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# Influence of pasture feeding on milk and meat products in terms of human health and product quality

C. Stanton[1,2,3†], S. Mills[2], A. Ryan[2,4], D. Di Gioia[5], R.P. Ross[2]

[1]*Teagasc, Moorepark Food Research Centre, Fermoy, Co. Cork, Ireland*
[2]*APC Microbiome Ireland, University College Cork, Cork, Ireland*
[3]*Vistamilk SFI Research Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland*
[4]*School of Food and Nutritional Sciences, University College Cork, Cork, Ireland*
[5]*Department of Agriculture and Food Sciences, University of Bologna, Bologna, Italy*

## Abstract

***Cows are fed either indoors on a diet of mixed ration or in areas with temperate climates, such as Ireland and New Zealand, the feeding regime of dairy and beef herds is almost entirely pasture-based. Animal feeding regimes and herd management practices are linked to differences in organoleptic and nutritional quality attributes of milk, dairy and meat/beef products, with pasture-based feeding systems being associated with superior quality produce. Consumers generally perceive that milk and meat products produced from outdoor grazing pastures are "healthier" than produce derived from indoor feeding systems, based on animals fed typical indoor rations and concentrates. However, while research has demonstrated differences in milk and meat quality, especially in terms of fatty acids, based on different feeding systems, data are limited on the impact of dairy and meat products produced from different feeding systems on human health.***

## Keywords

*Beef • milk • nutritional quality • pasture-fed*

## Introduction

The composition of bovine milk and meat, in particular the fatty acid composition, can be significantly influenced by the feeding regime. In many regions of the world including the United States, the Middle East, Asia and parts of Europe, cows and cattle are fed indoors and receive a diet of grass/maize (*Zea mays* L.)/alfalfa (*Medicago sativa* L.) silages supplemented with concentrates, known as total mixed ration (TMR). However, in Ireland and New Zealand, they are typically fed outdoors where they have access to fresh pasture, which is why there is a predominant seasonal calving regime and milk production system in both places. Pasture-based dairy and meat products are popular amongst consumers as they are positively associated by consumers with good animal welfare and more natural and healthier products (Verkerk, 2003). Specific feeding regimes and herd management practices such as pasture feeding are linked to superior organoleptic and nutritional quality attributes of milk, dairy and meat products (Mann *et al*., 2003; Haug *et al*., 2007). The aim of this review is to compare the nutritional quality of bovine milk, dairy and meat produce from pasture feeding with indoor feeding systems and summarise the current data with regard to human health impacts of dairy and beef from the different feeding systems.

## Nutritional quality of milk

Milk and dairy products derived from it are among the most nutritious foods available for human nutrition, being excellent sources of high-quality protein and important sources of many minerals, notably dietary calcium, magnesium and phosphorus, vitamins (fat-soluble vitamins, A, D, E and K, and water-soluble vitamins, B and C) and bioactive compounds. Bovine milk composition varies in response to animal genetics, nutrition and stage of lactation, but is generally composed of 5% lactose, 4% lipid, 3.2% protein and 0.7% mineral salts (Séverin & Wenshui, 2005).

Bovine milk is an important source of dietary protein as it provides a source of all essential amino acids. The major proteins in milk include whey proteins (6.3 g/L) and caseins

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[†]Corresponding author: C. Stanton
E-mail: catherine.stanton@teagasc.ie

(26 g/L) (Séverin & Wenshui, 2005). A scoring system to describe dietary protein quality was proposed by the Food and Agricultural Organisation (FAO) of the United Nations in 2013, called the digestible indispensable amino acid score (DIAAS) (FAO, 2013), and dairy proteins have one of the highest DIAASs (Wolfe, 2015) (Table 1). Furthermore, milk proteins contain latent bioactive peptides encrypted within their amino acid sequences which are released upon proteolysis such as those that occur in the gastrointestinal tract. These bioactive peptides exhibit a range of biological activities including antihypertensive, antithrombotic, cytomodulatory, immunomodulatory and antimicrobial activity, as examples (Mills *et al*., 2011). However, allergy to the proteins in bovine milk can be a problem for some infants and children. The exact extent of this in the developed world is hard to determine, but is estimated at 2–3% in infants and is reduced to less than 1% by the age of 6 years (Edwards & Younus, 2019).

