Chapter 21

Unveiling the Versatile Role of Essential oils in Food Industry for Enhanced Food Preservation

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ABSTRACT

The global food industry faces significant challenges stemming from the substantial loss of food materials due to spoilage and microbial contamination, exacerbating the scarcity of food per capita. Traditional preservation methods, reliant on synthetic additives, pose health risks, prompting a search for safer alternatives. Essential oils (EOs) have emerged as a beacon of hope, possessing multifaceted properties that render them invaluable in food preservation. This chapter delves into the pivotal role of EOs in combating food spoilage, elucidating their natural antimicrobial, antioxidant, and antifungal attributes with minimal health implications. Through an in-depth exploration of their application methodologies, the versatile efficacy of EOs in preserving food integrity is unveiled, underscoring their potential as avant-garde solutions in mitigating food loss and fortifying global food security.

KEYWORDS		
Encapsulation, Essential oils, Terpenoids, Antioxidants, Microencapsulation, Nano encapsulation	Received: 04-Jun-2024 Revised: 18-Jul-2024 Accepted: 07-Aug-2024	A Publication of Unique Scientific Publishers

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INTRODUCTION

Food Contamination or Spoilage

Organic substances which are mainly used to get energy or nutrition are referred to as food. Food can either be a plant or an animal origin. Foods are the source of micronutrients which are essential for the growth and development. Mostly food get spoiled which may cause change in the nutritional value of the food (Alonso et al., 2018). When the food does not affect the consumer's health and wellbeing it is considered as safe or secure. So food safety is referred as all the activities that guaranteed the food will not cause any health risk to the consumers (Kamala and Kumar, 2018). As human population has increased globally one of the major challenge is food insecurity or spoilage. A large portion of food get spoiled due to certain factors which is increasing the global hunger index. It has become difficult to fulfil the second sustainable development goal that is zero hunger due to unprecedented food spoilage. According to FAO almost one third of the food which can be used for human consumption get spoiled (Garvey, 2019). The primary stage of contamination started with changing the shape, color, texture and odor of food.

Causes of Food Contamination

Food contamination can be caused due to three main process that are microbial contamination, physical contamination and chemical contamination (Amit et al., 2017).

The food contamination through microorganisms is more common which enter in the food chain through several ways. Pesticides and inorganic fertilizers cause chemical contamination in food (Pina-Perez et al., 2017).

The microorganisms enter the food and start to multiply which causes a high level of food spoilage. They not only cause spoilage of food but also produce toxic materials in food which are usually referred as mycotoxins (Batiha et al., 2021). These microbes enter in food chain at any level during pre or post harvesting. These mycotoxins are contributors to food borne diseases which pose a great threat to public health and food security or sustainability (Alonso et al., 2018). Food spoilage due to microorganisms occurs in many ways as they alter the texture of food they cause a bad odor. As these microbes break down the proteins or fats in food it results in formation of grains or fungus over the food. Which identifies that the food gets spoiled (Hamad, 2012).

Traditional Food Preservation Methods

Food preservation encompasses methods and techniques employed to prevent the spoilage and degradation of food. Across ages, a plethora of traditional methods have been embraced to ensure the safety and security of food (Joshua Ajibola, 2020). A spectrum of preservation techniques is employed, spanning physical, biological, and chemical methodologies. Physical processing encompasses drying, chilling, pickling, irradiation, and freezing (Afsah-Hejri et al., 2020). Biological techniques for food preservation encompass fermentation processes, such as lactic acid fermentation for dairy goods or vinegar fermentation. Fermentation occurs spontaneously in certain foods, while in others, it may require initiation. Biological methods rely on microorganisms for food processing (Soomro et al., 2002).

