, it reduces the free radical activity in the human body and prevents the peroxidation reaction (Eggersdorfer and Wyss, 2018). Red pepper has a high content of vitamin E and vitamin C together with phenolics, carotenoids and alkaloids. The active ingredient of red pepper is capsaicinoid type “capsaicin” and capsinoids (Kawabata et al., 2009). The antimicrobial activity of capsaicin in red pepper has been determined on various Gram-negative and Gram-positive bacteria (Bacon et al., 2017; Baenas et al., 2019). Dorantes et al. (2008) examined the effect of *C. annuum* on *S. aureus* from fresh cheese samples. They reported that *S. aureus* increased significantly in numbers from log2 to log6 during one-day storage. On the other hand, 5% *C. annuum* extract showed a significant inhibitory effect during the 7-day storage period. In a study conducted by Naseer et al. (2021), it was reported that *Capsicum* extract had lower MIC (Minimum Inhibitory Concentration) values against multidrug-resistant *S. aureus*. Mokhtar et al. (2017) isolated polyphenols and capsaicinoids from *C. annuum* and they reported the antimicrobial activity of phenolic extracts and capsaicinoid and capsain extracts against *S. aureus*. In another study, the antibacterial efficacy of methanol extracts belongs to two different *C. annuum* species have been observed against *S. aureus* (Koffi-Nevry et al., 2012).

6.5. Gundelia tournefortii L.

The local name of *G. tournefortii* L. is Kenger, Eşek dikeni, Çakırdikeni, Çengel otu, Henger, Kalağan, Kengi Otu, Kepre, Kingar, Tatlı Sakız Otu, Kanak Sakızı in Türkiye and it belongs to the Asteraceae family. It has been specified that the localization of the plant is especially in Cyprus, Egypt, Iran, Israel, Türkiye, Azerbaijan and Turkmenistan (Haghi et al., 2011; Apuhan and Beyazkaya, 2019). The stem, leave, seed, and flower parts of *G. tournefortii* are cooked in pastries, soups, and stuffing in Türkiye (Ceylan and Akar Sahingoz, 2019). In addition to being a good source of nutrients, it has been used in herbal medicine for cramps, dyspepsia, migraine, inflammation of the liver, biliary tract inflammation, cirrhosis, parotitis, vitiligo, diarrhea, bronchitis, and chronic liver diseases from ancient times (Sarac et al., 2019). There are many studies focusing on the biological activities of the extracts obtained by different solvents from *G. tournefortii*. The inhibitory effects of methanol extracts of *G. tournefortii*, and its synergistic/antagonistic effects with some antibiotics against *S. aureus* have been demonstrated (Darwish et al., 2002). On the other hand, in a study in which only the extracts of the plant were tested against *S. aureus,* the ethanol extracts of *G. tournefortti* was found to be effective on this bacterium (Ayoubi et al., 2016). Ceylan et al. (2019) investigated methanolic extracts of eight plants against several bacteria including *S. aureus* and reported MIC value for *G. tournefortii* as 1000 µg/mL. In another study conducted by Sarac et al. (2019), it was observed that water extracts of seeds from *G. tournefortii* have a moderate level of antimicrobial activity with a MIC value of 0.3125 mg/mL. Similar moderate activity for the chloroform, ethyl acetate, methanol, and aqueous extracts of *G. tournefortii* was observed by Dastan and Yousefzadi, 2016. Nowadays, silver nanoparticles (AgNPs) have come into prominence for having good features for feasibility and efficiency in biomedical applications. In a recent study, AgNPs prepared with fresh leaves of *G. tournefortii* L. have been tested for the potential inhibitory effect on bacterial growth of *S. aureus* and inhibition was recorded at 2 and 4 mg/mL of AgNPs with *G. tournefortii* (Han et al., 2020).

