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Review

Natural products as antimicrobial agents

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ABSTRACT

The use of natural antimicrobial compounds in food has gained much attention by the consumers and the food industry. This is due primarily to two major factors. First, the misuse and mishandling of antibiotics has resulted in the dramatic rise of a group of microorganisms including foodborne pathogens that are not only antibiotic resistant but also more tolerant to several food processing and preservation methods. In addition, increasing consumers' awareness of the potential negative impact of synthetic preservatives on health versus the benefits of natural additives has generated interest among researchers in the development and use of natural products in foods. This has prompted the food industry to look for alternative preservatives that can enhance the safety and quality of foods. Compounds derived from natural sources have the potential to be used for food safety due to their antimicrobial properties against a broad range of foodborne pathogens. This article reviews the antibacterial activity of natural components from different sources including plants, animals, bacteria, algae and mushrooms, and their potential use in food systems.

Contents

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1. Introduction

Foodborne illnesses are a major concern for consumers, the food industry, and food safety authorities. In recent years, considerable effort has been made to find natural antimicrobials that can inhibit bacterial and fungal growth in foods in order to improve quality and shelf-life. Similarly, consumers have become concerned about the safety of synthetic preservatives used in food. As a result, there is increasing demand for natural products that can serve as alternative food preservatives (Tajkarimi, Ibrahim, & Cliver, 2010). This, in turn, has led to a search for antimicrobials derived from a variety of natural sources. Natural antimicrobials can be obtained from different sources including plants, animals, bacteria, algae and fungi. Several studies related to plant antimicrobials have demonstrated the efficacy of plant-derived compounds in food applications, as well as factors influencing this effectiveness (Cowan, 1999; Gyawali & Ibrahim, 2012; Hayek, Gyawali, & Ibrahim, 2013; Tajkarimi et al., 2010). However, there has been limited research related to the structure–function relationship of these compounds. As a result, the importance of the chemical composition of plant-derived compounds with regard to their antimicrobial activity is still not well understood. Among several plant-derived compounds, polyphenolic compounds have great structural diversity and variations in chemical composition, and thus differ in their antibacterial effectiveness against pathogenic microorganisms (Stojković et al., 2013). The antimicrobial activity of plant extracts may thus be due to the presence of phenolic compounds or other hydrophobic components in the essential oils (EOs) (Dorman & Deans, 2000). It should also be noted that the investigation of possible antibacterial activity of by-products generated from fruits and vegetables is very limited in the literature. These by-products can also be used as sources of antibacterial compounds (Baydar, Sagdic, Ozkan, & Cetin, 2006; Jayaprakasha, Selvi, & Sakariah, 2003; Matsumoto et al., 2004) and thus could be a potential source of low-cost natural antimicrobials. Antimicrobial compounds produced by algae and fungi (mushrooms) against pathogens have recently received considerable attention as a new source of novel antimicrobial substances (Bhagavathy, Sumathi, & Jancy Sherene Bell, 2011; Ramesh & Pattar, 2010). There are many unexplored sources of such potential compounds that could be used as natural preservatives in food applications. This paper reviews various antimicrobials from plants, animals, bacteria, algae and mushrooms. In addition, different methods of incorporating these antimicrobials into our food systems are discussed.

2. Antimicrobials of plant origin

2.1. Plant-derived compounds

Most of the available studies related to plant-derived antimicrobials found in scientific literature involve the antimicrobial or antioxidant activity of herbs, spices, and their compounds (Cueva et al., 2010; Negi, 2012; Tajkarimi et al., 2010). In this section, we provide an overview of the antimicrobial activity of these compounds mainly based on their structural characteristics. Plant-derived compounds from herbs and spices have been used since ancient times for flavoring food, as traditional medicine, and as preservatives. In addition to being used in food to impart flavor, pungency and color, herbs and spices also have antioxidant, antimicrobial, nutritional and pharmaceutical properties (Lai & Roy, 2004). Plant-derived compounds are mostly secondary metabolites, most of which are phenols or their oxygen-substituted derivatives. These secondary metabolites possess various benefits including antimicrobial properties against pathogenic and spoilage microbes (Hayek et al., 2013). Major groups of compounds that are responsible for antimicrobial activity from plants include phenolics, phenolic acids, quinones, saponins, flavonoids, tannins, coumarins, terpenoids, and alkaloids (Ciocan & Băra, 2007; Lai & Roy, 2004). Variations in the structure and chemical composition of these compounds result in differences in their antimicrobial action (Savoia, 2012). (Fig. 1).

The structural diversity of plant-dervied compounds is immense, and, the impact of antimicrobial action they produce against microorganisms depends on their structural configuration. Phenolic compounds possess great structural variations and are one of the most diverse groups of secondary metabolites. The hydroxyl (–OH) groups in phenolic compounds are thought to cause inhibitory action (Lai & Roy, 2004) as these groups can interact with the cell membrane of bacteria to disrupt membrane structures and cause the leakage of cellular components (Xue, Davidson, & Zhong, 2013). The presence of –OH group in the phenolic compounds plays an important role in the antimicrobial activity of carvacrol and thymol. Active group such as –OH promotes the delocalization of electrons which then act as proton exchangers and reduce the gradient across the cytoplasmic membrane of bacterial cells. This will cause the collapse of the proton motive force and depletion of the ATP pool and ultimately leading to cell death (Ultee, Bennik, & Moezelaar, 2002). Similarly, Farag, Daw, Hewidi, and El-Baroty (1989) reported that these –OH groups can easily bind the active site of enzymes by altering the cell metabolism of microorganisms. This action demonstrates the importance of –OH groups in antimicrobial activity. Phenolic compounds also act as antioxidants. The presence of a free –OH group in phenolic compounds results in the antioxidant properties. This property has been reported to inhibit the generation of reactive oxygen species, as well as the scavenging of free radicals thereby reducing the redox potential of the growth medium (Cueva et al., 2010; Stojković et al., 2013). This lowering of redox potential may further restrict the growth of undesirable microorganisms.

As reported by Dorman and Deans (2000), the position of the –OH group also influences the components' antimicrobial effectiveness. For example, the structure of thymol is similar to that of carvacrol; however, difference in antimicrobial effectiveness between thymol and carvacrol against Gram-positive and Gram-negative bacteria was observed when tested in agar medium. This difference has been attributed to the –OH group located at the *meta* position in thymol compared to the *ortho* position in carvacrol. Alcaraz, Blanco, Puig, Tomas, and Ferretti (2000) also reported the importance of the –OH group at position 5 of flavanones and flavones for activity against methicillin-resistant *Staphylococcus aureus* strains. Ultee et al. (2002) emphasized the importance of the –OH group and its system of delocalized electrons present in carvacrol against foodborne pathogens. Their study compared the activity of carvacrol to menthol, carvacrol methyl ester, and cymene. The authors concluded that the growth of *Bacillus cereus* was not inhibited due to the lack of –OH groups in carvacrol methyl