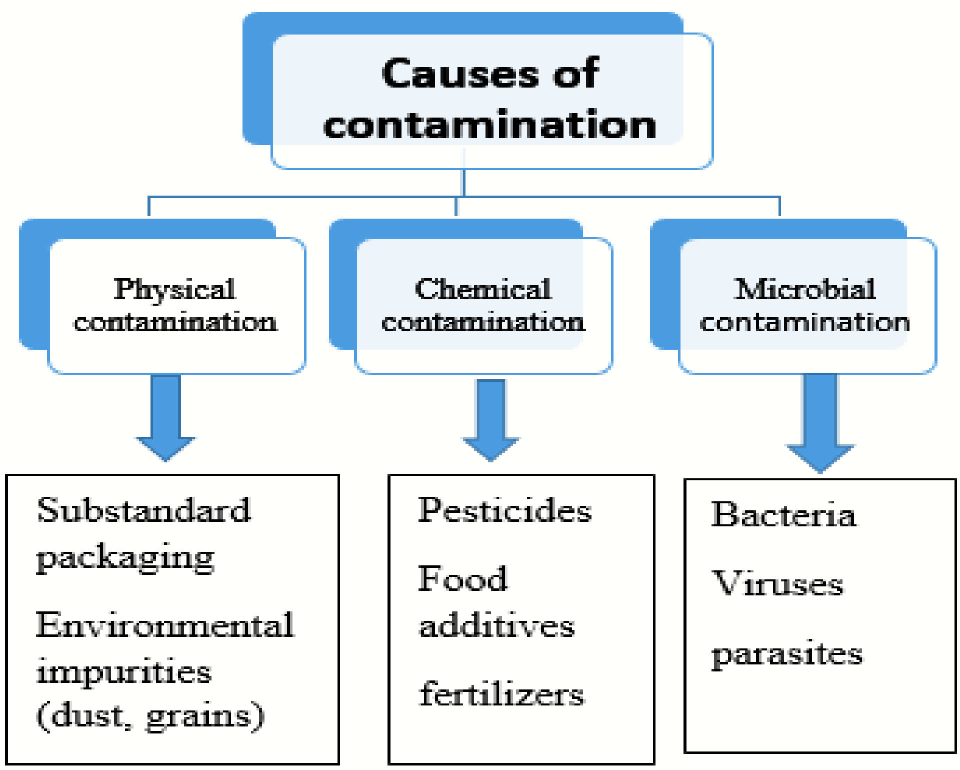

Fig. 1: Causes of food spoilage

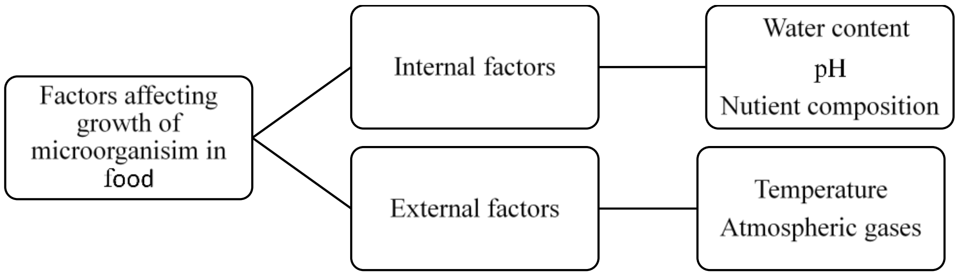

Fig. 2: Factors causing food deterioration by microbes

Chemical preservatives involve the incorporation of additives into food, encompassing both naturally occurring and synthetic food enhancements (Syamaladevi et al., 2016). Food additives are chemical compounds utilized to deter spoilage, enrich nutritional value, and augment flavor profiles in food products. Nonetheless, these additives have been linked to deleterious health ramifications (Mowafy et al., 2001). In our current era, artificial additives are extensively utilized in food production despite their recognized health hazards. These additives pose significant risks, especially for vulnerable populations such as patients, infants, the elderly, and expectant mothers, potentially precipitating various health conditions (Singh and Shalini, 2016). Therefore, there is an imperative need for additives or enhancements that carry no adverse health effects and instead offer favorable attributes for food preservation (Dwivedi et al., 2017).

The conventional approaches to food preservation have become obsolete in the face of modern advancements and preservative innovations. Essential oils have emerged as a cutting-edge alternative for safeguarding food, boasting a diverse set of properties that work wonders in ensuring food safety and stability, all without posing any harmful effects (Tiwari et al., 2009).

