ANIMAL NUTRITION, FATTY ACIDS AND NEW TECHNOLOGY

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SUMMARY

In Australia, animal products provide about 60% of the total fat consumed. The fat content of animal products and/or their fatty acid composition can be manipulated by animal breeding programmes, including the application of recent reproductive technologies, diet and use of metabolic regulators and in the future, developments in transgenic livestock. Such changes have significant implications for livestock producers, sensory characteristics of products and research on the role of lipids and their constituent fatty acids in cellular processes, such as signal transduction pathways and nutritionally related diseases.

1. INTRODUCTION

In recent years increased emphasis has focussed on improving animal productivity and the quality of derived animal products; such changes are necessary not only from the aspect of enhancing economic efficiency, but also to satisfy the changing needs of consumers. For example in relation to meat, a consumer preference is emerging for products with less fat. In addition to satisfing these requirements there is also a need to develop meat and dairy products that will fulfill the expanding opportunities in export markets. Such products must be consistent and reproducible in quality and be "designed" to meet the various consumer demands that exist in different countries. The last decade has seen the introduction and expansion of modified dairy and meat products into the domestic market. Many of these products have been developed as a result of changing life-styles (eg more demand for pre-packaged and "fast" foods) and an increase in consumer awareness about the significance of dietary constituents eg fat and fibre in relation to nutritionally related diseases, such as coronary heart disease and certain types of cancer. In Australia, animal products (eg meat, milk, cheese etc.) provide approximately 60% of the total fats consumed, the remainder being derived from vegetable sources. In this article we will summarize the nature of the fatty acids that occur in animal tissues, how these may be manipulated and what are some of the implications.

Fatty Acid Composition

The constituent fatty acids of animal fat largely reflect the nature of the fatty acids that are absorbed from the gut. In non-ruminants (eg pigs, poultry) the fatty acids of the diet are absorbed and retained primarily in the adipocytes as triacylglycerols (TAG) (Table 1). By contrast TAG's from ruminant adipocytes are characterised by a high content of stearic acid (C18:0) and positional and geometrical isomers of C18 fatty acids - these fatty acids are end-products of lipolytic and biohydrogenation processes (see Table 1) that occur in the rumen prior to absorption of the dietary lipids from the small intestine (McDonald and Scott 1977). The TAG's of ruminant milk also contain these fatty acids and, in addition, significant proportions of C4:0 to C16:0 fatty acids which are produced from endogenous biosynthetic pathways (Jensen et al 1990).

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Table 1. Fatty acid metabolism in ruminants and non-ruminants

Diet	Intestine	Tissue Lipid (muscle)	
		TAG[a]	Phospholipids[b]
Ruminant (sheep)			
Pasture[a]			
C18:3w6 (60%)	Rumen Biohydrogenation	< 1%	(w3) C20:4, C20:5, C22:6
C18:2w6 (5%)	Rumen Biohydrogenation	2%	(w6) C18:2, C20:4, C22:5
C18:1w9 (10%)	Rumen Biohydrogenation	42%[c]	(w9) C18:1, C20:3, C22:4
C18:0 (3%)		22%	C18:0, C18:1
C16:0 (9%)		26%	C16:0, C16:1
Non Ruminant (pig)			
Cereal[a]			
C18:3w3 (2%)	No Biohydrogenation	1%	(w3) C20:4, C20:5, C22:6
C18:2w6 (40%)	No Biohydrogenation	20%	(w6) C18:2, C20:4, C22:5
C18:1w9 (30%)	No Biohydrogenation	40%	(w9) C18:1, C20:3, C22:4
C18:0 (1%)	No Biohydrogenation	10%	C18:0, C18:1
C16:0 (20%)	No Biohydrogenation	24%	C16:0, C16:1

a % composition values are adapted from the literature.
b Major fatty acids occurring in total phospholipids from muscle; C18:3(w3) is not readily incorporated into tissue phospholipids.
c C18:1 in ruminant TAG contains approximately 16% trans formed from rumen hydrogenation.

