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Oxidation in foods and beverages and antioxidant applications

Volume 2: Management in different industry sectors

Edited by
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Oxidation and protection of red meat

C. Faustman, S. Yin and N. Tatiyaborworntham, University of Connecticut, USA and B. M. Naveena, National Research Centre on Meat, India

Abstract: This chapter discusses the basis for lipid and protein oxidation in fresh and processed red meat products. These processes lead to quality degradation, and a variety of antioxidant strategies have been developed to minimize and/or prevent this quality loss. The chapter provides an overview of the field’s status to date.

Key words: red meat, lipid oxidation, myoglobin oxidation, protein oxidation, antioxidants.

1.1 Introduction and compositional considerations

1.1.1 Red meat defined

Red meat includes the post mortem muscle of mammalian species. The degree of redness is proportional to the haem protein content of meat and is dependent on the specific muscles involved, the species, and age of the animal from which the meat was derived. Meat is composed of myofibres which contain the contractile apparatus critical to proper functioning in vivo. For simplicity sake, myofibres can be classified physiologically as slow, fast and intermediate, or biochemically as oxidative, glycolytic or oxidative/glycolytic. Slow, oxidative myofibres are characterized by a higher fat content, a slower contraction speed, oxidative metabolism, and greater myoglobin and mitochondrial concentrations. Fast, glycolytic myofibres contain less fat and more glycogen, contract more rapidly, rely on anaerobic metabolism and contain less myoglobin and mitochondria. Intermediate fibres contain elements that are intermediate between fast and slow
myofibres. Muscles that contain a greater proportion of red myofibres than white ones will contain more myoglobin and be more red in appearance. Traditionally, the primary species that yield red meat are cattle, pigs, sheep, goats and deer. However, within these species there can be significant differences in the degree of redness of different muscles and this is most readily observed in pork. For example, within a pig carcass, the longissimus muscle contains more white fibres and is considered more white than the psoas muscle. For the purposes of this chapter we will focus on oxidation and protection of meat from the common mammalian livestock species (i.e., cattle, sheep, pigs).

The substrates in meat that influence susceptibility to oxidation are derived from the animal’s diet. It is important to note that the extent to which nutrition can influence the concentration of nutrients capable of accelerating or delaying oxidation depends, in part, on the animal’s nutritional physiology. Specifically, pigs are monogastric animals, while cattle, sheep and goats are ruminants. The fat of monogastric animals is more readily altered by dietary fat composition.

Considerable understanding of oxidation in meat can be obtained by consulting related studies of tissue oxidation in the medical literature. Some caution needs to be observed when doing this. The conversion of muscle to meat during the antemortem to postmortem transition is characterized by many biochemical changes (Greaser, 1986). Cellular integrity is lost with time and a number of physico-chemical changes occur that affect oxidation in meat. For example, mitochondrial morphology is lost with time postmortem (Cheah and Cheah, 1971, 1974; Tang et al., 2005) and this is accompanied by changes in oxygen consumption capacity. The accessibility of oxygen to fatty acids in membranes and production of radical intermediates would both be affected by these changes.

Oxidation of meat lipids, specifically unsaturated fatty acids in triacylglycerols and phospholipids, and of cholesterol, is a critical concern. The generation of peroxides, radical species and secondary oxidation products has implications for flavour, colour and loss of myofibrillar protein functionality. Protein oxidation generally leads to decreased functionality relevant to processed meat texture and water-holding capacity. All oxidative reactions generally result in compromised sensory quality and an undesirable sensory experience for the consumer. Antioxidant mediation of oxidative events has been adopted strategically to lessen the undesirable effects of oxidation reactions in red meat. Delivery of antioxidants has been accomplished by dietary intervention and ingredient addition, and resulted in shelf-life extension. In addition, packaging technologies that alter the atmosphere in which meat resides has also been employed to minimize the undesirable consequences of oxidation.

The goal of this chapter is to provide a summary review of relevant studies published in the literature. Our emphasis will be on the more applied aspects of red meat oxidation because the fundamental aspects are covered in earlier sections of this book. The reader should recognize that results from studies of oxidation very much depend on the experimental conditions employed by specific investigators. Space limitations preclude us from recounting specific
details of conditions for all of the work cited and we encourage the reader to carefully consult the original investigations for these critical components when considering related work.