Introduction to Essential Oils

Essential oils represent the aromatic essence distilled or extracted from various botanical sources such as bark, herbs, woods, roots, and fruits (Turek and Stintzing, 2013). Commonly known as "volatile oils," they typically possess a colorless appearance alongside distinctive fragrances. Widely embraced across pharmaceuticals, cosmetics, and the culinary world, these oils are renowned for their potent aromas (Bakkali et al., 2008; Raut and Karuppayil, 2014), often utilized in perfumery and ambiance creation. Referred to as ethereal oils, they exhibit hydrophobic properties and are harbored within the oil glands of plant parts, particularly fruit peels. Diverse extraction methodologies are employed to harness these precious oils (Aziz et al., 2018).

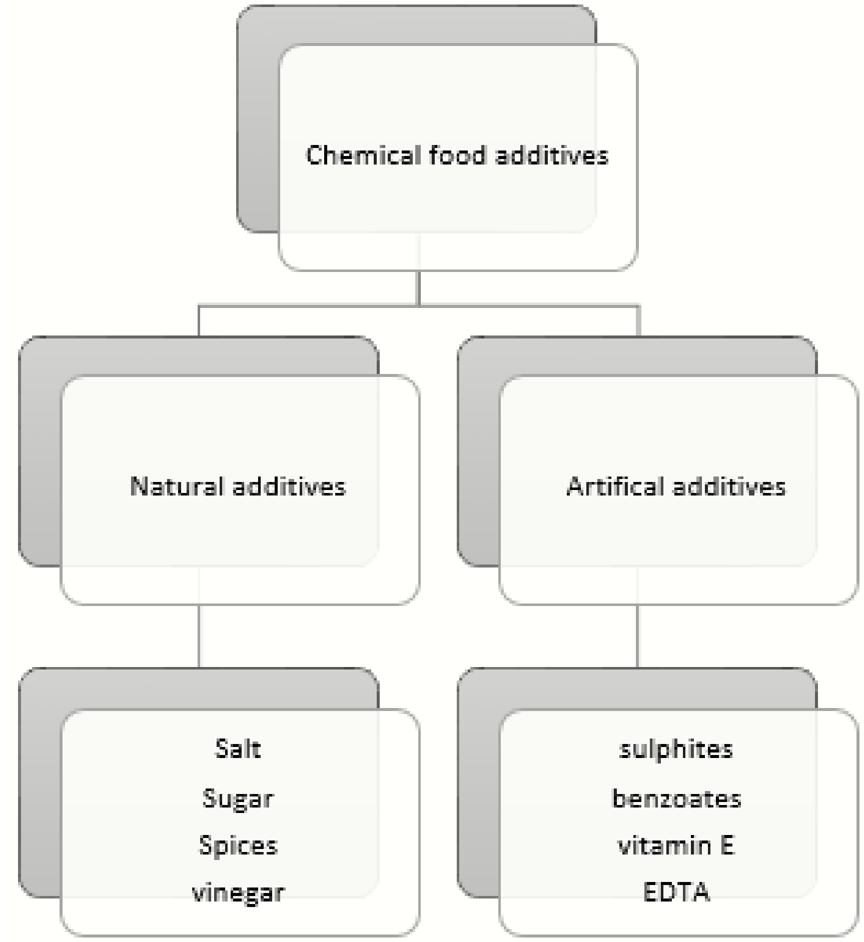

Fig. 3: Type of additives used in food

While essential oils have a historical presence, their resurgence in contemporary research and experimentation is fueled by their concentrated manifestation of nature's botanical treasures. Essential oils, derived from natural plant sources, are recognized for their innate antiviral, antifungal, and antimicrobial attributes (Langeveld et al., 2014). Classified as phytochemicals, they offer anti-inflammatory, analgesic, and fungicidal properties, along with acting as herbicidal agents. Additionally, they possess the capability to attract insects (Martins et al., 2017).