6.6. Chenopodium album L.

This plant is an annual herbaceous plant (with the local name of Sirken otu, Ak Kazayağı, Ak Sirken, Ak Pazı, Hoşkıran, Küllü ot, Yabani ıspanak) belongs to the Chenopodiaceae (Spinachaceae) family in Türkiye, which grows up to 150 to 200 cm (Atalay and Kamalak, 2019). Lambs quarter (English) and Bathu (Hindi) are the plant's known names around the world (Said et al., 2020). Chenopodiaceae family includes widely distributed more than 100 genera. Its vermifugal and laxative effect has been emphasized in the literature. The ethnobotanical utilization of this plant against wounds, high blood pressure, abdominal pain, intestinal ulcers, hepatic and liver disorders, piles, diarrhea, eczema, and eye inflammation was also stated. Above-ground parts of *Chenopodium* sp. are cooked and consumed as a vegetable like spinach. It is also boiled and roasted (Kaya et al., 2004; Yadav et al., 2007; Said et al., 2020). Also, it can be consumed as a raw vegetable in salads or wraps (Yucel et al., 2018). Cretan Turks add the leaves and fresh sprouts of *Chenopodium* sp. to chipohorta mix and also they use this herb in boiled salads (Kok et al., 2020). Besides the nutritional features of *C. album*, biological activities as an antioxidant, antibacterial, antipruritic, and antinociceptive were also investigated in several studies (Pandey and Gupta, 2014). Nayak et al. (2010) demonstrated potential inhibitory efficiency of *C. album* with 17.3 mm zone of inhibition against *S. aureus*. Singh et al. (2011) indicated considerable antibacterial activity against *S. aureus* by the aqueous extracts of *C. album* L. The methanol extract of *C. album* exhibits antibacterial activity against *S. aureus* with an inhibition zone of 13.0 mm at 100% concentration (Parkash and Patel, 2014). Lone et al. (2017) recorded significant antibacterial activity against *S. aureus* by different extracts of *C. album* with 28 ± 0.14 mm inhibition zone at a concentration of 500 µg/mL. In one of the studies emphasizing the potential antibacterial effects of the plant, a considerable inhibition percentage (88.86%) for *S. aureus* growth was recorded via the methanol extracts of the plant by Said et al. (2020). On the other hand, Amjad and Alizad (2012) reported no antibacterial potential for methanol extract of *C. album.* More recently, whereas efficacy of methanol extract of *C. album* leaves against *S. aureus* was shown after 24 h, no activity for aqueous extracts of the plant was shown by Suleman et al. (2021). The variability in results may be due to the amount used in the experiments, regional differences, type of solvent, and bacteria used.

6.7. Crocus sativus L.

C. sativus, commonly known as saffron, is a perennial flowering plant of Iridaceae family with a bitter taste and fragrant smell. Saffron, one of the oldest spices, is commonly utilized as a spice in Anatolia and worldwide. The local name of *C. sativus* in Türkiye is safran. It has high economic value since it is the most expensive spice in the world. The definition of saffron covers the stigmas of the plant, spice obtained from these stigmas and the plant itself. The petal, leaves and stigmas of *C. sativus* have traditionally been used in folk medicine for over 3000 years as it has various bioactive chemical compounds with antispasmodic, sedative, stomachic, stimulant, emmenegogue, anti-tumoral, anti-mutatic and possible application areas (Cinar, 2019; Jadouali et al., 2019; Shadmehri et al., 2019). Saffron is preferred in various cuisines and recipes due to its coloring and flavoring properties (Soureshjan and Heidari, 2014). Its aroma is described as honey-like but with metallic notes (Mzabri et al., 2019). Saffron dyes 100 thousand times liquid its own weight in yellow. It is widely used in Iranian, Arabian, Central Asian, European, Indian, and Moroccan dishes (pilaf cuisine, various halvah, dolma, soup, etc.) (Cinar, 2019). Saffron is utilized in various traditional dishes such as Paella Valencia, bouillabaisse, Milanese risotto, saffron cake, meatballs, chelow kabab, mrouzia, biryani, gulab jamun and kulfi (Mzabri et al., 2019). Many studies demonstrating the antidepressant, anti-inflammatory, anticoagulant, analgesic, antihypertensive, anti-cancer, and anti-tumor activities of aqueous and ethanolic extracts of *C. sativus* highlight the pioneering role of this plant for the pharmaceutical industry (Shadmehri et al., 2019). Okmen et al. (2016) tested methanolic, ethanolic and aqueous extracts of saffron against two *S. aureus* and five coagulase-negative staphylococci and recorded moderately inhibitory effect on the growth of *S. aureus* by aqueous extracts of *C. sativus* (8-10 mm). Jafari-Sales and Pashazadeh (2020) examined the potential inhibitory effects of methanol extracts of *C. sativus* L. on various Gram-negative and Gram-positive bacteria. Researchers observed that saffron extracts applied in varying concentrations showed reasonable inhibition on *S. aureus* and they indicated higher inhibition on Gram-positive bacteria than Gram-negative bacteria by the saffron extracts. Esmaeelian et al. (2021) tested saffron corm extracts, which were extracted via ultrasound and solvent utilization, on *S. aureus* and *E. coli*. No effect of extracts applied at a dose of 150 mg/mL on disk diffusion was observed in both bacteria. They reported that doses of 300 and 600 mg/mL showed inhibitory activity on *S. aureus*. Wali et al. (2020) extracted saffron petals by different solvents namely hexane, dichloromethane and ethanol which were then examined on various bacteria including *S. aureus* at the concentrations of 500-

