

Foods derived from animals: the impact of animal nutrition on their nutritive value and ability to sustain long-term health

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Summary

Foods derived from domestic animals are a significant source of nutrients in the UK diet. However, certain aspects of some animal-derived foods, notably levels of saturated fatty acids, have given rise to concerns that these foods may contribute to the risk of cardiovascular disease, the metabolic syndrome and other conditions. However, the composition of the many animal-derived foods is not constant and can often be enhanced by manipulating the nutrition of the animal. This paper reviews these possibilities with particular attention to lipids, and draws attention to the fact that milk in particular, contains a number of compounds which may, for example, exert anti-carcinogenic effects. It is clear that the role of animal nutrition in creating foods closer to the optimum composition for long-term human health will not only be more relevant in the future, but will be vital in attempts to improve the health of the human population.

Keywords: animal nutrition, food, health, nutritive value

Introduction

It is well established that foods of domestic animal origin make a major contribution to the UK diet. Although the consumption of full fat milk and meat from ruminant animals has declined during recent years, the amounts of skimmed milk and poultry meat in the typical human diet have substantially increased (DEFRA

2001). The contribution of various animal derived foods to key aspects of the UK diet in 2000 is shown in Table 1 expressed as both daily intake of nutrients and as a percentage of the total dietary intake (for phosphorus and magnesium as a percentage of the adult reference nutrient intake). These data clearly show the major contribution of these food sources to protein, calcium and phosphorus intake, and a sizable contribution to intake of magnesium and iron. The amounts of nutrients derived from eggs and fish/marine products are relatively small, and therefore these food sources are not considered further.

Table 1 also indicates that while the supplies of protein from milk/dairy products and meat are approximately equal, milk is a major source of calcium, whilst meat (predominantly red meat) makes an important

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Table 1 Energy and selected nutrients provided by animal derived foods in the UK during 2000*

Nutrient	Milk and dairy products	Meat and meat products	Eggs	Fish and fish/marine products	Total excluding fish
Energy					
Intake (MJ/day)	1.12	1.15	0.09	0.04	2.36
% of MDI†	15.3	15.7	1.2	0.5	32.2
Protein					
Intake (g/day)	14.0	23.5	1.7	1.1	39.2
% of MDI	21.1	35.5	2.6	1.7	59.2
Fat					
Intake (g/day)	17.8	15.2	1.5	0.45	34.5
% of MDI	24.1	20.5	2.1	0.6	46.7
Calcium					
Intake (mg/day)	465	45.3	7.8	3.5	518
% of MDI	54.0	5.3	0.9	0.4	60.2
Phosphorus					
Intake (mg/day)	366	223	27.5	13.7	617
% of RNI‡	66.5	40.5	5.0	2.5	112
Magnesium					
Intake (mg/day)	37	28	1.7	1.9	66.7
% of RNI	13.0	9.8	0.59	0.67	23.4
Iron					
Intake (mg/day)	0.13	1.6	0.26	0.05	2.0
% of MDI	1.3	16.2	2.6	0.5	20.1

*Data derived from a combination of the National Food Survey (DEFRA 2001) and Food Standards Agency (2002). †MDI, mean daily intake from the National Food Survey (DEFRA 2001). ‡RNI, adult reference nutrient intake from the Department of Health 1991).

contribution to iron in the diet. Overall, animal derived foods contribute about 32% of the total energy intake, but a high proportion (0.54) of this energy is derived from fat. Furthermore, lipids in milk and dairy products, and to a lesser extent in meat of ruminant animals contain relatively high amounts of saturated fatty acids, in particular lauric (C12:0), myristic (C14:0) and palmitic (C16:0) acids. These fatty acids have been associated with elevated plasma low density lipoprotein (LDL) cholesterol concentrations in human subjects (*e.g.* Katan *et al.* 1995; Temme *et al.* 1996). Some studies suggest that C12:0 and C14:0 exert more potent effects on plasma cholesterol than C16:0 whilst others suggest that C14:0 and C16:0 are more potent than C12:0. In any event, palmitic acid is quantitatively the most important saturated fatty acid in milk fat. Most of the C12:0 and C14:0 in the human diet is derived from milk fat (Gunstone *et al.* 1994), and therefore the consumption of milk and dairy products would be expected to have adverse effects on plasma cholesterol levels. However, the evidence from studies in adolescents (Samuelson *et al.* 2001) and elderly men (Smedman *et al.* 1999) suggests that consumption of milk and dairy products does not have a detrimental impact on blood lipid profiles and may even elicit beneficial

