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Nutritional enhancement of sheep meat fatty acid profile for human health and wellbeing

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ABSTRACT

Dietary fatty acids (FA) consumed by sheep, like other ruminants, can undergo biohydrogenation resulting in high proportions of saturated FA (SFA) in meat. Biohydrogenation is typically less extensive in sheep than cattle, and consequently, sheep meat can contain higher proportions of omega (n) − 3 polyunsaturated FA (PUFA), and PUFA biohydrogenation intermediates (PUFA-BHI) including conjugated linoleic acid (CLA) and *trans*-monounsaturated FAs (*t*-MUFA). Sheep meat is also noted for having characteristically higher contents of branched chain FA (BCFA). From a human health and wellness perspective, some SFA and *trans*-MUFA have been found to negatively affect blood lipid profiles, and are associated with increased risk of cardiovascular disease (CVD). On the other hand, $n-3$ PUFA, BCFA and some PUFA-BHI may have many potential beneficial effects on human health and wellbeing. In particular, vaccenic acid (VA), rumenic acid (RA) and BCFA may have potential for protecting against cancer and inflammatory disorders among other human health benefits. Several innovative strategies have been evaluated for their potential to enrich sheep meat with FA which may have human health benefits. To this end, dietary manipulation has been found to be the most effective strategy of improving the FA profile of sheep meat. However, there is a missing link between the FA profile of sheep meat, human consumption patterns of sheep FA and chronic diseases. The current review provides an overview of the nutritional strategies used to enhance the FA profile of sheep meat for human consumption.

1. Introduction

Meat is an essential component of human diets in several populations, providing high-quality nutrients (i.e., proteins and fats) and essential micronutrients, including iron, zinc and B vitamins (Boada, Henríquez-Hernández, & Luzardo, 2016; Wyness, 2016). In the developing world, meat also offers a means for reducing malnutrition and increasing food and nutrition security (McNeill & Van Elswyk, 2012; Mlambo & Mapiye, 2015). Regardless of the background, consumers are increasingly becoming aware of the interrelatedness between diet, health and the general well-being and have a tendency to search for foods with health-promoting properties (De Smet & Vossen, 2016).

The negative effects of fats on human health overshadow the benefits associated with consumption of ruminant-derived fat. This perception emanates from the high content of saturated fatty acid (SFA), more so the presence of thrombogenic and atherogenic fatty acids (FA), including myristic (14:0) and palmitic acids (16:0) (Salter, 2013). Myristic and palmitic acids have been associated with increased risk of developing cardiovascular disease (CVD) in humans relating to their low-density lipoprotein (LDL) cholesterol-raising properties (Jiang & Xiong, 2016; Salter, 2013). Another underlying mechanism is purported to be through the generation of carcinogens and mutagens by certain FA types during processing (Boada et al., 2016; McAfee et al., 2010). Previously, most interest has been in reducing the negative health impact of FA related to CVD, but it is now clear that some FA have positive influence on CVD and a range of other diseases. Recent research, for example, shows that $n-3$ polyunsaturated (PUFA), rumenic acid [RA; *cis(c)*9, *trans(t)*11-18:2], the main natural isomer of conjugated linoleic acid (CLA), and its precursor vaccenic acid (VA; *t*11-18:1) have many properties that seem to promote human health and wellbeing (Calder, 2015; Dilzer & Park, 2012).

Like other ruminants, sheep meat is a good source of $n-3$ PUFAs, branched chain FA (BCFA) and PUFA biohydrogenation intermediates (PUFA-BHI), particularly conjugated linolenic acids [CLnA, e.g., rume-

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lenic acid (RLA), *c*9,*t*11,*c*15-18:3], CLA (e.g., RA), *trans*-octadecenoic acids (i.e., VA), which exhibit potentially beneficial effects on human health (Dilzer & Park, 2012; Field, Blewett, Proctor, & Vine, 2009; Hennessy, Ross, Devery, & Stanton, 2011; Ran-Ressler, Bae, Lawrence, Wang, & Brenna, 2014). Besides having health effects, FA also play an important role by enhancing the texture, flavor and aroma, and subsequently acceptability of meat (Aranceta & Pérez-Rodrigo, 2012; Watkins et al., 2014). In this regard, production of sheep meat may be one area with considerable potential for providing whole foods enriched with health promoting FA for human consumption. Since nutrition is the major factor influencing the FA profile of ruminants (De Smet & Vossen, 2016; Mapiye, Aldai, et al., 2012), enrichment of sheep meat with healthful FA can be achieved by innovative nutritional approaches. Regrettably, the relationships between the FA in sheep meat, their consumption and effects on human health are not well documented. The current review evaluates the contribution of sheep meat consumption to the supply of health promoting FA in the human diet and the extent to which it can be enhanced through sheep nutrition.

2. Global sheep production and consumption patterns

Sheep meat production is widely distributed throughout the world with a head population of 1.2 billion as of 2014 (FAOSTAT, 2016). Asia (44.9%) and Africa (28.5%) contribute the largest percentage to global sheep population (Table 1). China is the leading sheep producing country (16%), followed by Australia (6%), India (5%), Iran (4%), and Nigeria, Sudan, Turkey and UK at 3% each (FAOSTAT, 2016). Globally, annual sheep production is expected to grow at 2.1% with the greatest contribution coming from China, Pakistan, Sudan and Australia (OECD, 2016). However, sheep production lags behind beef, pork and poultry, respectively (OECD, 2016). Overall, the growth rate of livestock production including sheep is driven by population growth, urbanization and increasing incomes (Montossi et al., 2013). In the developed world, sheep production is stagnating because in some countries, cattle are the preferred grazing species, while in others, public health issues are linked to ruminant meat consumption (Thornton, 2010).