The mineral composition of milk is dependent on stage of lactation, genetic factors and, to a lesser extent, animal nutrition (Zamberlin, 2012). Mineral elements in milk and dairy products exist as inorganic ions and salts and as part of organic molecules including proteins, fats and carbohydrates. While milk is a source of all the essential minerals for human nutrition (Cashman, 2006), the most abundant minerals present in bovine milk are calcium and phosphorus, mostly associated with the casein micelle structure, and it is also a good source of magnesium and potassium. Animal diet does not significantly influence the content of these minerals in milk. Milk is a good source of some vitamins, notably the fat-soluble vitamins (found in the milk fat fraction), which are influenced by animal diet, with high levels reported in fresh grass. It was reported that milk produced in summer months in Finland was 3–4 times higher in vitamin E than that produced in winter, as a result of feeding regime (Syvaoja *et al*., 1985). Milk is also a source of some water-soluble vitamins especially riboflavin (B2), thiamin (B1) and cobalamin (B12), which are derived from a combination of animal diet and the rumen microbiota and vary with the stage of lactation. It was reported that B12 concentration was six times higher in colostrum than in milk produced 39 d after calving, while folate concentration was nine times higher in colostrum (Duplessis *et al*., 2016).

**Table 1:** Digestible indispensible amino acid score (DIAAS) of milk and other protein sources

| Food (NDB)[1] | DIAAS[2] | FAO proposed system[3] |
|---|---|---|
| ***Animal-derived foods*** | | |
| Milk, whole (01077) | 114 | Good source |
| Eggs, hard-boiled (01129) | 113 | Good source |
| Chicken breast (05064) | 108 | Excellent source |
| ***Cereal-based foods*** | | |
| Oatmeal (08121) | 84 | Good source |
| Wheat bread, white (20083) | 29 | No claim |
| Rice, white (20045) | 57 | No claim |
| ***Mixed dishes*** | | |
| Macaroni and cheese (36009) | 90 | Good source |
| Beef stew (22905) | 45 | No claim |
| ***Legume/pulse foods*** | | |
| Baked beans (16006) | 56 | No claim |
| Chickpeas, boiled (16057) | 83 | Good source |
| Soy-based tofu (16426) | 52 | No claim |

Adapted from Marinangeli and House (2017)

[1] NDB = Nutrient Database Number from the USDA Nutrient Database USDA National Nutrient Database for Standard Reference: Release 28. http://www.ars.usda.gov/Services/docs.htm?docid=8964 (accessed 12 August 2016)

[2] DIAAS calculated using available digestibility coefficients (ileal or faecal) or using estimates of 0.85

[3] Food and Agriculture Organization of the United Nations Food and Nutrition paper 92, chapter 4.1: The digestible indispensable amino acid score (DIAAS) (FAO, 2013)

More than 50% of the fatty acids in bovine milk are derived from the diet (Lindmark Månsson, 2008) and over 50% of milk fatty acid content is composed of saturated fatty acids (SFAs). While these fatty acids have received negative attention in terms of human health, more recent research suggests that the association between SFA intake and heart disease risk factors requires re-evaluation. Indeed, a meta-analysis of prospective epidemiologic studies evaluating the association between SFA intake and cardiovascular disease (CVD) in 2010 revealed that there was no significant evidence to conclude that dietary SFA was associated with an increased risk of coronary heart disease (CHD) or CVD (Siri-Tarino *et al*., 2010). In 2015, a meta-analysis of 22 studies revealed an inverse association between dairy consumption and overall risk of CVD and stroke (Qin *et al*., 2015). Several of the SFA found in milk have been shown to exhibit beneficial activities; butyric acid (C4:0) accounts for approximately 10% of all fatty acids in bovine milk (Jensen, 2002) and has been associated with anti-cancer properties (German, 1999), and lauric acid (C12:0) and capric acid (C10:0) were revealed to have antimicrobial properties (Petrone *et al*., 1998; Sprong *et al*., 2001, 2002). It should also be stated at this point that milk of other species, including goats, are also good sources of beneficial fats (Barłowska *et al*., 2011). The long-chain SFA found in milk, stearic acid (C18:0), does not appear to raise serum cholesterol levels (Grundy, 1994). Bovine milk is also a source of monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs). The essential