Components of Essential Oils

Essential oils represent a fascinating amalgamation of diverse chemical compounds, spanning both polar and nonpolar realms. Their intricate composition is a result of a multitude of factors, including the intricate interplay of the extraction methodology, botanical origin, and geographical specificity (Majeed et al., 2015). Primarily, essential oils are delineated into two fundamental groups: aromatic compounds and terpenoids (Vokou, 2007), each contributing distinct characteristics to the overall profile. Aromatic compounds, often referred to as phenylpropanoids, boast aromatic rings in their molecular architecture (Kar et al., 2018). These compounds are frequently imbued with benzene derivatives (Garay et al., 2020), showcasing an array of functional groups such as alcohols, aldehydes, ketones, and esters. Their aromatic nature not only confers pleasing scents but also imparts various therapeutic properties, ranging from antimicrobial to analgesic effect (Tongnuanchan and Benjakul, 2014).

Conversely, terpenoids exhibit a more nuanced complexity, stemming from their isoprene-based structures (Rao et al., 2019). These hydrocarbon-based molecules are assembled from isoprene units and subunits, manifesting a rich diversity of chemical functionalities. Monoterpenes, comprising a single isoprene unit, and sesquiterpenes, consisting of three isoprene units, dominate this category (Dehsheikh et al., 2020). Their intricate molecular frameworks endow essential oils with a plethora of biological activities, including anti-inflammatory, antioxidant, and neuroprotective properties (Nazzaro et al., 2013).

Moreover, the specific composition of essential oils is further shaped by ancillary factors such as environmental conditions, seasonal variations, and genetic predispositions of the botanical source. Consequently, essential oils serve as veritable reservoirs of chemical complexity (Crepet et al., 2007), offering not only olfactory delights but also a myriad of therapeutic potentials that continue to captivate scientific inquiry and application in diverse domains, from aromatherapy to pharmaceuticals (Mahmoudi et al., 2017).

In addition to terpenes, aromatic compounds constitute a significant portion of essential oils. These aromatic compounds typically contain benzene rings, albeit in relatively small proportions within the oil's overall composition (Mahato et al., 2019). They may exhibit a variety of functional groups such as hydroxyl, methoxy, and carboxylic groups, contributing to the complexity of the oil's chemical profile (Saad et al., 2013). Moreover, essential oils are known to contain a diverse array of chemical constituents beyond aromatic compounds and terpenes (Lee and Ding, 2016). These may include straight-chain molecules as well as other functional groups such as sulfur and nitrogen, further enriching the oil's composition and properties (Moleyar and Narasimham, 1992).

Properties of Essential Oils

The food industry extensively employs essential oils owing to their remarkable attributes and advantages, rendering them valuable for food preservation and storage purposes. These oils possess exceptional properties that contribute to their efficacy in maintaining the quality and safety of food products over time (Raut and Karuppayil, 2014).

