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Review

Natural antioxidants against lipid–protein oxidative deterioration in meat and meat products: A review

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ABSTRACT

Oxidation is a well-known non-microbial cause of quality loss in meat. Oxidative stress occurs due to uneven generation of free radicals reactive oxygen species (ROS) and reactive nitrogen species (RNS) which triggers oxidative and/or nitrosative stress and damage of macromolecules including the lipid and protein fractions. Failure of synthetic antioxidants to combat multiple health risks associated with this stress and maintenance of functional integrity of oxidised meat hitherto remains a challenge to the meat industry. A search for a viable alternative amidst the unexploited novel sources of natural antioxidants stands as a sustainable option for preserving the meat quality. In this paper, the potential use of bioactive compounds in medicinal plants is reviewed as phytoremedy against lipid–protein oxidation. Synergistic antimicrobial potentials of these natural antioxidants are also revealed against oxidative deterioration in meat and meat products and, for enhancing their functional properties.

Contents

1. Introduction

Oxidation is one of the major causes of quality deterioration in meat. Meat becomes susceptible to oxidative deterioration due to high concentrations of unsaturated lipids, heme pigments, metal catalysts and a range of oxidizing agents in the muscle tissue. Oxidative deterioration in any type of meat manifests in form of discoloration, development of off flavour, formation of toxic compounds, poor shelf life, nutrient and drip losses, respectively (Contini et al., 2014; Palmieri & Sblendorio, 2007). Under normal physiologic conditions, the molecular oxygen undergoes a series of reactions that leads to the generation of free radicals. A small portion (about 2–5%) of the oxygen consumed during the metabolic reaction is converted to free radicals in the form of reactive oxygen species (ROS). These free radicals, particularly, the reactive oxygen species (ROS) and reactive nitrogen species (RNS), play key regulatory roles in several homeostatic processes by interacting with proteins, fatty acids and nucleic acids. They act as intermediate agents in essential oxidation–reduction reactions (Moylan et al., 2014; Wiseman and Halliwell, 1996).

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Fundamentally, when the production of ROS [(superoxide anions (O_2^-), peroxyl (RO_2–), alkoxyl (RO^-), hydroxyl radicals, singlet oxygen)] and RNS [(nitric oxide radical (NO^-), peroxynitrite ($ONOO^-$) and nitrogen dioxide radical NO_2^-)] does not exceed the capacity of endogenous antioxidant barriers in the body, it performs beneficial functions which include: the control of gene expression, regulation of cell signalling pathways, modulation of skeletal muscle and defence against invading pathogens. In contrast, when in excess and the activity of antioxidant defence is low, it potentially causes damage to cellular components, induces harmful autoimmune responses and causes oxidative and/or nitrosative stress (Barbieri & Sestili, 2012; Power & Jackson, 2008). In general, oxidative stress which is caused by an imbalance between the production of ROS and antioxidant defence mechanisms in multicellular organism (da Silva, Marques, & Chaveiro, 2010; Sung, Hsu, Chen, Lin, & Wu, 2013) often leads to the modification of redox cell signalling and activation of pathways, and mechanisms involved in cardiovascular or chronic health problems (Alfadda & Sallam, 2012; Gutierrez & Elkind, 2012).

Understanding the activity of free radicals in meat is then important, since high levels of the ROS in meat could reduce its sensory quality (Kolakowska & Bratosz, 2010) and cause loss of protein functionality (Hassan, 2012; Lund, Heinonen, Baron, & Estevez, 2011) and depletion of essential amino acids like phenylalanine and trypotophan (Ganhao, Morcuende, & Estevez, 2010). Also, the degradation of unsaponifiable and polyunsaturated fatty acid fractions of meat lipids and the conversion of oxymyoglobin [oxyMb (Fe^{2+})] to metmyoglobin [MetMb (Fe^{3+})] pigment resulting in the generation of free radicals might lead to deterioration of meat protein (Suman & Joseph, 2013). Although antioxidants have the capacity to avert tissue damage by preventing the formation of radicals, by scavenging them or by promoting their decomposition, the use of synthetic antioxidants is also found to impose health risks to man. Consequently, there is a need to explore a suitable alternative from natural sources, such as plant-derived antioxidants, to combat the challenges of oxidative instability of lipids and protein in meat. Aside from this, while the interest in oxidative stress and antioxidant activities continues to grow rapidly, many questions still remain unanswered as to how the chain of events prior to the conversion of muscle to meat can reduce oxidative stress in meat. In this review, attempts were made to address these issues and appraise the potential use of natural bioactive compounds from medicinal plants to ameliorate oxidative stress in meat, to prevent lipid–protein oxidation and improve oxidative stability in meat and meat products.