15.63 µg/mL. They reported that a concentration of 500 µg/mL for ethanol extract provided the highest inhibition on *S. aureus.* On the other hand, there are also studies showing that there is no antibacterial activity against *S. aureus*. Soureshjan and Heidari, (2014) observed no antibacterial potency of saffron onion at all tested concentrations of extract *S. aureus*.

6.8. Erodium cicutarium (L.) L'Hér. ex Aiton

The genus *Erodium* (Geraniaceae) is widespread all over the world except Antarctica with 74 species. The greatest species diversity is found in the Mediterranean region with 62 species. In the flora of Türkiye, it is known by local names such as Dönbaba, İğnelik or locally as Çoban İğnesi, İğnelik Otu, Leylek Gagası, and it is known to have 26 species. The members of the genus *Erodium* can be annual, biennial, or perennial. *E. cicutarium* is consumed particularly as a vegetable in Ankara, Aksaray, and Afyonkarahisar. Furthermore, it is used in different cuisines all over Türkiye such as it can be added to pastries, roasted, fried with eggs or onion, and eaten raw as a snack. This herb is also of ethnobotanical importance as it is a potential analgesic or a treatment option for snake bites and hemorrhoids. The plant contains a wide variety of phenolics, volatile and amino acids, and vitamins K and C. (Sargin et al., 2015; Celikler et al., 2020). There are studies showing antimicrobial, antioxidant, anti-inflammatory, and antiviral activities of *E. cicutarium* (Nikitina et al., 2007; Nikolova et al., 2010). In a study by Nikitina et al. (2007), bacteriostatic effects of 7 plant species belonging to the Geraniaceae and Rosaceae families were examined on a total of 32 bacteria (Gram-negative and Gram-positive). The water extracts of the above-ground parts which are obtained from *E. cicutarium* showed a higher bacteriostatic effect than the ethanol extracts. Quave et al. (2008) investigated antimicrobial and antibiofilm activities of various herbal extracts against *S. aureus.* The ethanol extracts, which were obtained from the aerial parts of *E. ciconium* and *E. malacoides* did not inhibit biofilm formation. Whereas *E. ciconium* extract had no effect against Methicillin-resistant *S. aureus* (MRSA), expected activity was observed for *E. malacoides* extract. The essential oils of *E. cicutarium* and *E. ciconium*, collected from Serbia, were studied against several Gram-positive and Gram-negative bacteria including *S. aureus. E. cicutarium* had moderate antimicrobial activity on tested bacteria with the highest activity on *S. aureus* (Stojanović-Radić et al., 2010).

