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Antimicrobial Properties of Spice Extracts and their Prospective Use as Food Preservatives: A Review

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ABSTRACT

Preservatives serve as a broad category encompassing various compounds that effectively inhibit or delay the growth of bacteria in a diverse range of items, encompassing consumables, pharmaceuticals, and personal care products, these substances may originate from either natural sources or be synthetically produced. Spices have held a significant place in human nutrition throughout history. Their prominent role in food stems from their attributes as natural colorants, flavor enhancers, antioxidants, and antimicrobial agents, rendering them valuable as preservatives. Essential oils, found within spice extracts, consist of a myriad of constituents, bearing the aromatic essence of plants with well-established historical significance in terms of bioactivity, flavor, and fragrance. The majority of synthetic chemicals currently employed for food preservation are associated with carcinogenic and toxic properties, posing risks to human well-being. Spices derived from herbs and plants in their natural state, generally, have gained recognition for being safe for consumption, this is further supported by the report of the United States Food and Drug Administration (FDA). Thus, the demand for spice extracts as natural food preservatives cannot be overstated. Presently, spice extracts are being both employed and investigated in the realm of food preservation, primarily because they possess antioxidant and antimicrobial characteristics, aiming at substituting preservatives synthetic of origin.

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1. INTRODUCTION

The spices encompass a variety of plant-based substances employed to season or add flavor to food. Typically, these substances are dried and possess distinct flavors and aromas. Examples of

such spices comprise nutmeg, cloves, cinnamon, onion, pepper, curry, thyme, ginger and garlic (Thielmann *et al.,* 2017). Historically Spices served as enhancer of sensory qualities of food. For instance, Turmeric and pepper possess the ability to modify certain food properties such as the taste, aroma, appearance as well as its colour while providing various nutritional benefits. Additionally, ginger, cinnamon and nutmeg are recognized for their digestive aid properties and are considered advantageous for soothing sore throats and the spleen (Rabiu *et al.,* 2023; Prasad *et al.,* 2011). These natural seasonings are obtained from either plants or herbs which have been acknowledged by the FDA as safe. Spices have been employed to prevent undesirable alterations in food, particularly those associated with microbial growth and oxidative reactions. Spice extracts, essential oils comprise a mixture of numerous compounds that carry the aromatic essence of plants. The bioactivity, flavor, and fragrance components of these essential oils have been recognized since ancient times (Michalina *et al*., 2017; Hamdy *et al*., 2012). In food, the peroxidation of lipids, reflecting the interaction between oxygen molecules and polyunsaturated fatty acids, can lead to food degradation, aging, and the accumulation of free radicals. These free radicals can be counteracted by antioxidants, making essential oils valuable as food additive. The antimicrobial and antioxidant properties present in natural products, whether in the form of herbs, spices, or essential oils, can exhibit variations, with their efficacy not being consistent across all plant species. Furthermore, this efficacy can differ even within the same plant species, depending on the environmental and agricultural conditions in which they are cultivated (Adamu *et al.,* 2023).
Food spoilage denotes an irreversible deterioration where it becomes unfit for consumption alternatively, experiences a compromise in its quality. These deviations have the potential to be initiated by a range features, including elements of a physical nature such as exposure to temperature fluctuations, light and oxygen, as well as biological factors such as enzymatic activity and microbial growth. Despite the presence of advanced food production technologies like freezing, drying, pasteurization and the use of preservatives, completely eliminating the risk of food spoilage appears to be an insurmountable challenge (Shamsudeen *et al*., 2014). The primary issue contributing to food spoilage is the proliferation of microorganisms. Preservatives play a vital role in prolonging the freshness of food, extending its shelf life, and mitigating alterations in color, flavor, or texture. They also help in delaying rancidity, reducing the likelihood of foodborne infections, and preserving the fresh attributes and nutritional quality of food products (Emmanuel *et al*., 2015).

2. COMMONLY USED SPICES WITH ANTI-FOODBORNE PATHOGEN PROPERTIES

2.1 Clove (*Syzygium aromaticum*): Clove, derived from the dried floral buds of *Syzygium aromaticum*, has a well-established reputation for its long-standing antioxidant and antimicrobial properties, primarily attributed to its active component, eugenol (Kayode *et al.,* 2017; Shamsudeen *et al*., 2014). Eugenol, the main chemical component of clove, is a clear to pale yellow oily liquid and can also be derived from certain essential oils present in nutmeg, bay leaf and cinnamon. It exhibits limited solubility in both water and organic solvents. Cloves are highly regarded not only for their role as a flavoring agent and spice but also for their use in scenting, chewing tobacco, betel chew preparations, therapeutic applications, and their potential to stimulate the nervous system. Additionally, cloves are recognized for their notable properties, including being antiseptic, antimutagenic, anti-inflammatory, antioxidant, antiulcerogenic, antithrombotic, antifungal, antiviral, and antiparasitic (Michalina *et al*., 2017; Emmanuel *et al*., 2015). Clove is also utilized as an antimicrobial agent in the context of food.