PUFAs, omega 3 (α-linolenic acid, 18:3n-3) and omega-6 (linoleic acid, 18:2n-6), which cannot be synthesised by any member of the Kingdom Animalia and must be acquired from the diet, occur in milk at levels between 0.5 and 2 wt% and between 1 and 3 wt%, respectively (Jensen, 2002). As well as exhibiting numerous beneficial effects *in vitro* and *in vivo* (Connor, 2000; Dupertuis *et al*., 2007; Poulsen *et al*., 2007; Siddiqui *et al*., 2008), these fatty acids are converted to eicosanoids which play essential metabolic roles in the body. The Western diet has been associated with an increase in the intake of n-6 fatty acids resulting in a dietary n-3 to n-6 fatty acid ratio of between 1:10 and 1:20 which is well above the desirable ratio of 1:1–4 (Molendi-Coste *et al.*, 2011). However, the ratio of n-3 to n-6 fatty acids in milk is favourable compared to most other non-marine foods (Haug *et al*., 2007) and can be influenced via feeding regime, as discussed later. The bioactive conjugated linoleic acid (CLA) has been associated with numerous beneficial effects and has been shown to provide protection against cancer, diabetes, obesity and CVD based on *in vitro* and *in vivo* studies in animals (Yang *et al.*, 2017). Bovine milk is a source of CLA, particularly the *cis*-9, *trans*-11 isomer (*c9t11* CLA), which accounts for over 90% of total milk fat CLA (Stanton *et al*., 2003). It is produced as an intermediate product in the biohydrogenation of unsaturated fatty acids in the rumen, when dietary linoleic acid is converted to stearic acid by bacteria in the rumen and it can also be produced in the mammary gland from vaccenic acid (C18:1, *t*11) by the action of the enzyme delta9-desaturase (Kepler *et al*., 1966).

The fat in milk occurs as milk fat globules surrounded by the milk fat globule membrane (MFGM) which is composed primarily of cholesterol, phosphatidylcholine, glycolipids, glycoproteins, sphingomyelin and gangliosides (Ward *et al*., 2006). The MFGM is recognised for its antimicrobial activity (Sanchez-Juanes *et al*., 2009; Douëllou *et al*., 2017) and has been associated with numerous health benefits (Spitsberg, 2005; Mills *et al*., 2011). Most recently, a randomised clinical trial in humans revealed that milk fat delivered within an encapsulated MFGM structure does not impair the lipoprotein profile of humans in contrast to milk fat without a MFGM (Rosqvist *et al*., 2015).

Lactose, the major milk sugar, and its derivatives have received increasing attention in light of their prebiotic activities (Schaafsma, 2008). In this regard, it has been suggested that lactose be redefined as a “conditional prebiotic” (Szilagyi, 2004). However, lactose intolerance, which describes an impaired capacity to digest lactose, can be a problem for both infants and adults. Indeed, the ability to digest lactose beyond weaning is generally only maintained in descendants of populations which practise cattle domestication (Deng *et al*., 2015). In the case of lactose intolerance related to dairy foods, enzyme replacement and dietary changes can effectively treat the issue (Deng *et al*., 2015).