6.9. Nigella sativa L.

N. sativa is an aromatic (bitter and pungent) annual plant with black-colored seeds and a member of the Ranunculaceae family. It is commonly known as black seed, black cumin, Ajaji, Kalika, Kalaunji, and Habbatul-Barakah. In Türkiye, the local name of *N. sativa* is çörek otu. The seeds of the black cumin plant are traditionally used as a spice, food additive, functional foods and nutraceuticals (Paarakh, 2010). In the culinary use of *N. sativa* with its unique smell, the seeds are used in the food industry to garnish or flavor bakery products, cheese (Armenian string cheese Majdouleh or Majdouli), confectionery, and liqueurs. Also, it can be added to recipes including fruit, vegetables, salads, poultry, yogurt, pickles, sauces, and salads. Its consumption with honey and syrup is quite common (Fawzy Ramadan, 2015; Hassanien et al., 2015). Besides the use of *N. sativa* seeds as a spice, they also have applications for food preservation.

N. sativa has traditionally been used as a folk medicine for many years. It is seen that its seeds and oil have healing properties in many health problems such as cough, jaundice, fever, skin diseases, anorexia, diarrhea, flatulence, etc. It has been reported that the seed oil is used as a local anesthetic. Several biological activities for *N. sativa* are indicated in the literature including carminative, anti-tumor, antidiabetic, gastroprotective, pulmonar, nephroprotective, hepatoprotective, immunomodulatory, antioxidant, antibacterial, diuretic, antifungal, antihelminthic, antiimplantation etc. (Paarakh, 2010). There are numerous studies evaluating the antibacterial activities of black cumin. The effects of different solvents or extraction methods on the antibacterial activity of black cumin were also studied. Khalid et al. (2011) investigated three extraction method namely cold water, hot water and methanol for *N. sativa* seeds and amongst them cold water extracts were successful against *S. aureus.* In another study using n-hexane for the extraction of black cumin, potentially inhibitory effect against *S. aureus* was reported by researchers (Abraham et al., 2019). The existence of these potential activities has led researchers to find their active ingredients. Halawani (2009) examined two compounds from black cumin for antibacterial efficacy on *S. aureus*. It has been determined that thymoquinone and thymohydroquinone can kill bacteria at doses of 3 and 6 µg/mL, and 400 and 800 µg/mL, respectively. In another study, a significant bactericidal activity of thymoquinone against *S. aureus* was detected (Chaieb et al., 2011). In recent years, studies on the antimicrobial properties of essential oils and their components, which have been revealed by detailed studies, have attracted attention. In a study by Salman et al. (2008), it was reported that *S. aureus* had sensitivity to essential oil of *N. sativa* seeds. Similarly, Emeka et al. (2015) studied inhibitory/suppressive/lethal potency of *N. sativa* oil on the growth of *S. aureus*. Most isolates were found to be susceptible to different concentrations of oil samples. Mouwakeh et al. (2019) reported antimicrobial activities of *N. sativa* essential oil and its compounds (thymoquinone, carvacrol, and p-cymene) against methicillin-susceptible and resistant *S. aureus* strains. Georgescu and Raita (2019) compared the antibacterial efficacy for 0.1 and 0.2 w/w of *N. sativa* seed oil samples to control groups against *Staphylococcus* spp. from kneaded, sheep´s milk Romanian cheese and observed that 0.2 w/w of *N. sativa* seed oil provided considerable inhibition in number of *Staphylococcus* spp.

Some of the biological activities and chemical composition of the plants mentioned above and the bacterial species, in which their antimicrobial activities are observed, are given in Suppl. Table 1.