effects (Buonopane *et al.* 1992). Furthermore, a recent prospective study examining the relationship between milk and coronary heart disease concluded that there was no association between the consumption of whole fat milk and death from coronary vascular disease (Ness *et al.* 2001). A more comprehensive treatise of the effects of milk fat on plasma lipid profiles and human health is provided by Lock and Shingfield (2004) and Minihane (2004).

However, it is important to recognise that the composition of animal derived foods is not fixed, and a number of components vary considerably in response to changes in the diet of productive animals. It therefore follows that animal and human nutrition are intimately linked and current research is actively investigating ways in which the nutritional-medical properties of animal derived food products can be enhanced, whilst not diminishing their inherent and widely acclaimed nutritional benefits. The purpose of this paper is to review key aspects of milk and meat as foods and how their qualities may be altered by animal nutrition. Emphasis is placed on manipulation of dietary lipids with reference to the important role of animal nutrition within the LIPGENE project (see Nugent 2004).

Milk and milk products

Milk is a food of outstanding interest, not least because it was designed to be a complete source of nutrients for young growing mammals. The role of bovine milk in the human diet as a source of fat, amino acids, calcium and other nutrients (see Table 1) has been recognised for centuries. Milk is a complex colloid consisting of globules of milk fat suspended in an aqueous solution comprised of lactose, proteins, minerals and water-soluble vitamins. Typical milk from Holstein/Friesian cows contains about 39, 33 and 45 g/kg of fat, protein and lactose, respectively, with an energy content of 2.7 MJ/kg (Food Standards Agency 2002). However, these values vary considerably between different breeds and in response to changes in nutrient supply. It is noteworthy that in the UK, consumption of whole milk has halved between 1990 (mean 1232 mL/person/week) and 2000 (mean 664 mL/person/week), but consumption of semiskimmed milk has almost doubled during this period (mean 975 mL/person/week in 2000). At present, milk and dairy products are available in many forms. The contribution of the major classes of milk and dairy products to nutrient and energy intakes of the UK human population during 2000 is shown in Table 2.

Milk proteins

The proteins in milk provide an excellent source of amino acids, the composition of which closely resembles the requirements of mammalian neonates. Proteins constitute about 95% of total milk nitrogen and are comprised of caseins (α , β , κ and γ), whey proteins (β -lactoglobulin and α -lactalbumin), serum albumin and immunoglobulins. Even though whey proteins are of high nutritional value, only the casein fraction is important to cheese makers. Casein accounts for between 76 and 86% of total milk protein (DePeters & Cant 1992). The concentration of protein in milk is dependent on both breed of cow and stage of lactation, in addition to nutrient supply of the dairy cow. Breeds that produce milk with a high fat content also tend to have higher protein concentrations.

It is now recognised that dietary energy intake of the dairy cow is the most important nutritional factor affecting milk protein content. Across a wide range of diets, an increase of 1 MJ of metabolisable energy (ME) intake has been estimated to stimulate 2–3 g/kg increases in milk protein content (Spörndly 1989). Whilst the impact of energy intake on milk protein synthesis is widely accepted, improvements in milk protein concentration only occur when additional energy is derived from carbohydrates or protein. Use of fat

Table 2 Energy and selected nutrients provided by milk and dairy products in the UK during 2000*