Table 1
Sheep populations (heads million), meat production (million tonnes) and consumption patterns (kg/capita) in selected countries.

Country	Population[1]	Meat production[1]	Consumption[2]
Algeria	27,807	0,291	7,1
Argentina	14,534	0,060	1,2
Australia	72,612	0,721	8,1
Brazil	17,614	0,086	0,4
Canada	0,874	0,020	0,9
China	194,927	2184	2,9
Ethiopia	29,332	0,088	1,3
India	63,000	0,235	0,5
Indonesia	16,091	0,044	0,4
Iran	45,000	0,148	3,3
Israel	0,574	0,010	1,9
Italy	7.166	0.025	1.1[6]
Japan	0,013	0,0002	0,1
Kazakhstan	15,198	0,139	8,1
Mexico	8576	0,058	0,5
New Zealand	29,803	0,487	2,4
Nigeria	41,327	0,139	2,1
Pakistan	29,095	0,164	2,1
Paraguay	0,472	0,003	0,5
Peru	12,388	0,034	1,2
Romania	9136	0,068	3.0[5]
Russia	22,247	0,186	1,1
Saudi Arabia	11,650	0,102	5,5
South Africa	24,123	0,184	3,1
Spain	15,431	0,114	1,7[4*]
Sudan	39,846	0,251	10,7
Turkey	31,100	0,313	4,1
United Kingdom	33,743	0,298	1,8[3]
Uruguay	7427	0,014	4,4
USA	5245	0,072	0,4

Sources: [1]- FAOSTAT (2016); [2]-OECD (2016); [3]- AHDB (2015); [4]- Rodríguez-Serrano et al. (2016); [5]- Soare (2016); [6]- Statista (2017); *- includes goat consumption.

Global sheep meat production in 2015 amounted to 8.9 million tonnes, with developing countries contributing 80% of this share and China topping the list (Table 1; FAOSTAT, 2016). Historically, sheep meat was a by-product of the wool industry, but the decline in wool production has changed this and resulted in a surge in lamb production and consumption (Hoon, Herselman, Heerden, & Pretorius, 2000), a trend predicted to continue increasing (Montossi et al., 2013). On average, world sheep meat consumption is about 1.7 kg per capita annually (OECD, 2016), varying from 0.7 kg in North America to 17 kg in Oceania (Montossi et al., 2013). China also dominates in terms of sheep consumption (46% of the global share) followed by India at 27% (AHDB, 2016). Chinese meat consumption is driven by consumer diversification from pork to beef and sheep meat and the high human population (Mao, Hopkins, Zhang, & Luo, 2016). Generally, the higher consumption per capita pattern in regions such as North Africa, the Middle East, India, and parts of Europe is related to sheep meat being a primary animal-source protein. This is also true for Australia and New Zealand, the leading global sheep meat exporters (Montossi et al., 2013; Sañudo, Muela, & Del Mar Campo, 2013).

Sheep meat consumption occupies fourth position, among the major livestock species currently dominated by pork, poultry and beef in that order (Font-i-Furnols & Guerrero, 2014). The reasons for low sheep meat consumption patterns in most countries include high meat prices (Brand et al., 2013; Brester, 2016; Rodríguez-Serrano, Panea, & Alcalde, 2016), preference for fish in countries such as Japan and Norway, health and food safety concerns related to red meat (McAfee et al., 2010) and the fact that most North Americans do not eat sheep meat at all (Jones, 2004). In addition, diverse culinary backgrounds also affect consumer perception of sheep meat (Sañudo et al., 2013). Overall, the variation in sheep meat consumption between and within regions reflects differences in population growth and socio-economic factors. In that regard, society should not disregard sheep meat as a vital source of nutrients, particularly its content of beneficial FAs, which may play key roles in achieving overall health and wellness.

3. Sheep meat fatty acid profile

Ruminants have a low PUFA content because of microbial biohydrogenation in the rumen, unlike non-ruminants, whose FA profile closely reflects the diets they consume (Wood et al., 2004). A unique characteristic of ruminants is the preferential incorporation of long chain (LC)$n-3$ PUFA into phospholipids as opposed to triacylglycerol (Bessa, Alves, & Santos-Silva, 2015). As a result, liver of beef and lamb are the richest sources of docosapentaenoic acid (DPA, 22:5$n-3$), containing approximately 140 mg DPA/100 g of edible portion (Byelashov, Sinclair, & Kaur, 2015). Lean trimmed meat averages 20 and 30 mg DPA/100 g for beef and lamb, respectively (Byelashov et al., 2015). Australian sheep meat provides > 60 mg of eicosapentaenoic acid (EPA; 20:5$n-3$) and docosahexaenoic acid (DHA; 22:6$n-3$) per serving (Williams, 2007). However, the deposition of PUFA in beef and sheep meat is limited by microbial biohydrogenation in the rumen, which lowers their ruminal outflow and subsequent absorption in the small intestines (Fievez, Vlaeminck, Jenkins, Enjalbert, & Doreau, 2007). Nonetheless, biohydrogenation contributes to accumulation of PUFA-BHI, such as CLnA, CLA, non-CLA/non-LA dienes (NCLA) and MUFA through isomerization and biohydrogenation of dietary PUFA by microbial enzymes in the rumen (Lee & Jenkins, 2011; Turner, Meadus, et al., 2015). In addition, rumen microbial metabolism is also directly or indirectly responsible for the presence of BCFA and odd-chained SFA (OCFA) in ruminant tissues. Odd-chain and BCFA are endogenously synthesized by ruminal bacteria and incorporated in their cell mem-