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Review paper

Protein oxidation in meat products: exploring the role of natural antioxidants in preservation and quality enhancement

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ABSTRACT

Protein oxidation is a complex process involving the oxidative damage of proteins by reactive oxygen species and other oxidizing agents. It can lead to structural and functional alterations in proteins, impacting their biological activity. The primary cause of protein oxidation in meat products is the presence of endogenous enzymes, such as myoglobin and hemoglobin, which contain iron and catalyze oxidation reactions. Additionally, the presence of heme pigments, unsaturated fatty acids, and transition metal ions in meat can further promote protein oxidation. Protein oxidation in meat products can lead to several undesirable changes. One of the most noticeable effects is the development of off-flavors and off-odors, commonly described as rancidity. Natural antioxidants are compounds found in various plant-based sources, such as fruits, vegetables, herbs, and spices. These antioxidants possess the ability to scavenge free radicals and inhibit oxidative reactions, including the oxidation of proteins in meat. By exploring the effects of natural antioxidants on protein oxidation in meat products, it is possible to gain insights into their potential as functional additives for enhancing product stability and maintaining desired sensory characteristics. This paper aims to delve into the impact of natural antioxidants on protein oxidation in meat products and shed light on their role in preserving product quality and extending shelf life.

1. Introduction

Meat and meat products are highly nutritious and contain significant amounts of moisture with a neutral pH, making them prone to spoilage. To maintain their quality, and safety, and prevent potential health risks, proper preservation methods are crucial (*Aminzare et al*., 2016). Oxidation and microbial degradation are the primary factors that limit the quality and acceptability of meat products. These processes negatively impact the taste, color, texture, and nutritional composition (*Kavuşan and Serdaroğlu*, 2021; *Das et al*., 2020). While oxidative damage leading to a quality loss in meat products has been primarily attributed to lipids, it has been recognized that proteins also serve as substrates in oxidation reactions (*Zungur-Bastıoğlu et al*., 2016). Protein oxidation is a complex chemical process that occurs in meat and meat products, leading to detrimental effects on technological and sensory quality and nutritional value (*Serdaroğlu et al*., 2017). Protein oxidation, in a general sense, refers to the covalent modification of proteins induced either directly by reactive oxygen species (ROS) such as OH• and H_2O_2, or indirectly by

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the secondary products of oxidative stress (*Estevez*, 2011; *Zhang et al.*, 2013; *Zungur-Bastıoğlu et al.*, 2016). The protein oxidation formation mechanism resembles the lipid oxidation reaction. In the initial stage, reactive oxygen and nitrogen species, such as hydroperoxides, aldehydes, OH, O_2, and ROO, metals like iron and copper, and hydrogen atom separation from amino acids cause protein radicals to form. These reactions result in the binding of protein radicals with OH ions, leading to the formation of water (H_2O) (*Zhang et al*., 2013). The generated protein radical reacts with oxygen, giving rise to protein peroxyl radicals (POO•), which then acquire hydrogen atoms to form protein hydroperoxides (POOH) and new protein radicals (P•) (*Bao et al*., 2018). Due to their instability, hydroperoxides rapidly decompose into alkoxy radicals (PO•) and hydroxyl radicals (HO•). This results in the conversion of certain amino acid residues into carbonyl compounds (*Ergezer et al*., 2016). Changes in particular amino acid residues, such as proline, arginine, lysine, and threonine, occur as a result of protein oxidation, leading to an increase in carbonyl content (*Dominguez et al*., 2021; *Hellwig*, 2020). Decreases in sulfhydryl and tyrosine content are observed due to the formation of disulfide bonds and dityrosine bridges through oxidation (*Ergezer et al*., 2016).