Nutrient	Liquid whole milk	Semi-skimmed milk	Full skimmed milk	Yoghurt and fromage frais	Cream	Butter	Cheese	Total
Energy								
Intake (MJ/day)	0.27	0.28	0.033	0.081	0.021	0.17	0.26	1.12
% of MDI†	3.7	3.8	0.45	1.1	0.28	2.3	3.6	15.3
Protein								
Intake (g/day)	3.2	4.9	0.82	1.2	0.08	0.03	3.8	14.0
% of MDI	4.9	7.4	1.2	1.8	0.1	0.1	5.7	21.1
Fat								
Intake (g/day)	3.8	2.4	0.05	1.1	0.49	4.6	5.3	17.8
% of MDI	5.1	3.3	0.1	1.5	0.7	6.2	7.2	24.1
Calcium								
Intake (mg/day)	115	173	29.4	31.2	2.3	1.0	113	465
% of MDI	13.4	20.0	3.4	3.6	0.3	0.1	13.1	54.0
Phosphorus								
Intake (mg/day)	90.9	135	23.2	29.5	2.0	0.1	85.7	366
% of RNI‡	16.5	24.5	4.2	5.4	0.36	0.02	15.6	66.5
Magnesium								
Intake (mg/day)	10.7	15.8	2.7	3.0	0.2	0.1	4.51	37.0
% of RNI	3.8	5.5	0.95	1.1	0.07	0.04	1.6	13.0

*Data derived from a combination of the National Food Survey (DEFRA 2001) and Food Standards Agency (2002). †MDI, mean daily intake from the National Food Survey (DEFRA 2001). ‡RNI, adult reference nutrient intake from the Department of Health 1991.

supplements to enhance dietary energy supply typically causes a 1–4 g/kg depression in milk protein content (Sutton 1989). The primary mechanism for increases in milk protein synthesis in response to carbohydrate energy is due to greater synthesis of microbial protein in the rumen, that following digestion, leads to an enhanced supply of limiting amino acids to the mammary gland (Reynolds *et al.* 1997). This underlines the complex relationship between diet, rumen microbes and the supply of absorbed nutrients in ruminant animals.

Whilst the value of milk proteins as a source of amino acids is well recognised, recent research has focused on the functional properties of milk proteins and protein hydrolysates. It has been shown that intact proteins from both major protein groups exert distinct physiological functions *in vivo*. The high concentrations of bioactive whey proteins, such as the immunoglobulins and lactoferrin in colostrum, reflect their importance to the new born, but it is also thought that milk proteins have other physiological functions due to the number of bioactive peptides present. These bioactive peptides exhibit a wide range of activities including anti-hypertensive, cytomodulatory and anti-microbial effects (see review of Korhonen & Pihlanto 2003). Full exploitation of the properties of many of these bioactive peptides is a clear priority for the future. However, as yet there is little information on the potential of animal nutrition to modify the relative amounts of specific proteins and associated peptides in milk. Further work is required, but it is highly probable that nutrition experiments will need to be conducted in conjunction with studies on the genes which encode for the various proteins in milk.

Milk fat

Based on both epidemiological evidence and controlled intervention studies in human subjects, it is known that saturated fatty acids increase blood cholesterol (and notably the LDL fraction) concentrations in a predictable and dose related fashion (*e.g.* Keys *et al.* 1965; Mensink & Katan 1990). More recently, it has been shown that myristic, palmitic and to a lesser extent lauric acids, are primarily responsible for elevating plasma LDL cholesterol concentrations (*e.g.* Temme *et al.* 1996), whilst the other major saturated fatty acid in foods, stearic acid (C18:0), has been shown to be essentially neutral (Bonanome & Grundy 1988). Most of the interest in high saturated fatty acid intakes has been centred around the increase in plasma LDL cholesterol levels and associated increases in cardiovascular disease risk, but there is now evidence that high intakes of saturated fatty acids may also be related to reduced insulin

sensitivity (Vessby *et al.* 2001), which is a key factor in the development of the metabolic syndrome (Nugent 2004). In a recent comprehensive study across 14 Western European countries (Hulsof *et al.* 1999), milk and dairy products were shown to contribute up to 58% of total saturated fatty acid intake, but these values vary considerably between individual countries.

Against this background there has been considerable concern surrounding the consumption of fatty acids in milk and dairy products and possible risks to health, and therefore research has been undertaken with a view to producing milk containing lower levels of saturated fatty acids and enhanced amounts of mono- and polyunsaturates.