2.2 Ginger (*Zingiber officinale*): A perennial herb that emerges from subterranean rhizomes, ginger features sturdy lobes with hues ranging from tan to white. Fresh ginger harbors some chemical compounds called 'gingerols,' which undergo conversion into 'shogaols' upon exposure to air and heat. The nutritional profile of ginger is known to contain different constituents such as minerals, carbohydrates, vitamins, lipids, proteins and various trace elements (Thielmann *et al.*, 2017). Additionally, ginger contains curcumin, capsaicin, limonene, and proteolytic enzymes. Remarkably, ginger is acknowledged as an effective botanical carrier, potentially amplifying digestive absorption up to a level approximately 200% (Emmanuel *et al*., 2015). In furtherance, ginger, commonly used as a spice, contains polyphenolic compounds, such as 6-gingerol and its derivatives, which endow ginger with robust antioxidant properties (Kayode *et al.*, 2017).

2.3 Cinnamon: These is obtained by peeling the inner bark of some given tress within the genus of Cinnamon. These include; *C. verum, C. loureiroi and C. burmanni* among others. Cinnamon is mainly utilized as an aromatic seasoning and flavor enhancer in a diverse range of culinary applications. Cinnamon is used in the preparation of several dishes such as snacks, preparation of different kinds of tea, savory dishes etc. Specifically, the Cinnamomum verum variety of cinnamon is acknowledged for its preservative qualities to include activities against diverse bacterial groups (Gram positive nad Negative bacteria). The chemical composition of cinnamon oil includes notable constituents such as eugenol, cinnamaldehyde, and cinnamyl alcohol (Cinnamon *et al.*, 2016).

2.4 Coriander: Coriander which is otherwise referred to as *Coriandrum sativum,* scientifically, is thought to have been in use for centuries, hence making it have different names, ranging from "Korider" in Hausa, "Efinrin" in Yoruba and Chinese parsley, in Chinese medicine. Coriander, belongs to the parsley family (Apiaceae), featuring feathery leaves that are used both as an herb and a spice. Coriandrum sativum is cultivated extensively across the globe, primarily for its culinary applications. The plant's dry fruits and seeds, commonly referred to as coriander, are utilized to flavor a wide range of foods, such as liqueurs, Scandinavian pastries, curries, sausages and other confectioneries. The tender Coriander youthful leaves are widely used traditional medicines as remedies for several conditions. Coriander contains essential oil, constituting approximately 0.5–1% of its composition, and is rich in beneficial phytonutrients, including geraniol, linalool, carvone, camphor, elemol, borneol, and limonene (Rabiu *et al*., 2022a).

3. ANTIMICROBIAL PROPERTIES OF VARIOUS SPICE EXTRACTS FOR FOOD PRESERVATION AND SHELF-LIFE EXTENSION

The term "preservatives" encompasses a wide groups of chemical compounds that are used in especially food products to impede the gradual proliferation of living cells especially microorganisms such as fungi, and diverse bacterial groups (Kayode *et al*., 2018). These preservatives may originate from either natural sources or be synthetically produced., derived from plants, animals, or microorganisms. Spices have been used for their nutritional benefits since ancient times. The definition of shelf life varies depending on specific purposes and contexts. In general, shelf life can be described as the period from production and packaging to the point at which a product becomes unacceptable under specified environmental and distribution conditions (Thielmann *et al.*, 2017).