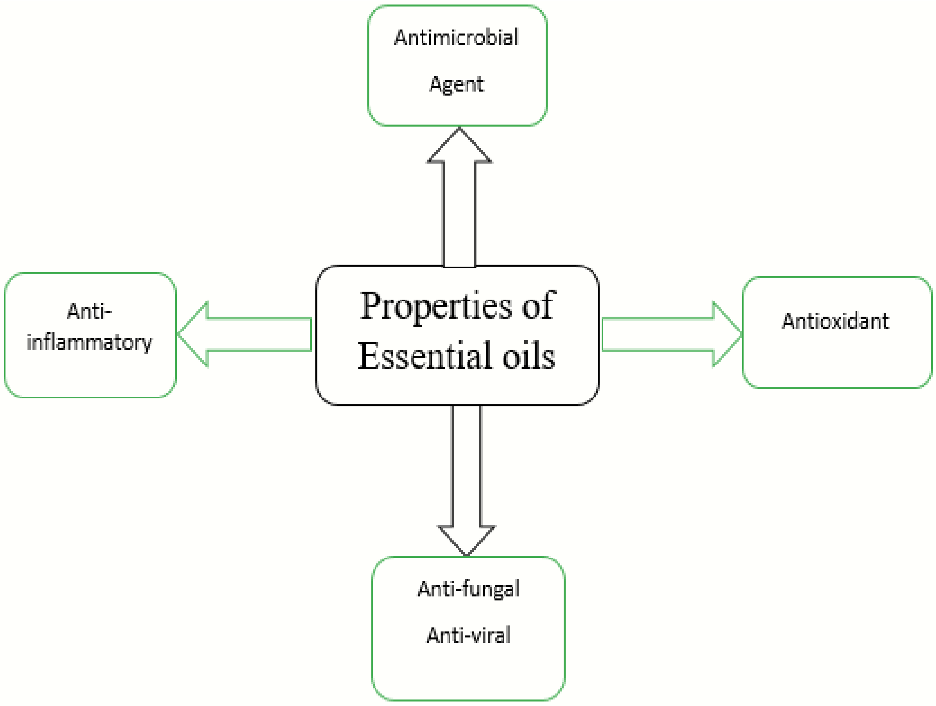

Fig. 4: Properties of essential oils

Elevating Antimicrobial Efficacy: The Prime Potential of Essential Oils

Antimicrobial agents represent a diverse array of compounds adept at impeding microbial growth or inducing their demise. Essential oils have emerged as particularly potent among these agents. Their hydrophobic nature facilitates penetration deep into microbial cell membranes, where they wreak havoc by disrupting the delicate balance of ion transport, ultimately leading to the demise of the microorganisms (Chouhan et al., 2017).

Recent findings suggest that aromatic essential oils (EOs) outperform their terpene-containing counterparts in terms of antimicrobial potency. In modern perspectives, EOs have garnered significant attention as potent antimicrobial agents owing to their health-preserving attributes and organic provenance, thus circumventing the apprehensions linked with harmful additives that pose substantial health risks (Dorman and Deans, 2000).

Essential oils featuring aldehydes, ketone, and ester moieties demonstrate heightened antibacterial effectiveness in contrast to those lacking such chemical constituents (Gyorgy, 2010).Essential oils possess the capability to induce cell wall damage, impede ATP synthesis crucial for bacterial energy metabolism, and heighten membrane permeability. This multifaceted action culminates in the degradation of microbial cell walls and subsequent leakage of intracellular contents. The antimicrobial prowess stems from the synergistic interplay of essential oils (EOs) sourced from varied botanical origins. Synergism, characterized by an amplification of effect when two compounds are conjoined, encapsulates this attribute. Despite the potential for antagonistic interactions, EOs exhibit synergistic effects (Ju et al., 2022; Probst et al., 2011).

When two distinct essential oils are amalgamated, their antimicrobial efficacy surpasses that of individual components, showcasing a heightened potency in tandem (Hammer et al., 1999).A catalog of plant sources yielding essential oils underscores their utility as antimicrobial agents, presenting intriguing prospects for future research. Notably, lemongrass oil, derived from Cymbopogon citratus (Mukarram et al., 2021), commonly known as lemongrass, emerges as a particularly noteworthy candidate. Exhibiting considerable antibacterial activity against a spectrum of pathogens, including both gram-positive and gram-negative bacteria such as Escherichia coli (Moore-Neibel et al., 2012), it showcases remarkable efficacy against disease-causing microorganisms. The aldehydes constituents found within lemongrass are credited for augmenting its antimicrobial potency (Premathilake et al., 2018), signaling promising avenues for further investigation.

Bustos C et al. (2016) was involved in pioneering research centered around the utilization of Lemon Grass Oil (LMO) as a protective film to impede the proliferation of E. coli bacteria. This innovative approach was tailored towards extending the shelf life of food commodities primarily sourced from fatty fruits. To accomplish this microcapsule for encapsulating lemongrass oil were developed, representing a cutting-edge strategy for enhancing food preservation and safety.

Boukhatem et al., (2014) research focused on unlocking the antimicrobial potential of lemongrass oil against both bacterial and yeast pathogens. By meticulously dissecting its chemical composition, we pinpointed the specific agents responsible for its antimicrobial efficacy. The findings underscored the superiority of certain components, particularly the essential oils, in providing formidable defense against gram-positive bacteria and select yeast strains. Moreover, we posited a novel conjecture that the efficacy of these essential oil constituents is heightened in their gaseous state compared to their liquid form. This revelation underscores the remarkable versatility and potency of lemongrass oil as a natural antimicrobial agent, positioning it as a cornerstone in the quest for innovative antimicrobial solutions.