In comparison to the TAG, the fatty acid composition of phospholipids and cholesteryl esters, ie the structural components of cell membranes, are characterized by a high content of C18, C20 and C22 polyenoic fatty acids. The C20 and C22 polyenoic acids are formed by chain elongation and desaturation from linoleic (C18:2w6) or linolenic (C18:3w3) acids and these C18 di- and trienoic fatty acids, or essential fatty acids, cannot be synthesized in mammalian tissues (Sanders 1988). In ruminants, only small amounts of these C18 essential fatty acids reach the intestine because of the hydrogenation activity of the rumen micro-organisms and, after absorption, they are selectively incorporated into plasma cholesteryl esters and phospholipids; this provides a subtle mechanism for preserving these essential fatty acids for structural lipids and metabolic function (Noble, 1980). Eggs and offal, especially brain contain significant amounts of C20 and C22 polyunsaturated fatty acids but the highest concentrations are found in fish and fish oils. During the last decade the role of these long chain w3 fatty acids has been examined in relation to their effects on lipid and lipoprotein metabolism. Evidence is accumulating that they inhibit fatty acid synthesis and acyl esterification and reduce the amount of very-low density lipoprotein TAG secretion (Harris 1989). There has also been a continuing assessment of the significance of dietary fatty acids on cholesterol metabolism; it seems to be accepted that C12:0, C14:0 and C16:0 dietary saturated fatty acids increase the concentration of cholesterol in low density lipoprotein (LDL), while C18:1(cis) and C18:2(cis cis) reduce this lipid (Grundy 1989). The mechanism for the cholesterol elevating effect of saturated fatty acids is not fully determined, but probably relates to their effect on suppressing the receptor mediated clearance of LDL (Grundy 1989). More

information is accumulating to suggest that C18:0 does not elevate blood cholesterol in man, and the most likely explanation is that it is converted to C18:1 by the Δ9 desaturase enzyme pathway.

Manipulation of Fatty Acid Composition

The fatty acid composition of most tissue TAG is dependent on the balance between dietary fatty acid intake and endogenous fatty acid synthesis. During growth and fattening, the proportion of TAG relative to phospholipid increases dramatically; hence the proportion of endogenously synthesised fatty acids, ie, C14:0, C16:0, C18:0 and C18:1 is much higher than the polyenoic fatty acids C18:2, C20:4, C22:5 and C22:6 (Fig 1).