## Milk and dairy product quality from a pasture-based feeding system

Life cycle assessment (LCA) is used to compare multiple livestock production systems in terms of environmental impact. McAuliffe *et al*. (2018) recently proposed a novel framework whereby the nutritional quality of meat should also be included in LCA. Interestingly, milk and dairy produce from pasture differ from those produced from TMR diets fed indoors. This was recently reported in a series of publications by Teagasc researchers as part of an ongoing research programme addressing the potential benefits of dairy produce from pasture-based systems compared to TMR systems. This work has already clearly shown benefits in terms of superior nutritional properties, appearance, colour and flavour of milk and dairy products including butter and cheese from pasture-fed dairy cattle (O’Callaghan *et al*., 2016a, 2016b, 2017). O’Callaghan *et al*. (2016a) investigated the impact of different feeding systems on milk composition and quality over an entire lactation. Feeding a perennial ryegrass (*Lolium perenne* L.) pasture or a perennial ryegrass/white clover (*Trifolium repens* L.) pasture resulted in milk with significantly higher concentrations of fat, protein, true protein, casein and whey compared to milk from cows fed TMR indoors. Moreover, milk of pasture-fed animals was two-fold higher in the *c9t11* CLA content of milk, which as mentioned earlier has been associated with numerous beneficial health effects. In addition, pasture feeding resulted in milk with significantly increased n-3 PUFAs, significantly decreased n-6 PUFAs and, therefore, an improved n-3/n-6 ratio compared to TMR-based milk. The TMR-derived milk had a significantly higher thrombogenic index compared to the pasture-derived milk. The thrombogenic index is an indicator of the tendency for clots to be formed in the blood vessels and a higher index is therefore undesirable.

Butters manufactured from milk produced on the perennial ryegrass pasture, perennial ryegrass/white clover pasture and TMR were significantly different in terms of quality characteristics, nutritional properties and consumer perception (O’Callaghan *et al*., 2016b). Butter produced from pasture-fed cows was superior in appearance, flavour and colour as confirmed by sensory panel data. Unsurprisingly, the pasture-derived butter revealed improved nutritional properties including lower thrombogenicity scores, higher *c9t11* CLA and β-carotene concentrations. β-Carotene is a precursor of vitamin A and carotenoids such as β-carotene exert several biological functions including antioxidant activities, tumour inhibition and induction of apoptosis (Milani *et al*., 2017). Feeding system also influenced the nutritional properties of full-fat Cheddar cheese (O'Callaghan *et al.*, 2017). Pasture-derived cheese was yellower than its TMR-derived counterpart which was positively correlated with increased β-carotene content. Again, significantly lower thrombogenicity scores were reported for the pasture-derived cheese as well as two-fold higher levels of *c9t11* CLA isomer and vaccenic acid, which is a precursor of CLA. The pasture-derived cheeses had significantly higher n-3 fatty acid contents, whereas the TMR-derived cheeses had significantly higher n-6 fatty acid contents.

Feeding system can significantly impact the technological properties of milk and dairy products, as has been well recognised in relation to the spreadability of butter (Wood *et al.*, 1975; Banks & Christie, 1990; Couvreur *et al.*, 2006; Hurtaud & Peyraud, 2007). We recently also reported similar findings in that significant differences were observed in the textural and thermal properties of butters manufactured from pasture-derived and TMR-derived milks as a consequence of differences in fatty acid concentrations (O'Callaghan *et al.*, 2016b). Significantly higher hardness scores at room temperature were reported for the TMR-derived butters compared to the pasture-derived butters which were attributed to the higher SFA content (which approached significance) and the significantly higher concentrations of palmitic acid in the TMR-derived butters. Onset of crystallisation for TMR butters also occurred at significantly higher temperatures, a factor which would contribute to increased hardness at room temperature. Volatile analysis revealed significant differences between butters, and toluene was higher in pasture-based products and was identified as a differentiating flavour compound. In terms of sensory analysis, the butter manufactured from grass-derived milk scored the highest in terms of appearance, flavour and colour. Similarly, the TMR-derived cheeses exhibited increased hardness compared to the pasture-derived cheeses at room temperature which was attributed to the significantly higher concentration of palmitic acid in the TMR milk.