Table 1.1: Utilizing Plant Essential Oils as Antimicrobial Agents for Optimal Food Preservation

Sources of EOs	Antimicrobial activity	Effect in food preservation	References
Lemongrass oil	Combating against bacterial and fungicidal microbes	Assist in the creation of coatings that prolong the shelf life.	(Bustos et al., 2016)
Clove oil	Enhanced antimicrobial potency against pathogenic bacteria such as *S. aureus, E. coli,* and *L. monocytogenes*.	Utilizing clove essential oil encapsulated within a polysaccharide matrix serves to inhibit bacterial proliferation, thus enhancing the preservation of meat products. Additionally, its robust scavenging capabilities play a pivotal role in extending the shelf life of cheese.	(Menon and Garg, 2001; Radunz et al., 2019)
Tea tree oil	Enhanced activity against *L. monocytogenes* and *E. coli*	Tea tree oil disrupts the cellular membranes of bacterial pathogens, leading to their demise, thereby aiding in the preservation of freshly squeezed fruit juices, particularly cucumber juice.	(Shi et al., 2018)
Limonene oil	Best antimicrobial agents against *Salmonella enterica and Listeria monocytogenes.*	The application of a d-limonene nanoeulsion coating on fresh bananas exhibited a notable extension in their shelf life and a marked reduction in microbial proliferation, promising enhanced preservation.	(Hou et al., 2022)
Lavender oil	Suppress bacterial and fungal growth	Demonstrated to be a cost-effective preservation additive, aiding in the preservation of ready-to-use mushrooms. This is achieved through the utilization of lavender oil encapsulated within chitosan, complemented by cinnamon oil serving as a natural preservative. The chitosan-encapsulated lavender oil also contributes to the preservation of food items.	(Farokhian et al., 2017; Liu et al., 2022)
Eucalyptus oil	Antifungal agents against fungus species (P. expansum)	A blend of eucalyptus essential oil and rosemary oil was employed to protect pears and apples, resulting in diminished fungal growth and prolonged fruit shelf life. This underscores its potential as a natural fungicidal preservative for food products.	(Xylia et al., 2021)
Thyme essential oil	Against bacteria, viruses and fungal species	Nanoemulsions of thyme essential oils were used for the preservation of meat and increasing the storage period.	(Snoussi et al., 2022)

Essential Oils: Superlative Antioxidants for Food Preservation

The inclusion of phenolic components endows essential oils with exceptional antioxidant properties, sourced from a diverse array of botanicals and herbs. These compounds, known as polyphenols, are present in minute proportions relative to oxidants but exert significant influence by impeding oxidation processes. Consequently, essential oils emerge as invaluable food supplements, instrumental in mitigating health risks and fortifying cardiovascular health (Baratta et al., 1998).

The innate redox characteristics of essential oils underscore their unparalleled efficacy as reducing agents. Employing diverse methodologies like the DPPH or FRAP assays enables the quantification of phenolic content (Teixeira et al., 2013), illuminating their radical scavenging prowess. Within essential oils, aromatic compounds serve as primary sources of polyphenols (Jirovetz et al., 2006), thus augmenting their anti-oxidative capacity. Certain botanical species, such as cloves, exhibit notably elevated levels of phenolic compounds in their essential oils, endowing them with exceptional antioxidant properties, often surpassing synthetic counterparts.

This heightened efficacy is primarily attributed to the presence of eugenol (Misharina and Samusenko, 2008). Similarly, carvacrol, a constituent found in oregano, imparts potent antioxidant attributes to its essential oil (Olmedo et al., 2014). The complex interplay between essential oil constituents and radicals serves as the cornerstone of their antioxidant functionality. Furthermore, the synergistic amalgamation of these bioactive components within essential oils further enhances their antioxidant potency, making them formidable allies in combatting oxidative stress and preserving health. In the endeavor to thwart oxidation, essential oils (EOs) deploy multifaceted strategies (Misharina and Polshkov, 2005).

