



Review

Enhancing the nutritional and health value of beef lipids and their relationship with meat quality



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ABSTRACT

This paper focuses on dietary approaches to control intramuscular fat deposition to increase beneficial omega-3 polyunsaturated fatty acids (PUFA) and conjugated linoleic acid content and reduce saturated fatty acids in beef. Beef lipid *trans*-fatty acids are considered, along with relationships between lipids in beef and colour shelf-life and sensory attributes. Ruminant lipolysis and biohydrogenation limit the ability to improve beef lipids. Feeding omega-3 rich forage increases linolenic acid and long-chain PUFA in beef lipids, an effect increased by ruminally-protecting lipids, but consequently may alter flavour characteristics and shelf-life. Antioxidants, particularly α -tocopherol, stabilise high concentrations of muscle PUFA. Currently, the concentration of long-chain omega-3 PUFA in beef from cattle fed non-ruminally-protected lipids falls below the limit considered by some authorities to be labelled a source of omega-3 PUFA. The mechanisms regulating fatty acid isomer distribution in bovine tissues remain unclear. Further enhancement of beef lipids requires greater understanding of ruminal biohydrogenation.

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1. Introduction

The nutritional value is an important contributor to the overall quality of meat. Consumers are increasingly aware of the relationships

between diet, health and well-being resulting in choices of foods which are healthier and more nutritious (Hocquette, Botreau, et al., 2012; Verbeke et al., 2010). Intramuscular fat level and fatty acid composition, along with the biological value of the protein, trace elements and vitamins, are key factors contributing to nutritional value (Wyness, 2013). Considerable attention has been given to enhancing beneficial fatty acids in meat and milk (Givens, 2010;

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Salter, 2013; Scollan, Hocquette, et al., 2006; Shingfield, Bonnet, & Scollan, 2013). Much of this research seeks to support the guidelines for fat intake by the World Health Organisation (2003). The WHO (2003) recommended that total fat, saturated fatty acids (SFA), $n-6$ polyunsaturated fatty acids (PUFA), $n-3$ PUFA and *trans* fatty acids should contribute <15–30, <10, <5–8, <1–2 and <1% of total energy intake, respectively. A recent meta-analysis of epidemiological studies has called into question the evidence that supports the association between SFA and cardiovascular disease (CVD) (Siri-Tarino, Sun, Hu, & Krauss, 2010a). Emphasis has been placed on reducing the intake of SFA (considered to be associated with increased cholesterol) and increasing the intake of omega-3 PUFA, and indeed epidemiological and clinical data support a beneficial effect of substituting SFA with PUFA, as opposed to substitution with carbohydrate (Siri-Tarino, Sun, Hu, & Krauss, 2010b). The beneficial effects of the longer chain $n-3$ PUFA, eicosapentaenoic acid (EPA; 20:5 $n-3$) and docosahexaenoic acid (DHA; 22:6 $n-3$) in reducing the risk of cardiovascular disease, cancer and type-2 diabetes, and their critical roles for proper brain function, for visual development in the foetus and for maintenance of neural and visual tissues throughout life are well recognised (Barceló-Coblijn & Murphy, 2009; Lopez-Huertas, 2010; Russo, 2009; Simopoulos, 1991).

Intramuscular fat in muscle of mature beef consists proportionally on average of 0.45–0.48 SFA, 0.35–0.45 monounsaturated fatty acids (MUFA) and up to 0.05 PUFA. The polyunsaturated:saturated fatty acid (P:S) ratio for beef is typically low at around 0.1 except for very lean animals (<1% intramuscular fat) where P:S ratios are much higher ~0.5–0.7 (Scollan, Hocquette, et al., 2006). The $n-6$: $n-3$ ratio for beef is beneficially low (usually <3), reflecting the significant amounts of desirable $n-3$ PUFA, particularly α -linolenic acid (18:3 $n-3$), but also EPA, docosapentaenoic acid (DPA; 22:5 $n-3$) and DHA. Beef and other ruminant products are important dietary sources of conjugated linoleic acid (CLA) of which the most prominent is *cis-9,trans-11* isomer, which has been identified to contain a range of health promoting beneficial properties (Salter, 2013). Beef lipids also contain *trans*-fatty acids (TFA) of which the most dominant is *trans-11* 18:1 (vaccenic acid). There is much interest in TFA produced by ruminants (rTFA) with emphasis on the potential protective effect against the development of coronary heart diseases, as distinct to industrial *trans* fatty acids (iTFA) (Salter, 2013; Wang, Jacome-Sosa, & Proctor, 2012). Hence considerable effort has been devoted to improving the fatty acid composition of beef.