7. Some other herbs and spices used to preserve foods and extend product shelf-life

In terms of food hygiene, recently, researchers have focused on the preservative effects of extracts and/or fractions from many herbs and spices against various food pathogens. In one such study, Márquez-Rodríguez et al. (2020) analyzed the brute phenolic extract of *Hibiscus calyces* as well as organic and aqueous phase and also fractions. They found that the F1 fraction, which is the richest fraction in phenolic acids, was successful in terms of MIC and MBC values for tested bacteria including *S. aureus*. Then, in situ studies revealed that beef steak slices sprayed with the hibiscus phenolic extract (HE) at the concentration of 500 mg/L and stored at 4 ± 1 °C for 15 days had decreased bacterial number. Also, no bad smell was observed during the 15 days of the storage. Weerakkody et al. (2011) evaluated the synergistic effect of extract combinations of *Alpinia galangal* and *Rosmarinus officinalis* against the growth of *S. aureus*. Frozen cooked, peeled, and deveined shrimps were inoculated by three strains of *S. aureus* at 8°C for 16 days. The mixture of *A. galangal* and *R. officinalis* extracts at the concentrations of 5 mg/mL and 10 mg/mL, respectively had no significant inhibition on *S. aureus*. However, they reported that the mix of *A. galangal* and *R. officinalis* extracts prolonged the shelf life of shrimp up to 8 days when stored at the tested temperature. Study results showed that *S. aureus* was completely inhibited in treated yoghurts with herb essential oil and the stability was provided for 29 days. Sayyari et al. (2021) investigated probable antibacterial efficacy by *Foeniculum vulgare* essential oil at the concentrations of 1%, 1.5%, and 2%, which were nanocoated with basil seed gum or *Lepidium perfoliatum* and also their mix, against *S. aureus* PTCC1431 on days 7, 14, 21 and 28. They obtained successful results from the test group of the mixed-coating samples with 2% of the fennel essential oil. Kanatt et al. (2010) demonstrated the potency of pomegranate peel extract against *S. aureus* in chilled chicken meat products with prolonged shelf life by 2-3 weeks. Abdolshahi et al. (2018) tested essential oils of *Thymus vulgaris* L., *Mentha piperita* L., and *Ziziphora tenuior* alone or mix against *S. aureus* in industrial doogh. During refrigerated storage, inhibition in bacterial growth was recorded on days 1 and 7. Furthermore, it has been reported that the components of essential oil which were obtained from *Alpinia pahangensis*, *Origanum vulgare*, *Origanum dictamnus*, *Mentha piperita*, *Lavandula hybrida*, *Zataria multiflora*, and *Hofmeisteria schaffneri* have been found to be successful against *S. aureus*. Some herbs and spices utilized in antibacterial food packaging are given in Suppl. Table 2.

8. Conclusion

Foodborne diseases are one of the global health problems that cause many complications and deaths all over the world. Food poisoning caused by staphylococci is one of the most common food-borne diseases via contamination by food or food processing equipment. Various synthetic antimicrobials are utilized in the food industry. However, in past decades, a tendency to use natural food products has started in line with the demands of customers. Herbs and spices for culinary purposes have been added to different recipes to give flavor, aroma, pungency and color to food from time immemorial. On the other hand, these herbs and spices are known to have unique compounds with properties of medicinal and numerous biological activities.

Extracts or their compounds, especially essential oils, are used in medicine, food, cosmetics, etc. Since natural extracts from herbs and spices have positive effects on shelf life, microbial degradation, and oxidation reactions, the feasibility of utilizing these natural materials such as extracts/their essential oils/other compounds in food processing for various purposes has come into prominence. More recently, it has been emphasized in the literature that there are synergistic or antagonistic effects between these compounds. Most studies focused on these interactions to increase expected impacts. Herbs and spices with medicinal importance have been used in the treatment of diseases among the people in Türkiye as well as all over the world for centuries. Studies to date focusing on the antibacterial properties of extracts from herbs and spices and their compounds have shown promising activity against *S. aureus*. More detailed experiments will provide comprehensive information on the applicability of these natural biological resources in the food industry. These natural herbs or spices can serve as alternative antibacterial agents against *S. aureus* and food preservation can be achieved with these ecological materials. In this context, herbs and spices that have been shown to be effective against *S. aureus*, which also causes food poisoning, can be used as an alternative to food preservation chemicals or may be integrated into food packaging material. Technologies to ensure the safety and quality of food, such as active packaging, which prolongs the shelf life of food products, and intelligent packaging, which reduces food waste by sensing changes in the food product, have become prominent in recent years. Therefore, some edible culinary herbs and spices that are traditionally used as folk medicine and have also been found to have antibacterial activity against *S. aureus*, can be used in antimicrobial active packages.