The results indicate that pasture-based milk contains significantly higher concentrations of fat, protein and casein than milk produced from cows fed TMR diets indoors, and in particular, milk from pasture-fed cows (grass with or without white clover) has significantly higher concentrations of healthy fatty acids. Such data provide scientific substantiation for dairy produce from pasture-fed animals as superior, from a compositional and nutritional perspective, to that derived from their indoor counterparts. However, the long-term benefits of pasture-based produce on human health remain to be confirmed through human clinical studies.

## Variation within pasture-based systems

Seasonal variation in grass growth has been shown to significantly influence the fatty acid composition of milk (Riel, 1963; Parodi, 1977; Stanton *et al.*, 1997). For example, the CLA content of milk fat has been reported to range from ~2 to 30 mg/g fat (Riel, 1963; Stanton *et al.*, 1997), with much of the variation being attributed to seasonal influences on pasture quality. High CLA contents were reported in milk from cows fed on pasture in spring (April and May, ~6.8 mg CLA/g fat) and low levels were reported in midsummer and winter (~4.3 mg CLA/g fat) (Kim *et al.*, 2009). There are seasonal variations in the n-3 content of milk with higher levels reported in summer and lower in winter. A recent meta-analysis of organic compared with conventional milk reported higher n-3 PUFA and CLA in organic milk and these milk composition parameters showed strong positive associations with grazing intake. In contrast, there were positive associations between concentrate, maize silage, hay and straw intake and SFA content (Średnicka-Tober *et al.*, 2016). Cullinane *et al.* (1984) showed a seasonal variation in the fatty acid composition of Irish butter including variations in the levels of butyric acid and C18-unsaturated fatty acids.

## Impact of different feeding systems on human health: milk

Studies investigating the differential effects of milk products produced from different diets and management systems on human health are scarce and those which have been conducted have generated mixed results. In a randomised controlled study, Werner *et al.* (2013) investigated the impact of consuming butter derived from mountain pasture-grazing cows compared to consumption of conventional Danish butter on risk markers of metabolic syndrome in a 12-wk study involving 68 healthy subjects. As there were no differences in blood lipids and inflammation between groups at the end of the study, the authors concluded that mountain pasture-derived dairy products were not healthier than those derived from high-input conventional systems despite the fact that cholesterol-raising SFAs were reduced by 20% in the butter derived from pasture-fed cows group. Consumption of butter naturally enriched with ruminant trans fatty acids, of which vaccenic acid was the predominant isomer and equivalent to ~1% of daily energy, did not significantly impact low-density lipoprotein (LDL) cholesterol levels in 61 healthy women following a 4-wk study (Lacroix *et al.*, 2012). The butter naturally enriched with vaccenic acid was produced from selected cows fed concentrates, alfalfa and corn (*Z. mays*) silage, with the addition of corn oil. In contrast, consumption of butter with a naturally higher content of vaccenic acid and MUFAs did reduce total cholesterol and plasma high-density lipoprotein (HDL) cholesterol concentrations in healthy young men in a double-blind, randomised 5-wk parallel intervention study, compared to the consumption of control butter with higher amounts of SFAs (Tholstrup *et al*., 2006). Consumption of dairy products naturally enriched with CLA from pasture-fed cattle for 56 d did not significantly alter selected health risk factors (insulin sensitivity, body composition, circulating lipids as well as other disease risk factors) in healthy women when compared to consumption of dairy products with three-fold less CLA, derived from grain-fed cattle (Brown *et al*., 2011). Livingstone *et al*. (2012) reviewed nine long-term human intervention studies that used modified dairy products (modified via cows' diet) to determine the effects on CVD risk markers where the majority of studies used modified butter and assessed changes in blood cholesterol as the main risk marker. Overall, the results suggest that modified dairy products may be beneficial to CVD risk in healthy and hypercholesterolaemic individuals; however, current evidence is insufficient and further studies are warranted.