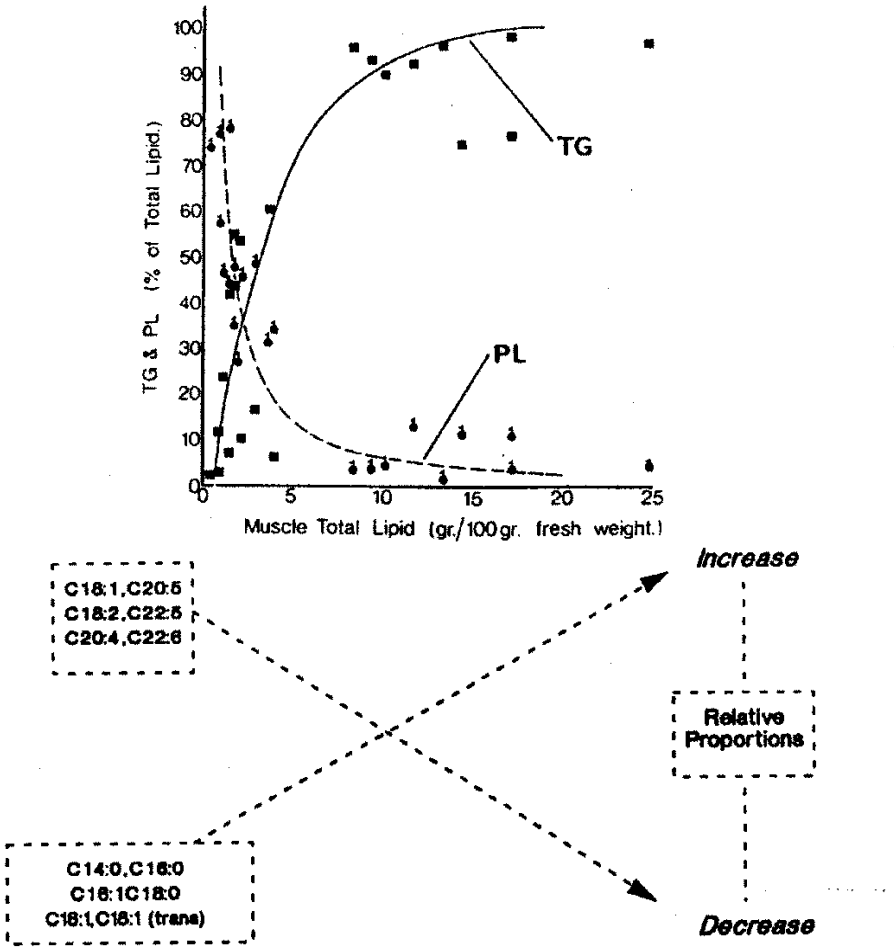

Fig. 1 An increase in the total lipid content of muscle results in a decrease in the proportion of phospholipid (PL) relative to triacylglycerol (TG) and corresponding changes in the proportions of the major fatty acids in each lipid class (adapted from Sinclair 1973).

Until recently most breeding programs and management practices were designed to maximise the total weight of an animal at slaughter - this also resulted in a high proportion of TAG-enriched fat in the carcass (Fig 1). As a result of changing consumer preferences many animal breeding programs, selection procedures and feeding strategies are now being directed towards the production of leaner animals. These trends, together with the introduction of CALM (Computer Aided Livestock Marketing system) and on-line carcass evaluation

procedures, eg AUSMEAT (Authority for Uniform Specification of Meat and Livestock) which will provide an electronic information system spanning the market chain from producer through to consumer, should result in the increased availability of animals with a reduced fat content. If this desirable trend continues it will significantly reduce the ratio of TAG to phospholipid in muscle and result in an increased proportion of polyenoic fatty acids in the meat.

In parallel with these improved breeding strategies (eg Breed plan, Lamb plan) and the implementation of new genetic evaluation procedures there is the development of new and/or improved technologies to manipulate the genome of our livestock to achieve desirable genetic change. These include:-

. Increased use of artificial insemination, multiple ovulation, embryo transfer techniques and cloning to create elite nucleus flocks and herds with desirable traits (eg faster growth and leaner carcasses).

. Development of transgenic livestock - ie animals that contain in the germ-line exogenous DNA (Transgenes), whose level of expression is regulated by heterologous promoters. Already pigs and sheep containing the growth hormone gene have been produced in laboratory experiments; these animals have an extremely low fat content, viz 3% compared to 25% for normal pigs and sheep of the same age. However, to date it has not been possible to effectively control the expression of the growth hormone gene and the animals, which have extremely elevated levels of growth hormone, develop severe health problems in early life (Murray et al 1989). Nevertheless, this technology offers a fundamental approach to manipulating the genome and in the future one could anticipate the production and commercial exploitation of transgenes which will produce animals with:

- Less fat - the result not only of manipulating the hormonal control of fat metabolism (eg Growth hormone gene), but also of inhibiting the fatty acid synthetase system.

- Altered fatty acid composition - either by introduction of new genes to allow biosynthesis of C18 polyenoic fatty acids in animal tissues or manipulating the expression of existing genes (eg desaturase enzymes).

A range of metabolic regulators have been examined to decrease the amount fat and increase the muscle deposition in the carcass of animals (Buttery and Dawson 1988). These include :-

. Growth hormone (or porcine and bovine somatotropin produced from recombinant DNA technology).

. Immunization procedures (eg somatostatin auto-immunity)

. Anabolic steroids (eg Oestradiol)

. β-Agonists (eg Clenbuterol)

. Growth factors - Growth hormone releasing hormone, insulin-like growth factor. More recently, the role of transforming growth factor (TGF.β) in regulating adipogenesis is being examined (Richardson etal 1989).

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The overall effect of these regulators is to reduce the total amount of sub-cutaneous fat and hence the proportion of fatty acids derived from TAG relative to phospholipid is decreased.