Conflict of interest: The authors declare that they have no conflict of interests.

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Supplementary

Suppl. Table 1. Chemical composition, biological activities and antimicrobial properties of some herbs and spices.

Plant Name	Chemical Composition	Biological Activity	Antibacterial Activity	References
***Falcaria vulgaris* Bernh.**	α-Pinene, Octanal, Limonene, Carvacrol, Germacrene-D, Spathulenol, Germacrene-B, Salvial-4(14)-en-1-one, Isospathulenol, Phytol	Antioxidant, Antimicrobial, Antidiabetic	*Bacillus cereus, Serratia marcescens, Escherichia coli, Staphylococcus aureus, Enterobacter aerogenes, Klebsiella pneumoniae, Pseudomonas aeruginosa, B. megaterium*	Jaberian et al., 2013 Choobkar et al., 2017
***Urtica dioica* L.**	Isorhamnetin rutinoside, Isoquercetin, Rutin, Ferulic acid, Caffeoylmalic acid, Caffeic acid, Quinic acid	Antioxidant, Anti-inflammatory, Antirheumatic, Antimicrobial, Antiulcer, Antiproliferative	*Candida albicans, S. aureus, K. pneumonia, Listeria monocytogenes, Proteus vulgaris*	García et al., 2021 Mahmoudi et al., 2021
***Rumex* sp.**	Rutin hydrate, Butyl gallate, Cardamonin, Phenoxodiol, Shikonin, Gallic acid, 3′-hydroxy-b-naphthoflavone, Anthraquinones, Tocopherols	Anti-inflammatory, Antioxidants, Antianalgesic, Antimicrobial	*S. aureus, B. subtilis, E. coli, K. pneumoniae, Salmonella typhi, Streptococcus pneumoniae, L. monocytogenes*	Hafaz et al., 2021 Saoudi et al., 2021
***Capsicum annuum* L.**	β-Tocotrienol, *α*-Tocotrienol, Capsidiol, Oxylipin, Capsianoside I methyl, Methyl cinnamate, Dihydrocapsaicin, Capsianoside F, Nordihydrocapsiate Capsaicin, Capsianoside C, Chlorogenic acid, Naringenin-7-*O*-glucoside, *p*-Coumaric acid, Naringenin, Liliolide	Antioxidant, Antiviral, Antimicrobial, Anticancer, Anti-inflammatory, Antiobesity, Analgesic, Antifungal	*Salmonella* sp. *E. coli, P. aeruginosa, S. aureus, B. subtilis, Streptococcus mutans, Helicobacter pylori*	Chilczuk et al., 2021 Hernández-Pérez et al., 2021 Molina et al., 2021
***Gundelia tournefortii* L.**	Lupeol, Lupeol-trifluoroacetate, Palmitic acid, β-amyrin, Ursolic acid, 4-hydroxybenzoic acid, 3,4-dihydroxybenzoic acid, Caffeic acid, Myo-inositol, Quinic acid	Antibacterial, Anticancer, Diabetes, Antiparasitic, Anti-inflammatory	*E. coli, P. aeruginosa, S. aureus*	Bati et al., 2021 Asadi-Samani et al., 2013 Kadan et al., 2021
***Chenopodium album* L.**	Quercetin, Rosmarinic Acid, Benzoic acid, Ferulic acid, Rutin, Syringaldehyde, p-Coumaric Acid, Vanillin, Epicatechin, Syringic acid,	Antioxidant, Antibacterial, Antifungal, Anticancer	*S. aureus, B. subtilis, B. polymexia, S. faecalis, P. aerugenosa, Shigella dysenteriae, S. typhimurium, P. vulgaris*	Saini and Saini, 2020 Karacelik and Sahin, 2021