Through the donation of hydrogen ions, EOs intricately disrupt the oxidative cascade, facilitating the conversion of free radicals into stabilized molecules. This pivotal role defines them as primary antioxidants (Damien Dorman et al., 1995). Concurrently, secondary antioxidants operate by engaging chelating agents, orchestrating the neutralization of free radicals, and orchestrating their transformation into inert components (Yang et al., 2010).

The rich array of antioxidants inherent in natural food matrices serves as a bulwark against diseases stemming from the menacing presence of nitrogen and oxygen species. Harnessing essential oils to stave off lipid oxidation heralds an innovation in the preservation of vegetable oils harboring both saturated and unsaturated lipids (Perumal et al., 2022), thereby significantly extending their shelf life. Descriptive accounts delineate how particular essential oils operate and their efficacy as natural antioxidants in ensuring food preservation and safety, elucidated as follows:

Rodriguez-Garcia et al. (2016) delved into the utilization of oregano essential oils' antioxidant prowess. Their investigation revealed a significant contribution in inhibiting lipid peroxidation, thus bolstering the longevity of dairy products, oils, and various lipid-rich food substrates.

Yang et al. (2010) undertook a comprehensive analysis to discern the antioxidant efficacy among six distinct essential oils. Notably, lavender oil emerged as a standout, boasting elevated phenolic content and robust lipid peroxidation inhibition. Their findings underscored the profound potential of these botanical extracts in quelling free radicals, thereby combatting food spoilage. Thus, the discerning use of essential oils as natural antioxidants holds promise for bolstering preservation strategies within real-world food systems.

Unveiling Essential Oils: Antifungal and Anti-inflammatory Potency

Fungal infections, often more menacing than those caused by bacterial pathogens, pose significant risks to living organisms. With chitin comprising the structural backbone of fungal cell walls, targeting its destruction becomes imperative for inhibiting fungal growth. To safeguard food materials against fungal contamination, the use of natural antifungal additives, notably essential oils extracted from a myriad of plant sources, has emerged as a frontline defense. Renowned for their formidable fungicidal properties, these essential oils deploy diverse mechanisms of action, presenting a sophisticated arsenal against fungal proliferation in food matrices (Nazzaro et al., 2017).

When tissues succumb to infection, inflammation swiftly follows suit, serving as the body's frontline response against intruders. Across centuries, essential oils sourced from select plants have emerged as venerable allies in combating inflammation. Notably, their profound anti-inflammatory prowess intricately intertwines with their robust antioxidant potency, forming a formidable defense against tissue damage and oxidative stress (Tsai et al., 2011).

Indeed, while the anti-inflammatory properties of essential oils stand out, their efficacy is influenced by various factors beyond antioxidant activity alone. Essential oils possess a diverse composition, each with its unique blend of bioactive compounds. Additionally, multiple mechanisms come into play, impacting their anti-inflammatory potential. Consequently, the effectiveness of essential oils in mitigating inflammation can be influenced by factors such as their chemical composition, concentration, and interactions with biological systems (Miguel, 2010).

Advanced Application Methods of Essential Oils in Real Food Systems for Enhanced Preservation Efficacy

During preparation, storage and distribution many food products must be preserved from deterioration as they are naturally perishable (Teodoro, 2019). The consumer demand of food products with improved shelf life has increased because of general availability of the goods in different regions of world (Mani-Lopez et al., 2018). International trading of perishable food has become possible but refrigeration is not promising process which assure the quality of food (Sahu and Bala, 2017). However, the worth of traditional methods of food preservations have been acknowledged and concerns has been raised about their safe (Ribes et al., 2018).

In order to satisfy consumers demand for food a number of nontraditional techniques have been developed. in order to kill vegetative bacterial species foods are processed via thermal heating at higher temperature for a specific interval of time (Powell et al., 2011). A great amount of energy is transferred to food during this process. But this process results in unwanted side reactions which effects the organoleptic properties of food (Pal, 2014).