Manipulating milk fatty acid composition

Milk fat typically contains 70–75% saturated fatty acids, 20–25% monounsaturates and small (2–5%) amounts of polyunsaturated fatty acids (Lock & Shingfield 2004). Fatty acids secreted in milk originate from two sources, either by direct incorporation from the peripheral circulation or from *de novo* synthesis using short chained (C2:0 and C4:0) precursors in the mammary gland. Mammary *de novo* synthesis accounts for all C4:0 to C12:0, most of the C14:0 and typically about half of C16:0 secreted in milk, while all C18 and longer chain fatty acids are derived entirely from circulating plasma lipids (Hawke & Taylor 1995). A distinctive feature of the bovine mammary gland is its ability to release fatty acids from the synthetase complex at various stages, resulting in the secretion of a wide range of short and medium chain fatty acids. Due to extensive biohydrogenation of dietary unsaturated fatty acids by rumen bacteria, C18:0 is, under most conditions, the predominant long chain fatty acid available for absorption. However, increasing the supply of long chain fatty acids (of chain length C18 and above) to the mammary gland inhibits the synthesis of short and medium chained saturates (Chilliard *et al.* 2000). It is also notable that the secretion of oleic acid (*cis*-9 C18:1) in milk exceeds its uptake by the mammary gland due to the activity of stearoyl Co A (Δ -9) desaturase in mammary secretory cells that convert C18:0 to *cis*-9 C18:1 (Kinsella 1972). Conversion of stearic to oleic acid is the predominant precursor to product process of the Δ -9 desaturase, and about 40% of C18:0 taken up by the mammary gland is desaturated (Chilliard *et al.* 2000).

As a result of the complex process by which milk fatty acids originate, several nutritional approaches can be used to manipulate milk fatty acid composition. Both the amount and source of dietary lipid affect the extent

Table 3 Typical milk fatty acid responses to dietary lipid supplementation (from Givens & Shingfield 2003)

Lipid source	Mean response*									
	C14:0	C16:0	C18:0	<i>cis</i> -9 C18:1	<i>trans</i> C18:1	C18:2 (<i>n</i> -6)	C18:3 (<i>n</i> -3)	Total saturates	MUFA [†]	PUFA [‡]
Rapeseed oil	-0.03	-0.20	0.55	0.39	0.30	-0.09	0.11	-0.07	0.30	-0.04
Rapeseed oil	-0.19	-0.33	0.51	0.67	2.00	-0.04	0.60	-0.18	0.60	0.15
Soyabean oil	-0.29	-0.28	0.45	0.23	4.61	0.33	-	-0.19	0.53	0.33
Sunflower oil [§]	-0.32	-0.32	0.14	0.27	3.07	-0.05	-0.24	-0.22	0.53	0.12
Sunflower oil	-0.23	-0.26	0.15	0.11	2.79	0.07	-0.21	-0.17	0.36	0.21
Linseed oil	-0.11	-0.15	0.27	0.26	0.94	-0.14	0.17	-0.07	0.23	-0.06
Fish oil	0.04	-0.01	-0.45	-0.25	8.08	0.24	0.03	-0.09	0.24	0.29
Fish oil	0.30	0.35	-0.77	-0.73	2.19	0.39	0.07	-0.05	-0.10	2.17
Tallow	-	0.06	0.04	0.22	0.19	-0.37	-0.37	-0.06	0.19	-0.36

*Responses calculated as proportionate differences between treatment controls and lipid supplemented diets. [†]MUFA, monounsaturates. [‡]PUFA polyunsaturates.

[§]Sunflower oil rich in *cis*-9 C18:1.

and type of change that can be achieved. A summary of the effects of including various lipids in dairy cow diets is reported in Table 3. In general, supplements of plant oils or oilseeds reduce short and medium chain but increase long chain fatty acids in milk, resulting in an overall shift towards C18:0 at the expense of C16:0 due to decreased *de novo* synthesis and/or reduced mammary uptake of absorbed C16:0. Reductions in milk unsaturated fatty acid content are characterised by small increases in the concentration of the predominant fatty acid in the lipid supplement. In all cases, feeding plant oils increases milk fat C18:0, *cis*-9 C18:1 and *trans* C18:1 content due to extensive ruminal metabolism of long chain fatty acids, leading to an increased supply of biohydrogenation intermediates (both *trans* C18:1 and C18:2 fatty acids) and C18:0 to the mammary gland.