As mentioned above it is a relatively straight forward process to change the fatty acid composition of non-ruminants by dietary means. For example, because of the renewed interest in the role of C18:1(cis) fatty acid in lowering serum cholesterol in man (Grundy 1989), pork has been produced with an elevated C18:1(cis), C18:2(cis,cis) and C18:3(cis,cis,cis) content by feeding pigs new varieties of canola seed (St John et al 1987). In this study, as one would predict, the feeding of canola seed to beef cattle did not change the fatty acid composition. In cattle, only small changes in the relative proportions of C18 and C20 polyenoic fatty acids in muscle can be achieved by altering the finishing diet; for example, beef produced from pasture has more C18:3, C20:3, C20:4 and C22:5 fatty acids in comparison to grain-feed animals (Brown etal 1979, Larick and Turner 1989). In contrast, the protection of dietary fats from ruminal hydrogenation by encapsulation with a layer of aldehyde-treated protein (Scott etal 1971) is still the most effective way of manipulating the fatty acid composition of ruminant TAG and phospholipids. In recent years this technology has been significantly improved by the introduction of computer controlled processing and quality control procedures - these developments have resulted in the production of lipid-containing feed supplements which are being assessed for use in the livestock industries (Ashes and Rich 1987). This technology enables the production of ruminant meat and milk products with a range of constituent fatty acids and different sensory characteristics: this strategy together with the feeding of protected proteins, particularly during the growth phase, provides an opportunity to enhance the efficiency of nutrient use for ruminant meat production.

Implications

Manipulation of the fat content and fatty acid composition of animals has important implications. For livestock producers it is essential that clear signals be given for the type of animal to be produced for the domestic and export markets. This must be supported by the appropriate price premium so that the livestock industries are encouraged to produce the necessary range of products. In some instances this may require a "feed-lot" strategy to ensure reproducibility and quality of meat because of the seasonal variation in the nutritive value of available forages. Moreover, for specific markets there may be a need to modify the sensory characteristics of meat products as well as maintaining high quality and consistency. In these circumstances for ruminants, a short term "feed-lot" regime to "finish" the animals is desirable (Ashes and Rich 1987). The sensory characteristics of meat are significantly affected by the fat content and its fatty acid composition; the influence of the latter is clearly demonstrated in sheep meat where the conventional flavour and cooking odour can be modified by feeding protected lipid supplements (Ashes and Rich 1987). Variations in the content of intramuscular fat influences tenderness, juiciness and flavour (Barton-Gade et al 1988). Pre- and post-slaughter treatment of animals will also influence sensory factors and, in meats where the content of polyenoic fatty acids is elevated, there is greater susceptibility to autoxidation. Oxidation of fat increases the content of aldehydes, enals and lactones in the meat and hence more care is required during processing and storage to prevent oxidative rancidity.

Alterations in the lipid content and fatty acid profile also have

important metabolic implications. New roles for lipids and their constituent fatty acids are constantly appearing. For instance, they are integral components of dynamic cellular membranes which regulate biological processes and dietary modifications of these lipid components have significant implications for normal cell function and disease. In recent years considerable emphasis has focussed on the role of lipids in cellular signal transduction. The stimulation of cell-surface receptors initiates hydrolysis of membrane-bound lipids which produces a series of "second messengers", eg diacylglycerols (DAG), inositol triphosphate, arachidonic acid (C20:4). Examples of these are diagrammatically represented in Fig 2.