The use of ingredients in food such as herbs, oils and spices in food preparation and preservation has a long documented history. Initially, they were used to impart flavor and aroma to beverages and foods, masking undesirable qualities, particularly in meat products. Over time, it became apparent that these substances not only masked organoleptic characteristics but also had the ability to preserve food. The healing and antiseptic properties of plant substances are ascribed to a diverse range of constituent elements, encompassing enzymes, proteins, and other phytochemicals such as alkaloids, carotenoids, anthocyanins and phenolics among diverse others (Rabiu *et al.,* 2022a). Beyond traditional nutrients, biologically active plant compounds that offer health benefits are referred to as "phytochemicals". Spices have the capacity to enhance the antioxidant properties of food, with their effectiveness being influenced by the specific food matrices (Kayode *et al.,* 2017). Certain essential oils have exhibited strong bactericidal properties against pathogens of public health concern especially Multidrug resistant Gram positive (Methicillin-resistant *S. aureus* (MRSA) and Gram negative pathogens (Multidrug Resistant *E. coli* and *Klebsiella pneumoniae*) (Rabiu *et al.,* 2022*;* Issa *et al.,* 2021). Various compounds, including aldehydes, phenolics, terpenes, and other antimicrobial agents. As a result, these essential oils prove highly effective against a broad spectrum of pathogens (Issa *et al.,* 2021; Michalina and Danuta, 2017).

To date, the scientific community as well as different researchers in the field of food science, food engineering and production have continued to stressed the increasing importance of the need for finding novel preservatives with high in vitro antimicrobial properties as well as enhancing the activities of the presently used preservatives in other to increase the shelf life of different types of foods as well increasing its overall safety. However, research has shown that by using spices, in addition to preserving food, they also confer different culinary taste to the food products. Extracts obtained from entire plants or specific plant components, using various solvents like water, N-hexane, methanol and ethyl acetate have been examined for their effectiveness against pathogenic bacteria and their effectiveness are well documented (Issa *et al.,* 2021).

Spices demonstrate a wide-ranging spectrum of activity against diverse microorganisms, encompassing both Dimorphic fungi as well as Gram-positive and Gram-negative bacteria. Despite the many reports describing the varying antimicrobial efficacy of different spices based on their type, origin, and bioactive constituents, different bacteria may exhibit varying responses. Notably, specific spices rich in antioxidants have been verified in vitro, including Paprika, onion, cardamom, curry powder, oregano, turmeric, pepper, garlic, coriander, ginger, cinnamon, clove, mustard seed, cumin, chili powder and parsley etc (Abdulfatai *et al.,* 2018).

A recent study conducted by Adamu *et al*. (2023) have highlighted that aqueous extracts of ginger, coriander, and cinnamon reduced bacterial load in tiger nut drinks during storage, with sample treated with cinnamon demonstrating the lowest bacterial count throughout the storage period. Several studies have highlighted the increasing importance of spices in preserving and prolonging the overall shelf life of food products. Oils of oregano have been reported to exhibit many antibacterial, antifungal and antiviral properties. There are many documented reports of bioactive properties of spices against Broad spectrum group of bacteria to include *S. aureus* and *Listeria monocytogenes* (Gram positive) and *Escherichia coli* (Gram negative) (Issa *et al*., 2021). Essential oils from basil and huacatay were effective against Bacteria (*Bacillus subtilis*, Escherichia coli, *Staphylococcus aureus*) and Fungi (*Candida albicans*) (Rabiu *et al.,* 2022b; Shirazi *et al*., 2014). Another study by Radwan *et al*. (2014) revealed that different extracts of nutmeg, turmeric and spices have displayed the highest activity against various group of pathogenic bacteria and fungi affecting plants belonging to the genus Colletotrichum. Coriander also exhibited inhibitory effects on *Klebsiella pneumonia*, *Staphylococcus aureus*, *Escherichia coli*, and *Salmonella typhi* (Abdulfatai *et al.,* 2018). Furthermore, extracts and compounds from olive (*Olea europaea L.*) have been explored as potential antimicrobials in food matrices, while essential oils from coriander hyssop (*Hyssopus officinalis L*.) and (*Coriandrum sativum L*.) have been studied for their impact on extending the overall shelf life of ground beef (Thielmann *et al*., 2017; Michalczyk *et al*., 2012). The combined effects of spices, whether used individually or in conjunction with their components or other natural substances, have been explored. For instance, the aqueous extracts of oregano, ginger, cinnamon and clove were used either separately at a concentration of 10 mg/L or together at 3.3 g/L each to raw chicken meat. During a 15-day storage period at a temperature of 4°C, various parameters were observed which finally revealed that the blend of the three extracts had the most significant impact on reducing bacterial load, and this was basically attributed to the extracts synergistic activity (Michalina *et al*., 2017). Furthermore, a toxicity assessment indicated that in a brine shrimp lethality assay, liquid chromatography (LC) yielded a concentration of 4945.30 µg/ml, and in human normal colon cell lines, the inhibitory concentration (IC) exceeded 1000 µg/ml for coriander and cumin seed oils. These findings suggest that this oil combination has the potential to be a safe and effective source of natural antimicrobial and antioxidant agents in both food, fashion/cosmetics and pharmaceutical industries (Rabiu *et al.*, 2022b; Bag and Chattopadhyay, 2015).