Polyunsaturated fatty acids (PUFA) are not synthesised in any appreciable quantities in ruminant tissues and therefore concentrations in milk are essentially a reflection of the amount leaving the rumen. Consequently, oils rich in linoleic (C18:2 *n*-6) and linolenic (C18:3 *n*-3) acids have been used to increase the concentrations of these PUFA in milk or ruminant meat. In addition, the potential to enhance the concentrations of the long chain *n*-3 PUFA eicosapentaenoic (EPA, C20:5 *n*-3) and docosahexaenoic (DHA, C22:6 *n*-3) acids in milk and beef has been examined typically using fish oil as a source of EPA and DHA.

However, the transfer efficiency of EPA and DHA from the diet into milk is very low due to extensive biohydrogenation in the rumen and subsequent transport of absorbed *n*-3 PUFA in phospholipid and cholesterol ester fractions of plasma that are poorly utilised by the mammary gland (Rymer *et al.* 2003). In addition, inclusion of fish oil in dairy cow diets reduces levels of C18:0

and significantly increases the amounts of *trans* C18:1 and *trans* C18:2 in milk (Shingfield *et al.* 2003).

Milk as a source of anti-carcinogens

As a result of the emphasis which has been placed on the hypercholesteraemic properties of some of the saturated fatty acids in milk fat, it is not always recognised that milk fat contains a number of potentially powerful anti-cancer compounds. Two of the most important groups of compounds are isomers of conjugated linoleic acid (CLA) and the sphingolipids.

CLA is a generic term used to describe a mixture of geometric and positional isomers of C18:2 that contain a conjugated double bond. There is now increasing evidence based on studies in rodent models that *cis*-9, *trans*-11 CLA exhibits anti-carcinogenic properties (Parodi 2003). Numerous studies have provided evidence that mixtures of CLA inhibit the growth of a number of human cancer cell lines and suppress chemically induced tumour development (Kritchevsky 2000; Roche *et al.* 2001), while studies in animal models have confirmed the anti-carcinogen properties of CLA are exerted by the *cis*-9, *trans*-11 isomer (Ip *et al.* 1999). Even though studies in human subjects are limited, there is tentative evidence to suggest that consumption of milk fat is inversely related to breast cancer risk in menopausal women (Knekt *et al.* 1996; Aro *et al.* 2000), while subsequent studies have been unable to demonstrate protective effects of CLA on post-menopausal breast cancer (Voorrips *et al.* 2002; Chajès *et al.* 2003).

Dairy products are the major source of CLA in the human diet (Lawson *et al.* 2001), and the *cis*-9, *trans*-11 isomer is the most abundant isomer in ruminant derived foods. In view of the potential benefits to human health,

there has been considerable interest in understanding the mechanisms that regulate CLA synthesis in the dairy cow, with the overall aim of producing CLA enriched milk. The evidence so far indicates that nutrition, rather than genotype, parity or stage of lactation is the single most important factor affecting milk fat CLA concentrations. A number of nutritional strategies involving extended grazing or lipid supplementation have been developed to enhance CLA concentrations in milk. Concentrations of CLA are higher in milk fat from cows offered fresh compared with conserved forages, and can also be enhanced using whole oilseeds or oil supplements (Grinari & Bauman 1999). Fish oil is more effective than plant oils for increasing milk fat CLA content (Chilliard *et al.* 2000), and these responses can be further enhanced when fish oil is fed in combination with C18:2 rich supplements.

Milk is also a rich source of sphingolipids, sphingomyelin in particular. Sphingolipids are digested throughout the whole digestive tract including the colon. A number of studies in animal models have shown that milk-derived sphingomyelin reduces colon tumour development (Schmelz *et al.* 2000). This work needs further development, including an examination of the potential of nutritional strategies for the enhancement of sphingolipid levels in milk.

