FACTORS AFFECTING FATTY ACID COMPOSITION OF FARM ANIMALS AND ITS IMPACT ON HUMAN HEALTH

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ABSTRACT

The fatty acid composition of farm animals is affected by species, breeds diet and differs between tissues. The levels of fat tissue in the carcass and meat are important underlying factors because fatty acid composition changes as fat is deposited. The fatty acid composition of pork can be readily modified by diet since fatty acids are deposited unchanged by digestion. In ruminants, the rumen is a barrier to the incorporation of Poly Unsaturated Fatty Acids (PUFAs) into meat although the effect of grass diet in increasing proportions of n-3 PUFA and possibly Conjugated Linoleic Acid (CLA) is an interesting area of current research, leading to more desirable meat products for the consumer. Poultry meat with skin not only contain more total fat but also have a greater proportion of monounsaturated fatty acids (primarily oleic acid) and lower proportions of saturated and poly unsaturated fatty acids than muscle alone. Poultry represents a muscle food in which diet can be used to increase the concentration of bioactive fatty acids in the final product. Increasing n-3 fatty acids in poultry products by dietary supplementation of marine lipid is possible. However, such process should not change the physical and chemical properties of muscle. Muscles containing high concentration of PUFA have lipids with lower melting point leading to muscle with soft and even liquid fat, eventually leading to consumer rejection. The fatty acid composition of meat is important for human health reasons and also has crucial effects on meat quality. The effect of diet on fatty acid composition and genetic effects on fatty acid composition on cattle, sheep, pig and chicken are discussed in detail. The impact of animal fatty acid on human health and future prospects are also discussed.

Keywords: Animal fat; fatty acid composition; diet

Fatty acid composition varies between species of livestock and also tissue sites in the body. Fatty acids are located mainly in adipose tissue commonly termed as "fat". Ruminants (cattle and sheep) contain relatively high amounts of saturated fatty acids (SFA) and are low in polyunsaturated fatty acids (PUFA). Fatty acid composition is greatly influenced by production factors such as animal diet, age, weight, sex and breed. Fatty acid composition also affects the texture, juiciness, sliceability, stability and flavour of meat (Tyc *et al.,* 2006). Fatty acids in adipose tissue and in muscle membranes also contribute to meat flavour, providing volatile degradation products during cooking.

Type of fatty acids

The fatty acids in animals are mainly of medium to long chain length that is they have 12 to 22 carbon atoms in the molecule, with the basic structure of CH3-(CH2)n–COOH. Small amount of shorter chain length C8-C10 are present in lamb fat.

About 40% of fatty acids are saturated, that is each carbon has two hydrogen atoms attached, about 40% have one double bond (monounsaturated fatty acid, MUFA) where adjacent carbon atom is attached to only one hydrogen atom each and a smaller proportion, about 2% -25% have more than one double bond (poly unsaturated fatty acid, PUFA). Fatty acids are commonly labelled according to carbon chain length and the number of double bonds, for example linoleic acid is labelled as 18:2 being 18 carbons in length and containing two double bonds. Double bonds are either of the more common cis-type, in which the hydrogen atoms point in the same direction or of the trans-type, in which they point in opposite directions, resulting in a straighter molecular configuration

Oleic acid (18:1 cis-9) is the major fatty acids in all meat, contributing over 30% of total fatty acids. The length, degree of unsaturation and configuration of the fatty acid molecule influence the physical properties such as melting point. The longer the chain length and fewer the number of double bonds present in the molecule, the higher the melting point. Saturated and trans fatty acids have a higher melting point than unsaturated and 'cis' fatty acids.