## Nutritional quality of bovine meat

Red meat is an important source of dietary protein for many people being a source of all the essential amino acids. Beef, in particular, is also a source of B vitamins and minerals including zinc and iron; indeed, it contains 2.5 times more iron than pork and 5 times more iron than poultry (Micinski *et al*., 2012). Interestingly, the European Environment Agency reported that consumption of bovine meat in the European Union (EU) decreased by nearly 14% between 2000 and 2013, coinciding with increased consumption of cheese and poultry meat (European Environment Agency, 2017). This reduction in consumption of bovine meat stems from associations between red meat, its SFA content and risk of CVD and cancer. Of note, beef has a higher proportion of the SFA stearic acid (C18:0) compared to other meats, which is regarded as being neutral in terms of raising blood cholesterol (Grundy, 1994; EFSA, 2010; Vargas-Bello-Pérez & Larraín, 2017). The link between beef intake and health risk is not the only reason for reduced consumption. Some EU countries reported a decline in beef consumption due to the correlation with outbreak of diseases such the bovine spongiform encephalopathy (Pires *et al*., 2009). In this regard, correct consumer information related to health risks and safety is very important. Another significant factor in the reduction of meat consumption is the impact of animal-derived foods on the environment. Studies have shown that reducing meat consumption could ease land-use pressures (Stehfest *et al*., 2009; Tilman & Clark, 2014) and reduce greenhouse gas (GHG) emissions (Stehfest *et al*., 2009; Popp *et al*., 2010; Hedenus *et al*., 2014; Tilman & Clark, 2014). Springmann *et al*. (2016) estimated that transitioning to more plant-based diets that are in line with standard dietary guidelines could reduce GHG emissions by 29–70% compared with a reference scenario in 2050. In addition, such a dietary change could also reduce global mortality by 6–10% (Springmann *et al*., 2016).

Fat in meat occurs in the form of glycerol esters, cholesterol, phospholipids and fatty acid esters deposited in intramuscular, intermuscular and subcutaneous adipose stores (Scollan *et al*., 2017). The intramuscular fat of beef varies between 20 and 50 g/kg and contains 450–480 mg/100 g of SFAs, 350–450 mg/100 g of MUFAs and up to 50 g/100 g of PUFAs (Bessa *et al*., 2015; Clonan *et al*., 2016). The ratio of n-6 to n-3 PUFA in ruminant meat is generally <3.0, but in animals fed high amounts of cereal grains it has been reported to exceed 5.5 (Scollan *et al*., 2006; Sinclair, 2007). Beef is also a source of CLA and trans fats, the proportions of which vary depending on the breed and production system. Conjugated linoleic acid in retail beef has been reported to vary between 340 and 820 mg/100 g of total fatty acids (Kraft *et al*., 2008; Aldai *et al*., 2009, 2010).

A number of studies have investigated the association between meat consumption and mortality or disease risk. The NIH-AARP Diet and Health Study investigated the link between meat intake and mortality with a cohort of 500,000 people aged 50–71 years and concluded that intakes of red meat and processed meat were associated with modest increases in total mortality, cancer mortality and CVD mortality (Sinha *et al*., 2009). This finding has been corroborated by other studies (Pan *et al*., 2012; Schwingshackl *et al*., 2017). A systematic review and meta-analysis of 111 cohort studies to quantify the dose response between food and beverage intake and colorectal cancer risk reported that colorectal cancer risk increases by 12% for each 100 g/d increase in red and processed meat intake, while the risk decreases by 13% for each 400 g/d increase of dairy product intake (Vieira *et al*., 2017). In a prospective cohort study of 51,683 Japanese people aged 40–79 years, Nagao *et al*. (2012) concluded that moderate meat consumption (up to ~100 g/d) was not associated with increased mortality from ischemic heart disease, stroke or total CVD. More recently, a meta-analysis of 24 randomised clinical trials revealed that consumption of ≥0.5 servings of total red meat/d does not impact blood lipids and lipoproteins or blood pressure (O'Connor *et al*., 2017). But as Vargas-Bello-Pérez and Larraín (2017) point out, there is no single definition of which meats are included in the term "red meats" and most often it includes pork, beef and lamb and in some studies, processed meat as well. In this regard, in a systematic review and meta-analysis of the evidence, Micha *et al*. (2010) concluded that consumption of processed meats, but not red meats, was associated with a higher incidence of CHD and diabetes mellitus. Given that modern evidence now questions the link between dietary SFA intake and CVD risk, it appears that compounds such as heme iron and sodium, in addition to other preservatives, may in fact contribute to the negative cardiovascular effects of certain meats (Mozaffarian, 2016). Known/suspected carcinogenic compounds may appear in processed meat as a result of certain processing procedures such as curing or smoking (Domingo & Nadal, 2017). In addition, the microbial metabolite trimethylamine-N-oxide (TMAO), derived from dietary choline, lecithin and carnitine, has been identified as a risk factor for CVD (Wang *et al*., 2011). These three nutrients are found in red meat (Velasquez *et al.*, 2016) and research has confirmed TMAO production from carnitine in humans by the gut microbiota (Koeth *et al*., 2013). This suggests that gut microbial-derived production of TMAO could be a link between red meat and CVD risk.