This paper reviews recent progress in the field including the important relationships between lipids and components of meat quality such as colour shelf life and sensory attributes. Although genetics does influence intramuscular fat deposition and fatty acid composition (Hocquette et al., 2010), this paper is focused on the nutritional influences on muscle lipids, as it is the major contributory factor (De Smet, Raes, & Demeyer, 2004). Reference is also made to recent research in vitamin and antioxidant content of beef.

2. Strategies to influence intramuscular fat deposition

Whereas intramuscular fat level is associated with juiciness, flavour, tenderness and overall liking (Jeremiah, Dugan, Aalhus, & Gibson, 2003; O'Quinn et al., 2012), it might be considered as prejudicial for human health since WHO recommendations are to reduce fat consumption (World Health Organisation, 2003). Therefore, different strategies were developed to reduce intramuscular fat level by genetic or nutritional factors.

Certain genotypes, for example, double-musled genotypes, have been characterised by an altered metabolic and endocrine status associated with a reduced fat mass in the carcass and an orientation of muscle metabolism towards the glycolytic type (Hocquette et al., 2010). Similarly, a high muscle growth potential induced by genetic selection is associated with a reduced fat mass in the carcass and a switch of muscle fibres towards the glycolytic type with less intramuscular fat

level (Hocquette, Cassar-Malek, et al., 2012). However, from studies on differential expression of genes associated with muscle growth, it seems that genes involved in muscle mass development probably differ from those implicated in the control of fat deposition (Bernard, Cassar-Malek, Renand, & Hocquette, 2009) suggesting that the biological mechanisms governing muscle growth and fat deposition are different. Other authors consider that intramuscular fat deposition is closely linked to muscle growth since both processes are physiologically in competition for nutrient use (Pethick, Barendse, Hocquette, Thompson, & Wang, 2007; Pethick, Harper, & Oddy, 2004). Indeed, intramuscular fat is deposited at a lower rate than muscle growth during the first periods of postnatal life when average daily gain is the highest. On the other hand, intramuscular fat is deposited at a greater rate than muscle growth rate when average daily gain of animals is reduced, i.e. when animals get older. In this period (corresponding to the finishing period), intramuscular fat level inevitably increases since less nutrients are used for muscle growth (reviews from Pethick et al., 2007 and Pethick et al., 2004).

Concerning the nutritional control of fat deposition, *de novo* synthesis of fatty acids in intramuscular adipocytes probably occurs mainly from glucose and less from acetate, as in other fat tissues of the carcass (reviewed by Smith et al., 2009). Therefore, it has been hypothesized that diets that promote glucose supply to the muscle might increase intramuscular fat deposition, whilst limiting fat deposition in external fat tissues of the carcass. A higher glucose supply to muscles may be achieved by maximising fermentation in the rumen to produce gluconeogenic precursors (propionate) or by increasing starch digestion (releasing glucose) in the small intestine. One way to achieve this is a high level of food processing in order to maximise the accessibility of dietary starch during digestion (Rowe, Choct, & Pethick, 1999). In terms of biological mechanisms, not only may higher glucose delivery to intramuscular adipocytes be important, but also the higher glucose supply increases the levels of circulating insulin, which is known to stimulate lipogenesis. All these mechanisms may explain why grain feeding promotes more intramuscular fat deposition than grass finishing (reviewed by Pethick et al., 2004).

3. Strategies to influence the fatty acid composition of beef

It is generally acknowledged that genetic factors have a smaller influence than dietary factors on the fatty acid composition of beef (De Smet et al., 2004). Nevertheless, even though breed differences are generally small they do reflect differences in underlying gene expression or activities of enzymes involved in fatty acid synthesis, and therefore warrant consideration. For example, stearoyl CoA desaturase (delta-9-desaturase) mRNA expression level was related to MUFA percentage in Holstein Japanese Black cattle and a single nucleotide polymorphism (SNP) in Japanese Black cattle which contributed to higher MUFA percentage and lower melting point in intramuscular fat has been described (Taniguchi, Mannen, et al., 2004; Taniguchi, Utsugi, et al., 2004). Advances in technology and knowledge of the bovine genome have resulted in the identification of several SNPs related to fatty acid metabolism in the bovine and the potential for targeted selection of animals with a particular fatty acid phenotype is increasing (for detailed discussion see (Shingfield et al., 2013)).

As discussed by Scollan, Hocquette, et al. (2006), the content of SFA and MUFA increases faster than the content of PUFA with increasing fatness and so the relative proportion of PUFA and the P:S ratio decrease. Hence lean and late maturing breeds will have a higher P:S ratio than early maturing breeds when slaughtered at the same carcass weight (Raes, de Smet, & Demeyer, 2001).

The potential to alter the fatty acid composition of bovine muscle by nutrition is determined to a large extent by ruminal biohydrogenation of dietary lipids. Durand, Scisłowski, Gruffat, Chilliard, and Bauchart, (2005) demonstrated the ability to markedly increase the concentration

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