Fatty acids in ruminant tissue are more complex than those in non-ruminants, containing higher portions of 'trans' fatty acids. Fatty acids with an odd number of carbon atoms act as precursor for fatty acid synthesis, e.g. (C15 and C17). Fatty acids with branched chains derived from amino acids, leucine, valine and isoleucine (i.e. 4-methyl octanoic acid, C8: 0 and 4-methyl nonanoic acid C9:0) and fatty acids with conjugated double bonds (i.e. the bonds are on adjacent carbon atom rather than being separated by CH2 group) are found in ruminants. These variations are a results of the action in the rumen that degrade plant structures and dietary fatty acids, producing a wide range of products, some of which are absorbed in the small intestine and incorporated into tissue lipids. An important group of fatty acids in ruminants are the Conjugated Linoleic Acids (CLAS) with 18 carbon and 2 conjugated double bonds. These have been shown to have

Table. 1 Effect of chain length and configuration of double bonds on the melting point of fatty acids

Increasing Chain Length		Increasing Unsaturation	
Fatty Acid	Melting Point °C	Fatty Acid	Melting Point °C
Lauric acid, 12:0	44.2	Stearic, 18:0	69.6
Myristic acid, 14:0	54.4	Elaidic, 18:1 *trans*-9	43.7
Palmitic acid, 16:0	62.9	Oleic, 18:1 *cis*-9	13.4
Stearic acid, 18:0	69.6	Linoleic, 18:2	-5.0
Arachidonic acid, 20:0	75.4	Linolenic, 18:3	-11.0

a range of physiological action in the body of the animals and meat consumers.

The SFA (Saturated Fatty Acids) in meat can be derived from the diet, produced in the rumen from unsaturated dietary fatty acids or synthesised from glucose or acetate in liver or adipose tissue.

MUFA (e.g. 18:1 cis-9) are mainly formed in adipose tissue from SFA by the action of desaturase enzyme, for example, delta-9-desaturase from oleic acid (C18:1 cis-9) from stearic acid (18:0) and palmitioleic acid (C16:1 cis-9) from palmitic acid (16:0). This same enzyme complex forms the main CLA isomer, cis-9, trans-11 CLA from 18:1 trans 11 which is produced in the rumen. Most CLA formation occurs in adipose tissue (the mammary gland in the case of lactating animals) but some occurs in the rumen.

PUFAS are of the n-6 or n-3 type that describes the position along the carbon chain from the methyl end where the first double bond is inserted. The n-6 fatty acid, present in the largest amount is the linoleic acid (18:2n-6) which is an essential fatty acid, i.e. it is derived entirely from the diet. (e.g., oil seeds and grams). The animal possesses desaturase and elongase enzymes that can convert 18:2 to longer-chain n-6 fatty acids such as arachidonic acid (20:4n-6). Similarly, the most common n-3 fatty acid is linoleinic acid (18: 3n-3) which is present in the leaves of plants and grasses. This fatty acid can be converted to long chain n-3 fatty acids such as eicosapentaenoic acid (EPA; 20: 5N-3) and decosahexaenoic acid (DHA, 22: 6n-3). There is competition between 18: 2n-6 and 18:3n-3 for conversion to the long-chain PUFA because the enzymes are shared. Evidence suggests that 18:3n-3 is the preferred substrate, but the presence of much more 18: 2n-6 usually results in greater synthesis and deposition of long-chain PUFA derived from this fatty acid (William and Burdge. 2006). These long-chain n-6 and n-3 fatty acids have important physiological roles in the body through their conversion to eicosanoids, which among other actions control thrombosis and tissue inflammation.

Ruminants and non-ruminants species differ greatly in their proportions of PUFA in tissue and meat, whereas these are hardly changed by digestion in pigs and poultry and are incorporated directly into the adipose tissue. In ruminants they are extensively hydrogenated by micro-organisms in the rumen. The microbial action results in generally low levels (10% or less) of dietary PUFAs being available for absorption into body tissue after passing through rumen.

The fatty acids in meat are found in two main lipid classes, neutral triacylglycerol (storage roles) and more polar glycerophospholipid (structural and metabolic role). The former is the main lipid component (>90%) of adipose tissue in mature animals (visible fat) and the latter, a constituent of cell membrane, contributes between 10% and 40% of the total fatty acids in muscle. Phospholipid has a much higher concentration of PUFA than triacyl glycerol. For example, pig loin muscle contained neutral lipid (triacyl glycerol) 12% and phospholipids 34% 18:2n-6, respectively as reported by wood *et al.,* 2005.