## Meat product quality from a pasture-based feeding system

In the same way that ruminant animal feeding regimen alters the fatty acid profiles of milk, the fatty acid profiles of ruminant meats can also be adjusted through diet, enabling the production of healthier meat with decreased SFA contents and increased MUFAs and PUFAs. Pasture-based diets have been shown to increase CLA and vaccenic acid (C18:1, *t*11) content of beef, to increase the cholesterol-neutral fatty acid, stearic acid (C18:0), and to reduce cholesterol-associated fatty acids including myristic (C14:0) and palmitic (C16:0) acids (Daley *et al*., 2010). In addition, pasture feeding has been associated with increased β-carotene content in beef (Descalzo *et al*., 2005), as well as increased vitamin E and antioxidant capacity (Realini *et al*., 2004; De la Fuente *et al*., 2009) compared to grain-fed animals. For example, the intramuscular fatty acid composition of beef was significantly improved by including pasture in the diet (French *et al*., 2000). Indeed, increasing pasture intake and decreasing the proportion of concentrates resulted in a significant linear decrease in SFA concentration and in the n-6:n-3 PUFA ratio and significantly increased CLA concentration. Meat derived from steers reared and finished on pasture had higher concentrations of n-3 fatty acids, lower n-6:n-3 PUFA ratios as well as higher magnesium and lower potassium contents compared to meat from steers finished on concentrates (de Freitas *et al*., 2014). The type of pasture may also impact the fatty acid profiles of meat. For example, sheep grazed on rangeland pasture (grasses and native shrubs) had higher percentages of n-6 and n-3 PUFAs compared with sheep fed on naturalised grassland (Ramírez-Retamal *et al*., 2014). However, the meat of lambs grazing on different dryland forages in Chile showed no significant differences in fatty acid profiles (Gallardo *et al*., 2011). Despite this, Whittington *et al*. (2006) reported that meat from lambs grazed on heather (dominant species: *Calluna vulgaris*, *Vaccinium myrtillus* and *Deschampsia flexuosa*) and mooreland (dominant species: *Festuca ovina*, *D. flexuosa*, *Nardus stricta*) had significantly higher n-6, C22:6 and n-3 PUFAs compared to sheep grazed on perennial ryegass. Such differences can be linked to lipids in the herbage itself as well as plant factors which influence endogenous lipolysis and biohydrogenation in the rumen, for instance, tannins and polyphenol oxidase, as examples (Buccioni *et al*., 2012; Toral *et al*., 2018).