1.2 Lipid oxidation in red meat

1.2.1 Substrates for lipid oxidation

Triacylglycerols, phospholipids and cholesterol are the three major substrates for lipid oxidation in red meat. The fatty acids esterified to meat triacylglycerols and phospholipids can be saturated or unsaturated. In general, oxidative susceptibility is directly proportional to the degree of unsaturation in the constituent fatty acids. Selected nutrient profiles including fatty acids are presented in Table 1.1. Phospholipids are the major components of cell membranes and sub-cellular organelles in meat. They contain two fatty acids and the fatty acid at the sn-2 position is commonly unsaturated. The oxidation of fatty acids in phospholipids, more so than in triacylglycerols, has been attributed as the cause of sensory quality deterioration in foods (Pearson et al., 1977). As noted previously, the fatty acid profile of fresh meat from monogastric animals is more easily manipulated than that from ruminants. The production of comminuted red meat products can utilize raw meat materials differing in fatty acid unsaturation to achieve products with a specific level of unsaturated fat.

The process of lipid oxidation in red meat leads to the production of a complex mixture of primary and secondary oxidation products that reflect the degree and location of unsaturations in the fatty acid substrates (Belitz et al., 2004). Aldehydes and ketones are produced in measurable quantities and are responsible for many of the odours and flavours associated with rancidity in red meat (Pearson et al., 1977). The most well-known secondary product of lipid oxidation in red meat is malondialdehyde (MDA). Some products of lipid oxidation are sufficiently reactive that they bind with other macromolecules. Previous research has suggested that MDA is predominantly complexed with protein in foods (Piche et al., 1988; Giron-Calle et al., 2002). \(\alpha,\beta\)-Unsaturated aldehydes are reactive products of lipid oxidation (Witz, 1989) and in particular, 4-hydroxy-2-nonenal (HNE) is very reactive. HNE is produced from oxidation of linoleic acid in membranes (Pryor and Porter, 1990) and has been identified in beef and pork (Munasinghe et al., 2003; Sakai et al., 1995, 1998, 2004, 2006).

The fundamental bases of lipid oxidation have been addressed in the literature and are not discussed in this chapter. However, a critical consideration when assessing oxidation as a function of fatty acid unsaturation is that of methodology. Methods may be qualitative or quantitative, and can focus on consumption of oxygen or the production of primary or secondary products from the fatty acid substrate. The commonly used thiobarbituric acid (TBARS) assay (Fernandez et al., 1997) is more sensitive to the generation of 3-carbon secondary oxidation products, specifically MDA, than to other oxidation products. Also, the profile of oxidation products can yield different chromophores in...
### Table 1.1 Selected nutrient profile of red meats (value per 100 g; USDA, 2008)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Beef&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Pork&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Lamb&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Goat&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Venison&lt;sup&gt;e&lt;/sup&gt;</th>
<th>Veal&lt;sup&gt;f&lt;/sup&gt;</th>
<th>Buffalo&lt;sup&gt;g&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximate</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water (g)</td>
<td>69.38</td>
<td>71.98</td>
<td>71.17</td>
<td>75.84</td>
<td>73.57</td>
<td>75.18</td>
<td>76.30</td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>173</td>
<td>152</td>
<td>160</td>
<td>109</td>
<td>120</td>
<td>120</td>
<td>99</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>19.05</td>
<td>21.80</td>
<td>20.12</td>
<td>20.60</td>
<td>22.96</td>
<td>19.97</td>
<td>20.39</td>
</tr>
<tr>
<td>Total lipid (g)</td>
<td>10.19</td>
<td>6.48</td>
<td>8.20</td>
<td>2.31</td>
<td>2.42</td>
<td>3.89</td>
<td>1.37</td>
</tr>
<tr>
<td>Ash (g)</td>
<td>0.98</td>
<td>0.98</td>
<td>0.90</td>
<td>1.11</td>
<td>1.16</td>
<td>1.02</td>
<td>1.05</td>
</tr>
<tr>
<td>Carbohydrate, by difference (g)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Fibre, total dietary (g)</td>
<td>0.0</td>
<td>0.0</td>
<td>–</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sugars, total (g)</td>
<td>–</td>
<td>0.00</td>
<td>–</td>
<td>–</td>
<td>0.00</td>
<td>–</td>
<td>–</td>
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<tr>
<td><strong>Minerals</strong></td>
<td></td>
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<tr>
<td>Iron, Fe (mg)</td>
<td>2.16</td>
<td>0.77</td>
<td>1.59</td>
<td>2.83</td>
<td>3.40</td>
<td>0.88</td>
<td>1.61</td>
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<tr>
<td>Copper, Cu (mg)</td>
<td>0.069</td>
<td>0.058</td>
<td>0.147</td>
<td>0.256</td>
<td>0.253</td>
<td>0.108</td>
<td>0.151</td>
</tr>
<tr>
<td><strong>Vitamins</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin C, total ascorbic acid (mg)</td>
<td>0.0</td>
<td>0.3</td>
<td>–</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Lipids</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatty acids, total saturated (g)</td>
<td>4.330</td>
<td>2.240</td>
<td>3.533</td>
<td>0.710</td>
<td>0.950</td>
<td>1.170</td>
<td>0.460</td>
</tr>
<tr>
<td>Fatty acids, total monounsaturated (g)</td>
<td>4.380</td>
<td>2.930</td>
<td>3.242</td>
<td>1.030</td>
<td>0.670</td>
<td>1.250</td>
<td>0.420</td>
</tr>
<tr>
<td>Fatty acids, total polyunsaturated (g)</td>
<td>0.380</td>
<td>0.700</td>
<td>0.320</td>
<td>0.170</td>
<td>0.470</td>
<td>0.400</td>
<td>0.270</td>
</tr>
<tr>
<td>Cholesterol (g)</td>
<td>59</td>
<td>55</td>
<td>66</td>
<td>57</td>
<td>85</td>
<td>83</td>
<td>46</td>
</tr>
<tr>
<td>Phytosterols (g)</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