In the meat industry, there is growing interest in identifying effective strategies to mitigate protein oxidation and preserve the overall quality of meat products. To mitigate the negative effects of protein oxidation on meat product quality, various strategies can be employed (*Paterio et al.*, 2018; *Nawaz et al*., 2022). These include the addition of antioxidants, such as natural extracts or synthetic antioxidants, to inhibit oxidation reactions (*Munekata et al*., 2020). Proper packaging techniques, such as vacuum packaging or modified atmosphere packaging (MAP), can minimize exposure to oxygen and delay oxidative processes (*Zhang et al*., 2013). Additionally, appropriate storage conditions, including refrigeration or freezing, can help slow down oxidation reactions and extend the shelf life of meat products. Herbs, spices, fruits, plant essential oils, and plant extracts are valuable plant materials that provide abundant sources of bioactive phenolic compounds (*Paterio et al*., 2018; *Hadidi et al*., 2022). They have emerged as effective alternatives to synthetic antioxidants in various applications. Natural extracts obtained from plant material can be added directly to meat products or incorporated into marinades, coatings, or casings to provide antioxidant protection. They can scavenge free radicals, chelate metal ions that promote oxidation, and inhibit enzymatic reactions associated with protein oxidation. By incorporating natural extracts into meat formulations, manufacturers can potentially extend the shelf life, maintain product quality, and enhance the nutritional value of meat products while meeting consumer demands for clean label ingredients (*Paterio et al.*, 2018 ; *Lorenzo et al*., 2019). This review provides an overview of recent advancements in the application of natural antioxidant compounds in meat and meat products, aiming to enhance their quality and extend their shelf life.

2. Protein oxidation in meat and meat products and the effects on the quality

Susceptibility to protein oxidation in muscle foods is influenced by a combination of intrinsic and extrinsic factors. Intrinsic factors encompass the animal species, animal origin, muscle type, and composition of the product. Extrinsic factors comprise processing conditions, packaging conditions, and preparation techniques. Together, these factors play a role in determining the extent of protein oxidation in muscle foods (*Dominguez et al.*, 2021).

Protein oxidation has been demonstrated to impact the quality of muscle foods in various aspects (*Zungur-Bastıoğlu et al*. 2015; *Zhang et al*., 2013). Protein oxidation can result in the development of off-flavors and off-odors in meat products. Oxidation of amino acids in proteins can generate volatile compounds, such as aldehydes and ketones, which contribute to rancid flavor and undesirable aromas. These flavor changes can negatively affect the sensory characteristics and consumer acceptance of meat products. Oxidized proteins in meat products can undergo structural changes, including cross-linking and aggregation (*Bao et al*., 2018). Consequently, cross-linking reinforces the protein structure, leading to a reduction in water-holding capacity. Moreover, the inhibition of proteolytic reactions, as mentioned earlier, due to protein oxidation can also have a detrimental impact on water-holding capacity. These modifications can lead to alterations in the meat's texture, making it tougher and less tender. The formation of disulfide cross-links in myofibrillar proteins due to oxidation strengthens the structure of actin and myosin, resulting in a decrease in important quality characteristics such as tenderness and water-holding capacity (*Zakrys-Waliwander* et al., 2012; *Bao and Ertbjerg*, 2019).

Protein oxidation can also impact the color of meat products. Oxidized proteins can lead to the formation of pigments, such as metmyoglobin, which can result in color changes, such as a brown or gray discoloration (*Tao et al*., 2021). This can negatively affect the visual appeal and perceived freshness of meat products. The oxidative changes of proteins in meat products can lead to an undesirable effect, namely a loss of nutritional value. Nevertheless, it is crucial to acknowledge that the impact of protein oxidation on digestibility is contingent upon the degree or severity of oxidation (*Dominguez et al*., 2021). Oxidized proteins can become less digestible and can result in a reduced bioavailability of essential amino acids. This can impact the protein quality and nutritional value of the meat, which is a crucial consideration for consumers seeking adequate protein intake from meat products (*Öztürk-Kerimoğlu et al.*, 2019). Protein oxidation is associated with the deterioration of meat product shelf life. Oxidation reactions can promote the development of lipid oxidation, leading to the generation of off-flavors, rancidity, and texture changes (*Kavuşan and Serdaroğlu*, 2021; *Serdaroglu et al.,* 2017). The combined effects of protein and lipid oxidation can accelerate the spoilage process and reduce the overall storage stability of meat products. Furthermore, various compounds resulting from protein oxidation, such as heterocyclic aromatic amines, advanced glycation end products, α-aminoadipic semialdehyde, kynurenines, and others, are deemed harmful. Consequently, protein oxidation has been demonstrated to produce potentially toxic compounds, leading to a decrease in the nutritional quality of muscle foods (*Hu et al*., 2017).