In a review of the literature examining the impact of forage feeding versus grain finishing on beef nutrients in the United States, Van Elswyk & McNeill (2014) concluded that “beef cuts from cattle consuming mostly forage appear to be lower in fat than those from grain-finished beef, largely at the expense of MUFA”. However, the study by Van Elswyk & McNeill (2014) also highlighted issues associated with sensory quality as changing the fatty acid content of beef can influence colour, flavour, sensory attributes and shelf-life (Scollan *et al.*, 2006). Steaks from pasture have been reported to be less tender than steaks from grain-finished beef (Blanco *et al.*, 2017). In addition, the external fat of pasture-derived beef has been reported to be more yellow (a consequence of increased β-carotene in adipose tissue). While flavour acceptability varies in terms of individual preference and cultural norms, trained sensory panellists reported that beef from pasture-finished cattle lacked beef flavour and presented greater off-flavours than beef from grain-finished cattle (Duckett *et al*., 2013). Interestingly, a study investigating health information impact on the relative importance of beef attributes including its enrichment with PUFA and CLA on Spanish consumers revealed that informed consumers are willing to accept meat with a higher amount of visible fat once it is enriched with beneficial fatty acids (Kallas *et al*., 2014) and a follow-on study revealed that informing consumers about beneficial fatty acids would favour marketing of beef enriched in n-3 PUFA through animal diet (Baba *et al.*, 2016).

## Impact of different feeding systems on human health: meat

Human intervention studies investigating the impact of beef as a result of the animal feeding system on human health are limited. A crossover dietary intervention involving 27 normocholesterolaemic men investigated the effect of consuming 114 g ground beef patties/wk for 5 wk derived from pasture-fed cattle (low MUFA) or grain-fed cattle (high MUFA) on cholesterol (Gilmore *et al*., 2011). It was reported that both beef interventions decreased HDL(2) and HDL(3) particle diameters and increased plasma C18:0 and C20:4 (n-6) PUFA relative to baseline. The high MUFA ground beef intervention derived from grain-fed cattle significantly increased HDL cholesterol from baseline. Ten mildly hypercholesterolaemic men consumed hamburger patties derived from pasture-fed cattle (MUFA:SFA = 0.95; high SFA) for 5 wk and following a 3-wk washout period consumed hamburger patties from grain-fed cattle (MUFA:SFA = 1.31; high MUFA) for another 5 wk (Adams *et al.*, 2010).

Following consumption of the high SFA hamburger, plasma triacylglycerols and the LDL:HDL ratio were significantly greater than after the high MUFA hamburger phase. Conversely, HDL cholesterol was greater after the high MUFA hamburger phase than after the high SFA hamburger phase.

While these studies used meat derived from pasture- or grain-fed cattle, each was a mixture of fat and lean trims. Thus, studies are required which examine the impact of lean trims only from different feeding systems on human health parameters. However, the studies presented suggest that different animal feeding systems may impact blood cholesterol profiles of meat consumers.

## Conclusion

The nutritional composition, especially lipid profile and micronutrient (vitamin) composition of dairy and beef products, can be modified through the animal's diet resulting in products which may be nutritionally more beneficial in terms of human health. The lipid composition of milk and meat, in particular, is amenable to significant alterations generating fatty acid profiles which are more favourable towards a healthy lifestyle. In terms of dairy products, a limited number of studies have indicated the advantages of pasture-feeding regimens over other feeding systems resulting in milk and milk-derived products with increased PUFAs and CLA and reduced SFAs. The resulting products can also differ in terms of their technological properties as we have seen with butter and can differ in terms of texture and taste.

There is a severe paucity of studies investigating the influence of meat from different feeding systems on human health and thus it is difficult to generate a conclusion.

Overall, further studies investigating the impact of pasture-derived dairy and meat products versus their grain-derived counterparts on human health are required. In addition, educating consumers on the role of the different fatty acids in promoting good health and on the levels of these fatty acids in food products is essential, enabling consumers to make informed decisions when choosing meat and dairy products as part of their daily diet. However, further research on the nutritional aspects of pasture-fed animals is envisaged, in line with the increasing consumer awareness that natural animal feeding correlates with animal and human health and the consumer desire for natural products, including animal-derived ones (Gaggia *et al*., 2011; Bolger *et al*., 2017).

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