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Natural antioxidants as food and feed additives to promote health benefits and quality of meat products: A review

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ABSTRACT

Fresh and processed meats offer numerous nutritional and health benefits and provide unique eating satisfaction in the lifestyle of the modern society. However, consumption of red meat including processed products is subjected to increasing scrutiny due to the health risks associated with cytotoxins that potentially could be generated during meat preparation. Evidence from recent studies suggests free radical pathways as a plausible mechanism for toxin formation, and antioxidants have shown promise to mitigate process-generated chemical hazards. The present review discusses the involvements of lipid and protein oxidation in meat quality, nutrition, safety, and organoleptic properties; animal production and meat processing strategies which incorporate natural antioxidants to enhance the nutritional and health benefits of meat; and the application of mixed or purified natural antioxidants to eliminate or minimize the formation of carcinogens for chemical safety of cooked and processed meats.

1. Introduction

Meat is a highly nutritious source of food that provides high-quality proteins, minerals, vitamins, and many other micronutrients. Consumption of meat, particularly red meat (beef, pork, and lamb), is dated back to antiquity and remains to be a dominant lifestyle and usually a nutritionally indispensable form of life in the modern society. However, despite the overwhelming nutritional benefits, red meat consumption has been linked with coronary heart diseases and several types of cancer. A purported underlying mechanism is the generation of chemical toxins (carcinogens and mutagens) during processing operations, such as curing, smoking, fermentation, and heat treatment (McAfee et al., 2010). Therefore, processed red meat is subjected to particular scrutiny.

Processed meat encompasses a wide variety of products prepared through some degree of muscle structural alterations along with the application of various functional food ingredients for organoleptic and preservation purposes. Deli-style sliced ham, frankfurters, and fresh sausages are examples of common processed products. In spite of the re-creatable taste, food variety, convenience, and good nutritional value desired by the consumer, processed meats are often perceived to be less healthy than many other types of food. In October, 2015, the International Agency for Research on Cancer (IARC) under World Health Organization (WHO) issued a monograph classifying processed meat as carcinogen (Group I) and red meat as probable carcinogen (Group 2A), based on the survey of published human and animal studies on meat consumption in relation to colorectal and other types of cancer.

While the IARC's claim remains disputable and the outweighing nutritional benefits of processed meats cannot be ignored, innovative processing and ingredient strategies must be developed to minimize the health concern and improve the products' overall organoleptic, nutritional, and health qualities. Much of the claim that processed meats are unhealthy stems from the ingredients that are added during processing as well as the processing condition itself (Jiménez-Colmenero, Carballo, & Cofrades, 2001; Vitaglione & Fogliano, 2004). On this, oxidation and associated deleterious changes often are viewed as a main causative factor. Due to the presence of added salt (NaCl), heme iron, and the relative abundance of endogenous phospholipids, processed muscle foods are very susceptible to oxidative reactions. Indeed, radical-induced lipid and protein oxidation occurring in high-temperature cooking contributes to the formation of potentially harmful health hazards. These include a variety of carbonyl-based cytotoxic and genotoxic compounds known as 'advanced lipid oxidation end products (ALEs)', such as 4-hydroxynonenal (4-HNE) and malonaldehyde (MDA) (Kanner, 2007; Negre-Salvayre, Coatrieux, Ingueneau, & Salvayre, 2008), mutagenic heterocyclic aromatic amines (HAAs) formed at high temperatures, such as 2-amino-1-methyl-6-phenylimidazo[4,5-b]pyridine (PhIP) and 2-Amino-3,8-dimethylimidazo[4,5-f]quinoxaline (8-

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MeIQx) (Shabbir, Raza, Anjum, Khan, & Suleria, 2015; Turesky, 2007), and carcinogenic nitrosamines in nitrite-cured products (Toldra, 2010).

Recent advances in antioxidant research have enabled meat scientists to think the possibility of mitigating chemical toxins in meat products through different strategies, for example, moderate thermal processing conditions to reduce the toxin formation, bioaccessibility restriction technology, and antioxidant interventions (Engel, Ratel, Bouhlel, Planche, & Meurillon, 2015). The latter is of particular interest because it is believed that many of the toxin-forming reactions involve free radicals in which reactive oxygen species (ROS) are particularly implicated. While synthetic antioxidants, such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), propyl gallate (PG), and tertiary butylhydroquinone (TBHQ), have long been used to inhibit oxidation-induced deleterious changes in meat, they are under increasing scrutiny due to the potential genotoxic effects. Therefore, the current industrial trend has shifted toward natural antioxidants derived from various plant materials which are rich in radical-scavenging polyphenols (Shahidi, Janitha, & Wanasundara, 1992). 'Nature-origin' antioxidants have also been developed from enzymatic hydrolysis of protein (peptides) and cross-linking of small molecules into amphiphilic antioxidants suitable for the interface (in emulsions, foams, etc.) (Elias, Kellerby, & Decker, 2008; Jiang & Xiong, 2015; Xiong, 2010). While synthetic antioxidants at high dosage application levels can be carcinogenic, there is much less documented evidence indicating adverse effects of natural antioxidants. Not only are natural antioxidants capable of neutralizing ROS therefore reducing the probability of toxin formation when high temperatures are applied (Balogh, Gray, Gomaa, & Booren, 2000), but when used in the product formulation they could also augment existing antioxidant potential even if meat is not subjected to extensive processing. This added health and nutritional benefit could be a distinctive advantage of natural antioxidants applied to meat processing.