As meat animal grow towards the point of slaughter, they deposit increasing amounts of fat even within the muscle (marbling fat) in the carcass. This results in an increasing ratio of triglycerol to phospholipids, producing a lower concentration of PUFA in total lipids. A clear picture of the effect of production factors on fatty acid composition can therefore only be obtained by analysing triacylglycerol and phospholipids separately.

Species Effect on Fatty Acid Composition

The fatty acid composition of longissimus muscle of beef, mutton, pork and chicken are given in the table.

The results in Table. 4 show that beef and mutton have higher pro portion of most SFA than pork and chicken. Conversely, chicken and pork is much higher than beef and mutton in the main PUFA 18:2n-6. Values for 18:3n-3 is more similar between the species, reflecting its presence at a high level in grass and forages. Although a high proportion (about 90%) of 18:3n-3 in the diets of ruminants is normally hydrogenated in the rumen (Scollan *et al.,* 2001), some do escape to the duodenum, to be absorbed and deposited in tissues as in pigs. The proportion of long-chain PUFA is also similar between the species, except for 20: 4n-6 that is high in pigs because of the high concentration of its precursor 18: 2n-6.

Table: 2. Fatty Acid Composition of Longissimus muscle from beef, mutton, pork and chicken

Percentage of Total Fatty Acids					
Fatty Acid	Beef	Mutton	Pork	Chicken	
				No Skin	With Skin
12:0	0.08	0.31	0.12	--	0.1
14:0	2.66	3.30	1.33	0.8	0.9
16:0	25.0	22.2	23.2	23.3	23.3
16:1 *cis*	4.54	2.20	2.71	3.3	6.3
18:0	13.4	18.1	12.2	10.8	6.3
18:1 *trans*	2.75	4.67	ND	ND	ND
18:1 *cis*-9	36.1	32.5	32.8	28.3	37.3
18:1 *cis*-11	2.33	1.45	3.99	2.24	3.22
18:2n-6	2.42	2.70	14.2	18.3	20.6
18:3n-3	0.70	1.37	0.95	0.8	1.0
20:3n-3	0.21	0.05	0.34	ND	ND
20:4n-6	0.63	0.64	2.21	5	0.6
20:5n-3	0.28	0.45	0.31	0.8	0.1
22:4n-6	0.04	ND	0.23	ND	ND
22:5n-3	0.45	0.52	0.62	0.8	0.1
22:6n-3	0.05	0.15	0.39	1.7	0.2
Total fatty acids (g/100g muscle	3.8	4.9	2.2	1.65	11.07

ND-Not Detectable, Source: Enser M. *et al.,* 1996. *Meat Science,* 42, 443-456

Enser *et al.,* (1996) analysed the subcutaneous adipose tissue removed from the carcass and reported that small proportion of the C20-C22 PUFA were present in pork and these were not detected in beef and mutton, reflecting the lack of incorporation of the long-chain PUFA into ruminant triacylglycerols.

In comparison of different species, Rosell (2001) found that broiler chicken meat fatty acid composition was similar to that of pork, although the proportion of the 18:2n-6 was much higher, that is 18.9% against 9.5%. Rule *et al.* (2002) also found a high value for the chicken 18:2n-6 in a comparative study, 17% of the total fatty acids in breast muscle. Among other species, difference is in the very high value of 18:3n-3 in horse muscle adipose tissue (Robb *et al.*, 1972).

Dietary effects on fatty acid composition

Compared with other production factors, diet has the largest effect on fatty acid composition in all species, particularly in the monogastrics.

Pigs

Studies conducted in the United States show clearly the effects of different oil sources in the diet on the fatty acid composition of pork (Ellis and Isbell, 1926). Different diets produced different commercial grades of subcutaneous fat tissue, from brewer's waste that produced hard fat to soybeans grazed in the field, which produced oily fat. These effects were due to the incorporation of relatively saturated fat from brewer's waste into body fats to a large amount of highly unsaturated fat as in the case of grazed soy beans. The fatty acid most affected by diet was 18:2n-6, which was 1.9%

and 30.6% of total fatty acids in subcutaneous fat of pigs, fed brewer's waste and grazed soybeans respectively.