<sup>a</sup>Beef, rib, shortribs, separable lean only, choice, raw, trimmed to 0% fat; <sup>b</sup>Pork, fresh, loin, centre rib (chops or roasts), boneless, separable lean only, raw; <sup>c</sup>Lamb, Australian, imported, fresh, rib, separable lean only, trimmed to 1/8% fat, raw; <sup>d</sup>Goat, raw; <sup>e</sup>Game meat, deer, raw; <sup>f</sup>Veal, rib, separable lean only, raw; <sup>g</sup>Game meat, buffalo, water, raw.
the TBARS test. Sun et al. (2001) reported on the generation of yellow chromophores ($A_{\text{max}} @ 450\,\text{nm}$) from the reaction of TBA with specific aldehydes known to be generated by lipid oxidation. Thus, the TBARS assay is not a good method to compare oxidation in meats with significantly different fatty acid profiles. Investigations concerned with the effects of lipid oxidation in meat products, rather than in vitro systems, benefit from inclusion of sensory panels to complement objective laboratory analyses of lipid oxidation. In fact, the TBARS assay cannot be used reliably to predict rancidity unless it is correlated with sensory analyses.

A third class of lipids found in red meats, in addition to triacylglycerol and phospholipid, is the steroid alcohol, cholesterol. It is found only in animal-based food products and is capable of being oxidized. In general, cholesterol oxidation products (COPs) are absent from fresh meat but have been identified in processed meats. For example, Paniangvait et al. (1995) reported that seven species of COPs were identified in processed meats while fresh meat contained only trace amounts or lacked them completely. The presence of COPs was reported in freeze-dried pork at concentrations of approximately 460 ppm (Park and Addis, 1987) and 177 ppm (Csallany et al., 1989). In a study on the development of COPs, Engeseth and Gray (1994) reported initial low concentrations of COPs in raw and cooked beef round steak of 1.4 ppm and 3.1 ppm, respectively. Following storage at 4°C for 4 d, COPs levels increased, particularly in cooked beef, from 3.1 to 17.3 ppm. In raw meat, COPs increased from 1.4 to 5.9 ppm. The effects of cooking and storage on the production of COPs were also reported in buffalo meat (Rao et al., 1996) and mutton (Kowale et al., 1996). The process of pre-cooking meat for subsequent preparation by consumers or the food service industry (e.g., frying) prior to consumption can lead to formation of COPs (Larkeson et al., 2000). Not surprisingly, inclusion of antioxidants in marinated pork (Lee et al., 2008), and the exclusion of oxygen from packaging atmospheres via vacuum packaging was reported to prevent cholesterol oxidation in cooked turkey, pork, and beef patties (Du et al., 2001).

Cholesterol oxidation in processed foods is influenced by the presence of unsaturated fatty acids in triacylglycerols and phospholipids (Liu et al., 1994; Osada et al., 2000). Cholesterol was unstable in the presence of unsaturated fats; however, it was relatively stable at 100°C (Osada et al., 1993). Lipid radicals formed during the processing and storage of foods can accelerate the oxidation of cholesterol and produce cholesterol oxidation products (COPs) (Paniangvait et al., 1995).

1.2.2 The role of oxygen
Oxygen is necessary for lipid oxidation to occur in meat. Both triplet and singlet forms of oxygen have been implicated. The diffusion of oxygen into intact cuts of red meat is relatively slow while incorporation of oxygen into comminuted meat products occurs readily during meat processing. Oxygen can be limited in,