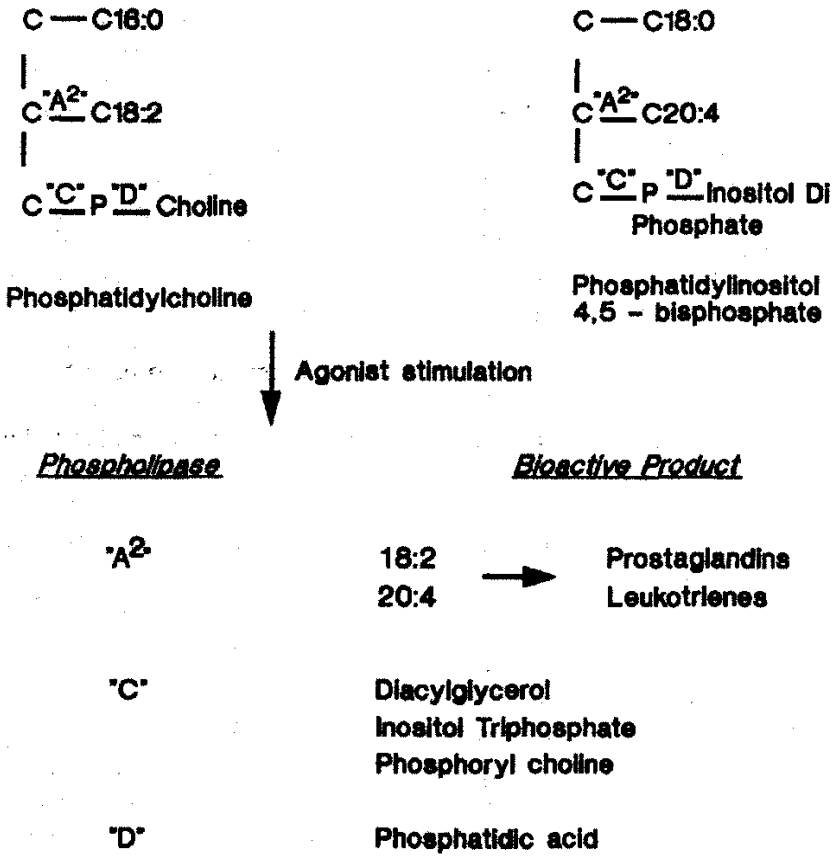

Fig. 2. Second messangers and/or bioactive products derived from membrane lipids following agonist/hormonal activation of specific phospholipases "A^2", "C" and "D" (Adapted from Merrill 1989).

It is outside the scope of this article to detail the biological effects of these second messengers, apart from the comments that :-

1) C18:2, C20:4 are metabolised to form a range of prostaglandins and leukotrienes, which affect the immune system, inflammation and reproductive function (Budowski 1988).

2) DAG Activates Protein Kinase C, a family of proteins which in turn, influence a number of physiological functions including gene expression, cell proliferation, calcium homeostasis and down-regulation of receptors (Nishizuka 1986). Inositol triphosphate and its metabolic products (eg inositol tetraphosphate) regulate calcium signalling within cells (Berridge and Irvine 1989).

However, it is important to note that the fatty acids of the membrane phospholipids are arranged specifically on the glycerol molecule; for the most part, the polyenoic fatty acids eg C20:3, C20:4, C22:5, C22:6 are on the second carbon atom and their combinations with C16:0, C18:0 and C18:1 produce an array of different molecular species. The physiological significance of these different species remains to be determined, although there is evidence that their turnover rate is influenced by diet, physiological state and hormone action (Holub and Kuksis 1978). It is also tempting to speculate that the different molecular species of DAG may activate various sub-species of Protein Kinase C, (see Nishizuka 1988). Likewise changes in the proportion of C20:4, or its precursor C18:2, and C18:3 in membrane phospholipids will affect the levels of various lipid biomodulators, eg prostaglandins, leukotrienes (Merrill 1989) that are produced following phospholipase A^2 action (see Fig 2). As mentioned above, the w3 fatty acids (C20:5, C22:6) in fish oil inhibit the $\Delta 6$ desaturase pathway and thus reduce the conversion of C18:2 to C20:4; they also inhibit cyclo-oxygenase activity and reduce the level of specific eicosanoids, eg TXA_2, a platelet aggregating agent, and PGI_2, a vasodilator, actions which may be important in thrombosis and hypertension (Budowski 1988). A reduction in fat content together with an increase in the relative proportion of C18 and C20 polyenoic or C18:1(cis) fatty acids will reduce LDL serum cholesterol, one of the major risk factors in the development of atherosclerosis and coronary heart disease (Grundy 1989). In the dietary management of coronary heart disease, individuals are encouraged to reduce their intake of total fat and saturated fatty acids (ie, C12:0, C14:0 and C16:0) and increase the proportion of C18:1(cis), C18:2, C20:5 and C22:6. Because of the susceptibility of polyenoic fatty acids to oxidation and the recent evidence on the occurrence of oxidised fatty acids in LDL (Haberland 1988), there is continuing debate about the level of these fatty acids to be included in the diet; nevertheless it is clear that appropriate levels of antioxidants (eg Vitamin E) should also be recommended for inclusion.

The above examples are only some of the means by which changes in fat content and fatty acid composition can influence metabolism and physiological function. However, they demonstrate the opportunities that exist for examining and understanding the role of lipids and their constituent fatty acids in the regulation of biological processes and the prevention of nutritionally related disease.

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