A review by wood (2005) showed that 18:2n-6 from oil source such as soy bean meal is incorporated into muscle and adipose tissue in direct proportion to its concentration in diet. Similar results were found for other PUFA source e.g. linseed, which contain a high proportion of 18:3n-3 (Enser *et al.*, 2000) and fish oil which contains the long-chain n-3 PUFA, EPA and DHA. (Irie and Sakimoto, 1992)

Feeding SFA does not raise their proportion in muscle and adipose tissue as much as feeding PUFA. This is because of a lower incorporation into lipid and elongation and desideration of these fatty acids into other SFA and MUFA. Comparison of papers published in the 1970's and 1980's with more recent ones show that the level of 18:2n-6 in pig muscle and adipose tissue has greatly increased during this time. This is partly not only because the oil content of diet has increased to promote faster growth but also due to lower carcass fat levels leading to softer fat tissue in modern lean pigs compared with the fatter pigs of former years.

Cattle

Despite the hydrogenating effect of the condition of the rumen on dietary PUFA, small but significant amounts of fats enter the duodenum to be absorbed into blood and is delivered to tissues. A recent study conducted by the university of Bristol and the institute of Grass land and Environmental Research (IGER) compared fatty acid composition of cattle fed either a grain based concentrate diet and a grass silage diet. The concentrate diet raised the proportion of 18:2n-6 and 20:4n-6, where as the grass silage diet increased levels of the n-3 PUFA 18:3, 20:5, and 22:6. All these changes reflect the fatty acid composition of the diets. The increased concentration of 22:6n-3 in the grass silage group was significant since the provision of more 18:3n-3 does not always result in the higher levels of 22: 6n-3 in tissue. (Scollen *et al.*, 2003). The higher levels of SFA and MUFA in the grass silage group can partly be explained by overall greater fatness resulting from denovo fatty acid synthesis in cattle. When cattle are fed concentrate alone, the rate of PUFA passage through the rumen is rapid limiting the access to microorganism action, compared with a mixed forage/ concentrate diet. This helps to explain the high values for muscle PUFA proportion seen in young bulls fed a barley diet (Enser *et al.*, 1996).

The concentrate portion of beef cattle diets can be fortified with dietary oils with positive effects on muscle and adipose tissue fatty acid composition. Scollen *et al.* (2001) fed linseed and fish oil to increase proportions of 18:3n-3 and the long chain n-3 PUFA, respectively.

The effects of dietary oils on meat fatty acid composition are enhanced if they are protected from bio-hydrogenation in the rumen. Chemical protection can be achieved if protein in the diet is treated with formaldehyde, which results in a matrix structure with in which dietary fatty acids are encapsulated.

Several studies have shown that there is a linear relationship in muscle and adipose tissue between the proportions of 18:1 trans-4 (transvaccenic acid) and the main CLA isomer, cis-9, trans-11 CLA, reflecting the synthesis of CLA from its precursor. The results of the study of Warren *et al.* (2007) confirm the linear relationship between 18:1 trans-11 and CLA and shows that both fatty acids are at higher proportions following the consumption of fresh grass compared with grass silage and concentrates. Wood *et al.* (2005) showed that there were three main CLA isomers in beef cattle muscle and the levels were affected by dietary oil source. The cis-9, trans-11 isomer always exceeded 80% of the total, the other two isomers being trans-11, cis-13 and trans-11, trans-13. Other factors that affect grass fatty acid composition and there by meat fatty acid composition include the preservation process. Excessive drying of grass prior to producing hay or silage reduces PUFA proportion through the action of plant enzymes and fatty acid oxidation (Dewharst *et al.,* 2003)

Sheep

The effects of grass based diets compared with concentrate diet are similar in sheep to those in cattle. Fisher *et al.* (2000) conducted a study in which Suffolk cross sheep were grazed on low land pasture or fed with a standard concentrate diet for three months before slaughter and reported that all the long chain n-3 PUFA were higher in the grass fed lambs than in those fed concentrate, including DHA. Wachira *et al.* (2002) fed diets containing 6% oil from different sources to sheep between 24 to 44 Kg live wt. The results showed that the proportion of 18:3n-3 in the group fed linseed was higher than for the grazed lamb but the proportion of 20:5n-3, 22:5n-3 and 22:6n-3 was lower. The results confirmed the effect of grass diet in raising levels of long chain n-3 PUFA.