3. Plant extracts can play a role in preventing protein oxidation

The use of synthetic antioxidants in mitigating oxidative damage of meat products raises concerns regarding consumer safety. Therefore, there has been a shift towards replacing synthetic antioxidants with natural bioactive compounds due to increased consumer awareness of the potential hazards associated with synthetic alternatives (*Aminzare et al*., 2019; *Munekata et al*., 2020). Plant materials, such as herbs, spices, fruits, plant essential oils, and extracts, offer rich sources of bioactive phenolic compounds and serve as effective alternatives to synthetic anti-

Table 1. Effect of different plant extracts on protein oxidation in meat products

Product	Type of treatment	Effects on product	References
Beef patties	Rosemary extract	Samples with rosemary extract had lower carbonyl content	*Lund et al*., 2007).
Cold stored porcine liver pâté.	Sage extract significantly inhibited the increase of protein carbonyls.	Protein oxidation has been prevented.	*Estevez et al.*, 2006
Cooked burger patties	Strawberry tree, common hawthorn, dog rose and elm-leaf blackberry extracts.	Fruits tested displayed intense antioxidant activity against protein carbonylation.	*Ganhão et al.,* 2010
Beef patties	Artichoke by-product extract	The addition of AE significantly inhibited the formation of protein carbonyls in beef patties during cold storage.	*Ergezer and Serdaroğlu,* 2018
Dry minced pork slice	Mulberry extract	Concentrated mulberry juice was found to be effective antioxidant in dried-minced pork slice, inhibiting both lipid and protein oxidation.	*Cheng et al*., 2018
Beef burgers	Elderberry encapsulated extract	Elderberry extract delayed protein oxidation	*Rocchetti et al*., 2022
Dry uncured sausages	Pomegranate peel extract	Pomegranate peel extract added at 1 or 2% (v/w) improved oxidative stability lowering the formation of carbonyls from protein carbonylation during drying.	*Cava and Ladero*, 2023
Heat treated fermented sausages	Arugula and barberry extract	Reduced carbonylation	*Serdaroğlu et al.,* 2023

oxidants. It is important to note that the effectiveness of natural extracts as antioxidants may vary depending on factors such as extract concentration, extraction method, and the specific meat product formulation (*Lorenzo et al*., 2019). Fruits and vegetables are widely recognized as rich sources of antioxidants. Various fruits, including pomegranates, strawberries, kinnows, acerola, white grapes, plums, blackcurrants, annatto, bearberries, bananas, and sapodilla, contain notable concentrations of antioxidants. These fruits have been extensively studied for their antioxidant activity and find applications in various industries. Polyphenols, acting as natural antioxidants, exhibit remarkable capacity for absorbing radicals and possess potent hydrogen atom-donating activity (*Falowo et al.*, 2014). Among the main antioxidative polyphenols are phenolic acids, flavonoids, and essential oils. Certain polyphenols regulate the formation and spread of free radicals and ROS, while others directly eliminate free radicals and bind to transition metals (*Hadidi et al*., 2022). Table 1 presents the impact of different plant extracts on protein oxidation in meat products.

4. Conclusion

In conclusion, protein oxidation poses significant challenges to the quality and shelf life of meat products. Natural plant extracts with antioxidant properties offer promising solutions to mitigate protein oxidation. These plant extracts contain bioactive compounds that can effectively scavenge free radicals and inhibit oxidative reactions, thus protecting proteins from oxidation. Additionally, the use of natural plant extracts as antioxidants offers a more desirable and consumer-frien dly alternative to synthetic antioxidants, aligning with the increasing demand for clean label and natural food ingredients. It is worth highlighting that the efficacy of natural extracts as antioxidants can vary based on factors including extract concentration, extraction method, and the specific formulation of the meat product. Therefore, it is essential to conduct appropriate studies and optimize the application of natural extracts to achieve the desired antioxidant effects while ensuring food safety and regulatory compliance.

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