Plant Name	Chemical Composition	Biological Activity	Antibacterial Activity	References
***Chenopodium album* L.**	Caffeic acid, Chlorogenic Acid, Catechin, Gallic acid, Protocatechuic acid, Myristic acid, cis-10-pentadecanoic acid, α-linolenic acid	Antioxidant, Antibacterial, Antifungal, Anticancer	*S. aureus, B. subtilis, B. polymexia, S. faecalis, P. aerugenosa, Shigella dysenteriae, S. typhimurium, P. vulgaris*	Saini and Saini, 2020 Karacelik and Sahin, 2021
***Crocus sativus* L.**	Crocin, Picrocrocin, Safranal, Coumaric acid, Quercitrin, Gallic acid, Ellagic acid, Catechin, Epicatechin	Antidepressant, Antioxidant, Anticarcinogenic, Anti-inflammatory Antibacterial	*S. aureus, L. monocytogenes, S. enterica* subsp. *bungori, E. coli*	Caser et al., 2020 Mzabri et al., 2019 Zara et al., 2021
***Erodium cicutarium* (L.) L'Hér. ex Aiton**	Gallic acid, Protocatechuic acid, 3-O-galloyl shikimic acid, 3-O-(6”-O-galloyl)-β-D-galactopyranoside, Corilagin, Didehydrogeraniin (dehydrogeraniin), Geraniin, Hyperin, Isoquercitrin, Methyl gallate 3-O-β-D-glucopyranoside, Rutin	Anti-inflammatory, Antimicrobial, Antiviral	*E. coli, S. aureus, Azotobacter* sp., *Pseudomonas sp., B. polymyxa, B. subtilis, K. pneumoniae*	Bussmann et al., 2010 Munekata et al., 2019
***Nigella sativa* L.**	Thymoquinone, Thymohydroquinone, Dithymoquinone (nigellone), *p*-cymene , carvacrol, 4-terpineol, *t*-anethole, α-pinene, Thymol, Carvone, Limonene, Citronellol, Linoleic acid, Oleic acid, Eicosadienoic acid	Antidiabetic, Anti-inflammatory, Antioxidant, Antimicrobial, Anticancer	*P. aeruginosa, K. pneumoniae, Acinetobacter baumannii, S. aureus, Yersinia enterocolitica*	Srinivasan, 2018

Suppl. Table 2. Some herbs and spices utilized in antibacterial food packaging.

Plant	Applications	Microorganisms	References
Garlic (*Allium* sp.) **Oregano (*Origanum* sp.)**	Edible film	*S. aureus*, *L. monocytogenes*, *B. cereus*, *E.coli* O157:H7, *S. enteritidis*, *L. plantarum*	Pranoto et al., 2005 Seydim and Sarikus, 2006
***Satureja hortensis* L.**	Edible coating	*S. aureus*, *B. subtilis*, *S. enteritidis*, *E. coli*, *Penicillium expansum*	Krasniewska et al., 2014.
***Hibiscus sabdariffa* L.**	Sprayed	*E. coli*, *S.enterica*, *S. aureus*, *L. monocytogenes*, *B. cereus*	Márquez-Rodríguez et al., 2020
***Thymus vulgaris* L.,** ***Origanum majorana* L.,** ***Ocimum basilicum* L.**	Film Coating	*E. coli*, *S. aureus*	De Souza et al., 2020
***Urtica dioica* L.**	Edible Film	*E. coli*, *S. aureus* *Enterobacteriaceae*	Alp and Aksu, 2010 Mohammadian et al., 2021
***Portulaca oleracea* L.**	Edible Films	*E. coli*, *S. aureus*	Qoeroti et al., 2021
***Crocus sativus* L.**	Edible Films	*E. coli*, *S. sonnei*, *S.* typhi, *S. aureus*, *B. cereus*	Hashemi and Jafarpour, 2020
***Nigella sativa* L.**	Active pad or sachet	*E. coli*, *S. aureus*, *Aspergillus flavus*	Hosseini et al., 2021
Cranberry (*Vaccinium* sp.)	Films	*E. coli*, *S. aureus*	Severo et al., 2021
***Amaranthus* sp.**	Films	*S. aureus*	Kanatt, 2020
Olive (*Olea* sp.)	Edible Films	*S. aureus*, *E. coli*	García et al., 2020
***Sonneratia caseolaris* L.**	Edible Films	*S. aureus*, *P. aeruginosa*	Nguyen et al., 2020