Encapsulation of essential oils

Encapsulation techniques have promising effect on food safety and preservation. Encapsulation is widely used method for engineered goods in many food industries, specifically in production, processing and development of new products (Vemmer and Patel, 2013). Encapsulation involves entrapment of functionally active core material into matrix of inert material. It requires a core material and a coating material (Comunian et al., 2021). There are many methods of encapsulation which are classified into physical and chemical methods (Zhang et al., 2021).

Microencapsulation of Essential Oils

The process through which a coating is made around small particles that may be solid, liquid and gas to form small capsules which are referred to as microcapsules. ME is basically a food packaging technology of materials in sealed and tiny capsules (Ozkan et al., 2019). It helps in protection of flavors and aroma of volatile compounds during their processing and storage. Which in turn are used in enhancement of taste of food products. Microencapsulation results in extension of shelf life of food materials by encapsulating active ingredients (Aloys et al., 2016). Which results in maintenance of quality of food products.

Emulsification Encapsulation of Essential Oils

Emulsification encapsulation is extensively used technique in food and pharmaceutical industries to encapsulate a liquid or solid particle in any of the liquid medium. Two liquids that are immiscible are used to form a stable emulsion (Kakran and Antipina, 2014).

Nano Encapsulation of Essential Oils

The use of nanotechnology in food industry results in innovation of large scale properties for food as its color, flavor, texture, taste, coloring strength and stability. Furthermore, nanotechnology can increase the water solubility, thermal stability and oral absorption of bioactive compounds (Paredes et al., 2016) It has enormous benefits as Nano encapsulation provides better stability to the active materials as EOs, vitamins, enzymes, polysaccharides and carbohydrates and results in targeted drug delivery in pharmaceutical industries as well as in food industries. It protects targeted substances from external environmental conditions (Ayala-Fuentes and Chavez-Santoscoy, 2021)

Formation of Edible Films and Coatings

Essential oils play a pivotal role in crafting edible coatings and films, instrumental in safeguarding food items. These innovative coatings, when applied to food materials, effectively extend their shelf life. The creation of these edible coatings and films involves diverse encapsulation techniques, which are subsequently utilized to enhance their effectiveness upon application to food products.

Pirozzi et al. (2020) a studied the utilization of Nano emulsions containing oregano oil demonstrated remarkable efficacy in preventing the spoilage of tomatoes during prolonged storage periods. This innovative approach showcased the extraordinary capacity of essential oils to extend the shelf life of tomatoes by up to 14 days, effectively inhibiting microbial growth and preserving their freshness.

Usage of Essential Oils as Natural Preservatives

In the realm of food preservation, the drawbacks of synthetic preservatives, including health risks and environmental harm due to their pesticidal properties and non-eco-friendly nature, spurred a quest for viable alternatives (Ballesteros et al., 2017). Essential oils emerged as a transformative solution, offering a blend of natural efficacy and sustainability in replacing artificial additives (Galvez et al., 2014).

Their innate hydrophobicity and volatility make them adept at preserving food without altering its composition or sensory attributes, thus seamlessly integrating into food systems(Tiwari et al., 2009). As a result, essential oils extracted from plant sources have become prized assets in the food industry, supplanting synthetic preservatives and championing a greener, more health-conscious approach to food preservation.

Conclusion

The aforementioned discussion indicates that essential oils extracted from different plants possess distinct effects and harbor numerous beneficial properties that can be harnessed in actual food systems to combat pathogens, effectively safeguarding food from spoilage. Moreover, these oils are considered safe for consumption, given their organic nature, and have not been associated with adverse health effects. Examples showcasing the utilization of essential oils, which exhibit potent antimicrobial properties against specific microorganisms, highlight their efficacy as unparalleled antimicrobial agents in preserving food integrity and prolonging its shelf life during storage periods.

Despite their remarkable benefits, some challenges such as strong odors can be addressed through techniques like encapsulation. Various methods have been devised to incorporate essential oils into food applications. While numerous essential oils have already found application in real food systems, there remains a necessity to explore their potential as bio preservatives further. Extensive research is warranted to unravel their full spectrum of beneficial properties. Nonetheless, the integration of essential oils into food preservation techniques represents a sophisticated approach, paving the way for enhanced bio preservation methods in the food industry.

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