Meat and meat products

Table 1 clearly shows that whilst the amount of energy in the human diet derived from meat and meat products is similar to that from milk and dairy products, meat provides more protein, marginally less fat (with a different fatty acid profile) and substantially more iron. However, these data disguise the fact that meat from ruminant animals (cattle, sheep) is of markedly different composition to that from non-ruminants (pigs, poultry). In this regard, it is important to note that the consumption of ruminant derived meats has dramatically declined over the past 25 years, whereas that of non-ruminant meat sources (poultry meat in particular) has substantially increased.

In general, fat in ruminant derived meats is comprised of approximately between 45 and 55% of saturated fatty acids, 45–50% monounsaturated fatty acids and relatively minor amounts of PUFA (Mir *et al.* 2003). Most of the research effort on manipulating the fatty acid composition of beef, and to a lesser extent lamb, has been directed towards increasing the ratio of PUFA to saturated fatty acids (P : S) and enhancing the ratio of *n*-3 PUFA : *n*-6 PUFA. The most effective means of manipulating the fatty acid composition of beef is

Table 4 The effect of including fish oil in the diet of broilers on selected fatty acids in the thigh meat (from López-Ferrer *et al.* 2001)

Fatty acid (g/100 g total carcass lipids)	Dietary inclusion rate of fish oil (g/kg)		
	0	20	40
C14:0	0.77	1.26	1.47
C16:0	33.8	32.1	29.0
C18:0	8.54	9.42	8.54
C18:1 <i>n</i> -9	34.7	31.8	29.3
C18:2 <i>n</i> -6	11.7	11.4	12.9
C18:3 <i>n</i> -3	1.63	2.46	2.98
C20:5 <i>n</i> -3	0.20	0.77	1.33
C22:6 <i>n</i> -3	0.10	1.03	2.42
Total saturates	43.8	43.6	39.8
Total monounsaturates	41.3	38.7	37.6
Total polyunsaturates	14.9	17.5	22.2
<i>n</i> -6: <i>n</i> -3	6.11	2.50	1.73

through nutrition, using high forage based diets or the use of oil supplements rich in PUFA. Of particular note are the advantages associated with feeding grass which is an important feed for beef cattle in Northern Europe. Beneficial effects of all grass diets relate to α -linolenic acid (C18:3 *n*-3) being the major fatty acid in grass (Dewhurst *et al.* 2003). Even though most is metabolised in the rumen, a small proportion of C18:3 *n*-3 can escape and, once absorbed, is available for incorporation into tissue lipids.

In contrast, the fatty acid profile of non-ruminant meat is essentially a reflection of that in the diet, since limited transformation of dietary fatty acids occurs during digestion. As a result, it is much easier and feasible to enhance long chain *n*-3 PUFA levels in non-ruminant tissue lipids using dietary sources. Both EPA and DHA are generally only associated with oil-rich fish, and therefore supplements of fish oil have been the most common means of enriching pig and poultry meat with EPA and DHA (Table 4). Whilst this nutritional strategy is relatively effective it can result in the production of meat with a metallic taint, fish-like flavour and reduced shelf-life (Leskanich & Noble 1997). Because world stocks of oil-rich fish are declining and concerns exist about heavy metal contamination, one of the key challenges ahead is to identify novel alternative sources of EPA and DHA.

Conclusions

Foods derived from animals are a significant source of nutrients in the UK diet. However, certain aspects of some animal derived foods, saturated fatty acids in par-

ticular, have led to concerns about the contribution of these foods to increased risk of cardiovascular disease and the metabolic syndrome. The fatty acid composition of various animal derived foods is not constant and can, in many cases, be enhanced by animal nutrition. In the future the role of animal nutrition in creating foods closer to the optimum composition for long-term human health will become increasingly much more important. Furthermore, certain animal derived foods contain compounds which actively promote long-term health. Research is required to fully characterise the benefits associated with the consumption of these compounds and to understand how the levels in natural foods can be enhanced. The development of nutritional strategies for the production of milk and poultry of enhanced nutritional characteristics is an important component of the LIPGENE Project (see Nugent 2004; see also Graham *et al.* 2004). LIPGENE is an integrated project within the EU funded Sixth Framework Research programme (see <http://www.lipgene.tcd.ie>).

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