2. Oxidative stress and implications on pre-slaughter welfare of animals

The term oxidative stress is used to describe the condition of oxidative damage as a result of an unfavourable critical balance between free radical generation and antioxidant defences (Mc Cord, 2000; Rock, Jacob, & Bowen, 2009). Oxidative stress may occur due to succession of stimuli that disrupt the homeostatic condition of an animal before slaughter (Cataldi, 2010). These external stimuli result from stress imposed on animals during transportation. The effects of rough handling during traditional slaughter, loading or unloading, poor road conditions, over-speeding and vibration of the vehicle, distance covered from farm to the abattoir, overcrowding in the vehicle, deprivation of food and water, mixing of animals with unfamiliar ones, aggressive behaviour and stunning are common sources of oxidative stressors (Fayemi & Muchenje, 2012; Minka & Ayo, 2009; Warriss, 2000, chap. 4). Other sources include environmental stressors, such as poor or high air velocity, harsh ambient temperature, relative humidity, lightning, and sound (Chulayo, Tada, & Muchenje, 2012; Minka & Ayo, 2009).

The cumulative effects of all these stressors on the animals from farm to slaughter point at the abattoir often result in pains, compromise their welfare, distort their normal behaviour and cause undesirable changes in meat quality (Fayemi & Muchenje, 2013). Animals experiencing these stressors may have fractures in the bones and bruises in the muscle (Broom, 2000). The stress may also cause an abnormal rise in heart rate, blood pressure and body temperature. They can also instigate rapid release of enzymes, cortisols and catecholamines which may lead to the depletion of glycogen, high meat ultimate pH (pHu) and dark cuts (Chulayo & Muchenje, 2013; Muchenje, Dzama, Chimonyo, Strydom, & Raats, 2009). Overproduction of ROS (oxidants) in muscle tissue and the release of stress hormones into the blood stream also occur in the process (Fergusona & Warner, 2008; Piccione et al., 2013). The occurrence of lipid oxidation in muscle food, due to oxidative damage in muscle tissue and the eventual negative effect on meat quality, has thus been established (Costantini & Bonadonna, 2010; Mapiye et al., 2012; Sazili et al., 2013) and is summarised in Fig. 1.

2.1. Effects of oxidative stress on meat quality

Oxidative stress in tissues injured by shock, hypertoxia, toxin stress or several disease conditions, including sepsis, mastitis, enteritis, pneumonia, respiratory and joint diseases (Lykkesfeldt & Svendsen, 2007) results in functional and/or structural damage to muscle organelles, cells and tissues. It has been found that myofibril protein is affected by ROS during meat maturation and storage (Martinaud, Mercier, Marinova, & Tassy, 1997) and that high production of free radicals and ROS results in degenerative damage of cellular structure and affect meat quality (Piccione et al., 2013). It has also been demonstrated that oxidative stress affects meat tenderness. Evidence for this is shown by the ability of ROS to influence the turnover of the intramuscular collagen, in terms of the balance between its degradation by the enzyme matrix metalloproteinase-2 (EMP-2) and synthesis by intramuscular fibroblasts derived from bovine muscles (Archile-Contreras & Purslow, 2011). The findings showed that ROS increased EMP-2 activity and reduced collagen synthesis in the muscle. This reduction in the collagen synthesis results in a decrease in collagen solubility and hence increases meat toughness. The same authors also reported the problem of inconsistency in meat tenderness in the meat industry, which may perhaps have resulted from an increase in ROS production when farm animals were exposed to different types and degrees of stresses. However, since no evidence is available on how the use of medicinal plants could play a vital role in this regard, it would be necessary to test the efficacy of the bioactive compounds in their roots, leaves, flowers or stem backs on the moderation of ROS generation, meat tenderness and other quality parameters

3. Oxidation in meat and meat products

Since the discovery of oxygen in the early 18th century and its inevitable roles in plants and animals, the necessity to control its levels and impacts on food and food products, especially during processing, packaging and distribution, has been a major challenge in the food industry. Basically, oxidation involves the loss of at least one electron when chemicals in the food are exposed to oxygen in the air. Oxidation in lipid and protein fractions of meat has been demonstrated as the main, non-microbial cause of quality deterioration during processing. This is because lipids and proteins in meat are easily susceptible to oxidative damages due to the rapid depletion of endogenous antioxidants after slaughter (Xiao, Zhang, Lee, & Ahn, 2013). However, the susceptibility of meat to oxidation has also been found to be influenced by animal breed and species, muscle types and anatomical location (Min, Nam, Cordray, & Ahn, 2008). The findings of Faustman and Cassens (1991) on two cattle breeds revealed that Holstein meat displays a higher lipid oxidation (TBA) than cross breed beef meat. Their study also showed that meat from the *gluteus medius* muscles had a higher amount of thiobarbituric acid than the *longissimus* muscle type.

Different studies have shown that the amount of metal ions, such as iron from heme compounds, copper, zinc and heavy metals that are present in enzymes and metalloproteins or those migrated from the