In human bodies, the antioxidant defense system includes enzymes (e.g., superoxide dismutase, glutathione peroxidases, and catalase), iron and copper-binding extracellular proteins (e.g., albumin, transferrin, lactoferrin, haptoglobin, and ceruloplasmin), antioxidant vitamins (e.g., vitamin C, vitamin E, and β-carotene), and other cellular compounds (e.g., quinones, glutathione, uric acid, and bilirubin) (Krinsky, 1992). In addition, various exogenous phenolic compounds derived from dietary fruits, vegetables, legumes, or ingredients added to food, such as spices and herbs used in processed meats, contribute to the antioxidant pool. These dietary sources of antioxidants are essential when the body is exposed to a high degree of radical stress.

Antioxidants used to preserve raw and precooked meat have recently been reviewed. Karre, Lopez, and Getty (2013) analyzed the antioxidant effects of several fruit juice and plant extracts on meat and poultry; Shah, Bosco, and Mir (2014) reviewed the protective role of several plant extracts in the oxidative stability of meat; similarly, Kumar, Yadav, Ahmad, and Narsaiah (2015) described recent trends in the use of natural antioxidants for meat and meat product quality protection. In our present review, we describe the potential efficacy of several antioxidant strategies, including those applied to meat animal production to boost the antioxidant pool in muscle tissue and those directly added to meat product formulations, to improve the health and nutritional benefits of meat and meat products. Our focus is on the inhibition of toxin formation and the enhancement of nutritional status of meat products by natural antioxidants.

2. Lipid and protein oxidation in meat and meat products

Lipid peroxidation in meat products occurs primarily through the radical chain reaction mechanism although singlet oxygen may provide an alternative pathway (Min & Ahn, 2005). The high degree of susceptibility of animal fat to oxidation in such products is due to a variety of factors: the relatively high proportion of polyunsaturated fatty acids (PUFA) as constituents of membrane phospholipids, the deficiency of endogenous antioxidants, such as tocopherols, when compared with vegetable and other plant oils, yet, high concentrations of pro-oxidants and radical initiators, such as heme species, high concentrations of salt (NaCl) added, and the abundance of molecular oxygen that is usually incorporated into blended meats during processing operations (Kanner, Harel, & Salan, 1988). Salt has been found to reduce the activity of catalase, glutathione peroxidase, and superoxide dismutase (Lee, Mei, & Decker, 1997), which may be one of the reasons why salted fresh meat has poor oxidative stability.

During meat processing, oxygen can be converted to various reactive species (ROS), including hydroxyl radical (•OH), superoxide anion (O_2•$^-$), ferryl and perferryl species [Oxy-Fe(IV)•$^+$], lipid peroxyl radical (LOO•), alkoxyl radical (LO•), and many others (Decker & Hultin, 1992; Kanner et al., 1988). A variety of secondary products are generated in the process of lipid peroxidation, notably reactive carbonyl species, such as MDA and 4-HNE. Many of the lipid oxidation end products (ALEs) are responsible for oxidative rancidity and can participate in heath-hazardous compound formation through reaction with other meat components.

The advances in meat science research over the past two decades have led to a wealth of information indicating that muscle proteins are also susceptible to both radical and non-radical ROS, and, in some cases, even more labile to radicals than PUFA (Yang & Xiong, 2015). The mechanism of protein oxidation has been described in several comprehensive reviews (Stadtman, 2006; Xiong, 2000). Discussion of the specific impact of protein oxidation on the functionality and quality of meat has been presented by Xiong and Decker (1995) and Estevez (2011). In general, the same oxidants that initiate lipid oxidation have been found to cause and propagate protein oxidation, and carbonyl formation is a common reaction pathway found in the oxidation process. In addition, proteins can react with secondary products of lipid peroxidation, for example, aldehydes and ketones, to produce carbonyl derivatives and protein–protein and protein-lipid complexes (Butterfield & Stadtman, 1997). In muscle food systems, •OH is readily generated through the reaction of H_2O_2 or lipid peroxide with iron or copper and causes site-specific modification of amino acids, such as methionine and lysine (Park & Xiong, 2007).

$$H_2O_2 + Fe(II)/Cu(I) \rightarrow \bullet OH + OH^- + Fe(III)/Cu(II)$$

$$\bullet OH + Protein(lysine) - NH_2 \rightarrow Protein - COH \text{ (carbonyl)}$$

The formation of protein radicals via reacting with ROS involves the abstraction of a hydrogen atom from methylene groups (α-carbon) next to the peptide bond (carboxyamide). This is essentially similar to lipid oxidation where free radicals are formed initially by producing an unpaired electron while abstracting a hydrogen from the methylene group adjacent to the double bond. Many amino acid residue side chains are readily modified by ROS. Amino acids with reactive side chains (sulfhydryl, thioether, amino group, imidazole ring, and indole ring) are most susceptible to oxidation initiated by oxidizing lipids and their products (Roubal & Tappel, 1966; Stadtman, 2006). Thus, cysteine, methionine, lysine, arginine, histidine and tryptophan residues are common targets of ROS generated via lipid peroxidation. Other susceptible amino acids include valine, serine and proline. Electron spin resonance (ESR) has been used to identify protein and amino acid radicals as direct evidence of protein oxidation (Lund, Luxford, Skibsted, & Davies, 2008).

Common consequences of protein oxidation in complex meat systems include increased susceptibility to proteolytic enzymes, protein polymerization which produces soluble aggregates that may promote gelation and emulsification, or insoluble aggregates that are impedimental to water binding and texture (Srinivasan & Hultin, 1997; Xiong, Blanchard, Ooizumi, & Ma, 2010; Xiong, Park, & Ooizumi,