Chicken

Like that of most monogastrics, the fatty acid composition of chicken is influenced by the type of fat in the diet (Phetteplace and Watkins, 1989& 1990). Changes in fatty acid composition due to diet are seen in all tissues. The adipose fat of broilers fed a basal diet with no added fat contained 30.7% saturated, 34.7% monounsaturated and 34.5% poly unsaturated fatty acids. Adipose fat from chicken fed the basal diet plus cotton seed oil contained 29% less monounsaturated, 29% more poly unsaturated and about the same proportion of saturated fatty acids as chickens fed the basal diet. The fatty acid changes were due to a decrease in the amount of palmitoleic and olieic acids and an increase in linoleic acids. n-3 fatty acid levels in poultry meat can be increased by inclusion of fish oil or fish meal in the diet. The increase in n-3 fatty acids in chicken fed with fish oil was eight folds more than the chicken fed with chicken fat. The increase in the n-3 fatty acid content was primarily due to increase in eicosapentaenoic, docosapentaenoic and docosahexanoic acids.

Conjugated linoleic acids (CLA) are another group of fatty acids receiving considerable attention due to potential health benefits. A number of studies (Cresp and Esteve-Garcia, 2001., Badinga *et al.,* 2003) have shown that content of CLA in broiler meat and fat can be increased by including CLA in chicken's diet. Most of these studies have also shown that dietary CLA changes fatty acids levels in tissues by increasing saturated fatty acids and decreasing monounsaturated fatty acids, while usually not altering PUFAS.

Fatty Acid Composition of different Muscles, Tissues and Meat Products

Muscles in the carcass differ in fiber type, with muscles involved in rapid movement having predominantly white glycolytic type-II fibers and those involved in posture retention having predominantly red oxidative type-I fibers. All muscles contain a mixed population of fiber types, including intermediate types between these two extremes.

Red oxidative fibers contain more mitochondria and a higher proportion of phospholipid than white glycolytic fibers and as a result contain a higher proportion of PUFA.

Liver is also a metabolically active tissue with a high proportion of phospholipid in total lipids. The phospholipid in liver was less unsaturated than that in muscle. For example, 18:2n-6 was 12.4% and 5.8% of phospholipid fatty acids in muscle and liver respectively. The presence of long-chain PUFA in pigs subcutaneous fat although at low levels, contributes to a high nutritional value of pig meat.

Fatty Acid Composition of Chicken Eggs

Two chicken eggs constitute a typical serving, with each egg providing roughly 50g of edible material. Thus the values in tables showing the fatty acid concentration in g/100g edible portion can be used to approximate the fatty acid content of a serving of two chicken eggs. The values can be halved to obtain the amounts of fatty acids from a serving of one egg.

The fatty acid composition of chicken egg is as shown below.

These values apply to raw eggs, fresh or frozen as well as to whole eggs hard cooked in the shell. A 100g edible portion of whole egg contains 3.35 g saturated fatty acids, 4.46 g monounsaturated and polyunsaturated fatty acids, respectively. Almost one-half of the total fatty acids are monounsaturated, whereas a little more than one-third are saturated.

The values for fresh yolk are for yolk with a small amount of albumen. The albumen is essentially fat free. Therefore, the effect of its inclusion is to dilute slightly the fatty acid concentration in the yolk. The proportions of the various fatty acids for the fresh yolk are similar to the ratios for the whole egg. The levels of fatty acids for the yolk are higher than those of the whole egg, as the entire lipid in the yolk fraction. The yolk of an average large egg (60 g) weighs approximately17g. Thus, the amount of various fatty acids provided per yolk can be readily calculated. However, it should be noted that the percentage of yolk is not constant for eggs of various weight classes. Smaller eggs tend to have a larger ratio of yolk to albumin, and they would therefore have relatively higher fatty acid levels.