4. MECHANISM OF ACTION OF SELECTED SPICE EXTRACTS

Spices have been reported to alter some specific metabolic pathways within a bacterial and or fungal cells. Some spices act on the lipid partition of the cell membrane, leading to the leakage of cellular contents. They also disrupt the cell cycle, inhibit protein synthesis, and hinder DNA replication. Consequently, these spices are considered promising antibiotics to combat multidrug-resistant bacteria (Eshetu *et al*., 2019). Terpenes are generally considered to have lower antimicrobial activity compared to other compounds. Terpenoids, including well-studied compounds like thymol and carvacrol, express their antimicrobial effects through functional groups such as hydroxyl groups and delocalized electrons. These functional groups enable interaction with the membrane, influencing its permeability (Els Debonne *et al.*, 2018). Additionally, they can engage with proteins, resulting in the accumulation of misfolded protein structures. Specifically, thymol has the capacity to disrupt essential metabolic processes, such as ATP synthesis and the citrate metabolic pathway among others. Conversely, carvacrol primarily affects the cell membrane as a transmembrane carrier of monovalent cations, facilitating the exchange of K+ with H+ in the cytoplasm (Shamsudeen *et al*., 2014).

The presence of phenolic groups in these spice extracts is responsible for damaging the cell wall, interfering with and disrupting the cytoplasmic membrane, harming membrane proteins, causing the leakage of cellular components, coagulating the cytoplasm, and depleting the proton motive force. All these effects collectively lead to the death of microorganisms (Valdés *et al*., 2015). Eugenol primarily exerts its antimicrobial activity at the cellular membrane and protein level, resulting in increased permeability and deactivation of enzymes. In contrast, cinnamaldehyde, while somewhat less potent than eugenol, can interact with DNA and proteins and cross-link them, aside from its interaction with cell membranes. Mustard essential oil induces cell cycle arrest, resulting in bacterial filamentation (Clemente *et al*., 2016).

5. CONSTRAINTS AND FACTORS INFLUENCING THE ANTIMICROBIAL EFFECTS OF SPICE EXTRACTS

Many different factors are considered before spices are employed for industrial use in other to maximally harness their antimicrobial effects. These antimicrobials must undergo approval, demonstrate documented efficacy, provide the requisite level and contact time for specific

processing steps, be cost-effective, and should not adversely affect product quality (Kayode *et al.*, 2018). The primary challenge in utilizing One challenge associated with the use of herbs and spices as food preservatives is the necessity for elevated concentrations to hinder microbial growth and prevent oxidation. Regrettably, these heightened concentrations pose a drawback. concentrations often lead to unfavorable sensory effects, such as alterations in taste, color, odor, and texture in food products. Addressing these negative sensory impacts is crucial to enable the incorporation of spices and herbs into food preservation systems and to make a highly effective compounds for use as food preservatives (Michalczyk *et al*., 2012).
The effectiveness of essential oils, including their antioxidant properties, is influenced by a range of factors, including their structural features, factors such as temperature, exposure to light, concentration, substrate type, and the physical state of the system influence the effectiveness of essential oils. Additionally, the presence of specific microcomponents which acts as pro-oxidants or synergists can significantly affect their activity (Majid *et al*., 2016). While many plant antimicrobials exhibit activity against pathogens and spoilage microorganisms, their effectiveness can vary between laboratory systems and real food applications. Application on food surfaces through spraying must consider the instability of the active components in many essential oils, which can undergo oxidation or volatilization. Microencapsulation is one solution to address this issue of instability (Els *et al*., 2018).
In summary, several various elements contribute to determining Several factors influence the antimicrobial efficacy of spices, including the type and composition of the spice, the quantity used, the specific microorganism, the food's composition, pH value, environmental temperature, and the presence of proteins, lipids, salts, and phenolic substances in the food environment (Kayode *et al*., 2018). However, using spices like clove or cinnamon has limitations, as their antibacterial activity may decrease when added to food materials containing protein, carbohydrates, and fats. Furthermore, the strong flavor imparted by large amounts of spices to inhibit foodborne pathogens may not be acceptable to certain consumer groups. Therefore, combining spices with traditional preservatives like acids, salt, sugar, and employing specific processing and storage conditions can help control microorganisms in food products (Mahfuz *et al*., 2008).

6.0 CONCLUSION

An array of plant-based spices offers medicinal and antimicrobial advantages. These spices or their extracts exhibit a wide range of bioactivities and have found applications in pharmaceuticals, food products, and cosmetics owing to their valuable properties. The antimicrobial efficacy primarily hinges on factors such as the susceptibility of the target microorganisms, the spice concentration, the type of food, and the prevailing environmental or storage conditions. Nevertheless, the challenges linked to their use can be surmounted by employing them in conjunction with other preservatives within a hurdle technology approach.

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Table1: Minimum Inhibitory Concentrations of Various Essential Oils on Pathogen

S/n	Spice	Microorganisms	MIC (% v/v)	Mode of Extraction	References
1.	Cloves	*Penicillium* spp	5.0		(Shamsudeen *et al*., 2014)
		Alternaria spp	2.5		
		Rhizopus spp	2.5		
		Aspergillus niger	2.5		
		Aspergillusflavus	2.5		
		Aspergillus fumigates	2.5		
		Aspergillusocraceus	2.5		
		Sporotricum spp	2.5		
2.	Cloves	*Escherichia coli*	0.78		(Rabiu *et al*., 2022a)
		Corynebacterium spp	0.39		
		Streptococcus pyogenes	0.78		
		Staphylococcus aureus	1.56		
	Thyme	*Staphylococcus aureus*	0.39		
		Streptococcus pyogenes	0.78		
		Corynebacterium spp	0.39		
3.	Cinnamon	*Staphylococcus aureus*	6.25	Commercial Oil	(Ferreira *et al*., 2019)
		Escherichia coli	3.12		
		Salmonella enterica	3.12		
4	Basil	*Campylobacter jejuni* (ATCC 29428,CC1,CC2,CC3,CC4,CC5)	0.83-2.0	Steam Distillation	(Pongsak and Parichat, 2010)
	Cinnamon		0.42-1.0		
	Corriander		0.03-0.06		
	Garlic		0.21-0.67		
	Tumeric		0.06-0.83		

Key; ATCC (reference strain), CC1 - 5 clinical strains.

Table 2: Minimum Inhibitory Concentrations of Various Extracts on Pathogens

S/N	Spice	Microorganisms	MIC	Mode of Extraction	References
1	Cinnamon	*Acinetobacter*	8	Aqeous Extraction	(Issa et al., 2021; Emmanuel *et al*., 2015)
		K. pneumonia	2		
		Protreus vulgaris	8		
		E. fecalis	4		
		S. aureus	0.5		
2	Cloves	*Bacillus subtilis*	100	Aqeous Extraction	
		S. epidermidis	6.25		
		Escherichia coli	6.25		
		Proteus mirabilis	6.25		
		Klebsiella pnuemoniae	6.25		
3	Corriander	*Bacillus cereus*	0.05	Hydro-distillation	(Bag and Chatopadhyay, 2015)
		Escherichia coli	0.14		
		Staphylococcus aureus	0.16		
	Cumin	*Bacillus cereus*	0.11		
		Staphylococcus aureus	0.13		
		Escherichia coli	0.30		
	Mustard	*Escherichia coli*	0.40		
		Bacillus cereus	0.15		
		Staphylococcus aureus	0.10		
4	Ginger	*Klebsiella* sp.	85.58	Solvent	(Karuppiah and Rajaram, 2012)
		Proteus sp.	70.20		
		P. aeruginosa	67.00		
		Enterobacter spp.	185.5		
		Escherichia coli	75.60		
		Staphylococcus aureus	68.45		
		Bacillus sp.	74.50		
	Garlic	*Bacillus* sp.	80.10		
		Staphylococcus aureus	78.90		
		Klebsiella sp.	160.20		
		Proteus sp.	89.00		
		P. aeruginosa	58.50		

		Enterobacter sp.	110.80		
		E. coli	65.50		
5	Cumin	*Bacillus subtilis*	12.5	Aqeous	Baljeet *et al*., 2014)
		Salmonella typhi	12.5		
		Candida albicans	12.5		
	Ginger	*Bacillus subtilis*	12.5		
		Salmonella typhi	12.5		
		Candida albicans	12.5		
	Garlic	*Bacillus subtilis*	12.5		
		Salmonella typhi	12.5		
		Candida albicans	12.5		
6	Ginger	*Bacillus subtilis*	2.5	Hydro-distillation	(San-guanpuang *et al*., 2011)
		p. aeruginosa	2.5		
		Salmonella enteritidis	2.5		
		Fusarium sp	10		

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