Omega - 3 Enrichment of Eggs

In recent years, following recommendations for the increased intake of n-3 fatty acid in human diets, there had been considerable interest in providing consumers with eggs containing elevated levels of n-3 fatty acids. Most studies have shown that the egg composition could be altered within two weeks of dietary changes. A change in yolk fatty acid composition can be expected within weeks as much of the development of the egg yolk occurs within the 10 days before ovulation.

In some studies fish oil were fed to laying hens, and the long-chain n-3 fatty acids in these oils appeared in eggs. In a typical study, 5% fish oil increased the egg DHA content from 2.9% to 11.8% of total yolk fatty acids. Hargis *et al*. (1991) observed that the long chain n-3

Table:3 Fatty Acid Composition of Chicken Eggs

Fatty Acid	Whole Egg g/100g
12:0	0.03
16:0	2.26
18:0	0.78
Total Saturated	3.10
16:1	0.30
18:1	3.47
Total monounsaturated	3.81
18:2	1.15
18:3	0.03
20:4	0.14
Total polyunsaturated	1.36
Total fats	9.94

Source: Adapted from USDA Nutrient Database for Standard Reference, Release 19 fatty acid concentration increased from 35 to 210 mg/100 g yolk, whereas the concentration of n-6 fatty acids, especially arachidonic acid decreased from about 100 to approximately 30 mg/100 g yolk upon feeding fish oil. High levels of long chain n-3 fatty acids might have suppressed the hepatic production of arachidonic acid from dietary linolenic acid. Most studies have showed roughly a fivefold increase in the long chain n-3 percentages when fish oil was fed. Yalcyn *et al.* (2007) found feeding of fish oil and flaxseed reduced the total saturated fatty acids content in chicken eggs. Similarly Nanjapan *et al.* (2013) reported that inclusion of n3 fatty acids rich feed ingredients in diet which are available in local market like bajra, linseed, rapeseed and fishmeal would be able to produce desired ratio of n3: n6 fatty acid enriched eggs with lesser cholesterol content.

Impact of Animal Fatty Acids on Human Health

Some SFA, that is those with less than 18-carbon atoms chain length, raise blood levels of low density lipoprotein (LDL) cholesterol, which increases the risk of atherosclerosis leading to chronic vascular disease (CVD) in man (Williamson *et al.*, 2005). On the other hand, MUFA and PUFA lower blood levels of LDL cholesterol. According to the recommendation of the World Health Organisation (2003), the total fat should constitute not more than 15 to 30% of total energy in the diet., SFA around 10%., n-6 PUFA around 5 to 8% and n-3 PUFA 1 to 2%. The U.K Department of Health (2004) has recommended that ratios between these fatty acid groups should be greater than 0.4 for PUFA: SFA and less than 4.0 for n-6: n-3 PUFA. Several studies agree that n-3 PUFA are necessary for proper brain and visual development in the foetus and have a role in reducing various cancers (Enser, 2001).

Trans fatty acids have more potent effects on LDL- cholesterol than SFA. Although trans fatty acids are generally low in meat, there is some evidence that the trans fatty acids in meat and milk are less damaging to human health than those in other processed foods (Williamson *et al.,* 2005). Trans-11 18:1 (transvaccenic acid) is the precursor in tissue of the major CLA isomer, cis-9, trans-11 CLA, which is recognised to have several positive health benefits including inhibition of carcinogenesis and atherosclerosis and enhancement of the immune response.

Future prospects

The fatty acid composition of pork can be readily modified by diet since fatty acids are deposited unchanged by digestion. In ruminants, the effect of grass diet in increasing proportions of n-3 PUFA and possibly CLA is an interesting area of current research, leading to more desirable meat products for the consumer. Poultry represents a muscle food in which diet can be used to increase the concentration of bioactive fatty acids in the final product. Increasing n-3 fatty acids in poultry products by dietary supplementation of marine lipid is possible. However, such process will change the physical and chemical properties of muscle. Muscles containing high concentration of PUFA have lipids with lower melting point leading to muscle with soft and even liquid fat, eventually leading to consumer rejection. The fatty acid composition of meat is important for human health reasons and also has crucial effects on meat quality. Incorporating bioactive fatty acids which are beneficial to human health *vis-a-vis* maintaining consumer appeal in animal products by different methods offer great research prospects in the present health conscious society.

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