RECENT ADVANCES IN FAT UTILIZATION BY POULTRY

STEVE LEESON*

SUMMARY

Fats are added to poultry diets as a source of energy and essential fatty acids. Additionally fats aid in reducing dustiness of most diets and at low levels act as a lubricant for the pellet die. Fat utilization is affected by a number of factors including fat composition, bird age, bird species, intestinal status and composition of the diet into which fat is incorporated. In general, young birds (< 21d) digest fats less efficiently than to older birds, and this is most pronounced when saturated fats are used, and especially when fats contain a high proportion of free fatty acids. This may relate to inadequate bile salt production by the young bird. There appears to be a synergism between unsaturated and saturated type fats and oils, such that mixtures can lead to improved utilization of these harder fats. This phenomenon relates to micelle formation in the gut lumen, which is an important prerequisite to fatty acid absorption and transport. Fatty acid digestibility can also be affected by other diet ingredients, most notably the source of fibre, and the levels of such minerals as calcium and magnesium.

GENERAL CONSIDERATIONS

Fats and oils are now commonly added to poultry diets as an economic means of producing high-energy and/or high nutrient dense formulations. In some feeds, added fats can contribute 20% of overall diet energy, and so there is great incentive to adequately profile these ingredients within the formulation matrix. There is currently only scant information available on appropriate energy values for fats, and as will be discussed later, this largely reflects limitations of current methods of assay. Unlike many other ingredients, the nutrient profile of fats is not fixed, but rather it fluctuates with bird age and feeding scenario.

Traditionally feed-grade fats have been derived from rendering of cattle and pigs, although reflecting the current significance of the poultry industry, there is now proportionally more poultry fat available. While good quality vegetable oils are rarely used in animal feeds, off-grades and by-products such as soapstocks, used alone or as mixtures are now available. Certainly the mixing of fat sources seems to be more common, and this hopefully reflects our understanding of fat saturation as it affects digestibility. Of more recent concern has been the increase in feed fats that have cycled through the fast-food industries. Since both hydrogenation and repeated cooking cause changes in fat structure, the consumption of trans fatty acids by poultry poses an essentially unknown scenario. Watkins et al. (1991) indicates that feeding of trans fatty acids, as supplied by hydrogenated soybean oil, leads to inhibition of prostaglandin precursor fatty acid biosynthesis, and this in turn may contribute to tibia1 dyschondroplasia lesions in meat birds.

There is also current interest in the role of fats as they influence the immune response of animals. In most feeding situations, it is the effect of higher levels of fat that may be important,, rather than the well established effects of deficiencies. Fritsche

*Department of Animal and Poultry Science, University of Guelph, Guelph, Ontario, Canada N1G 2W1

et al. (1991) recently indicated marked differences in antibody titers of chicks fed fish oil rather than vegetable oils or lard. The exact cause of this improved immune status was not clarified, although with mice, Locniskar et al. (1987) have shown that elevated dietary PUFA's induce changes in the immune response related to splenic hyperplasia. Fritsche et al. (1991) suggest that PUFA's may exert their beneficial effect by reducing eicosanoid production, especially PGE_2, indicating a mechanism perhaps comparable to that associated with high levels of Vitamin E.

Fat quality

To feed manufacturers, fat quality most often means impurities and degree of rancidity. More importantly fat quality relates to fatty acid profile, although obviously optimizing the utilization of such fats can be affected by rancidity and oxidation. The principal route of deterioration of feed-grade fats is oxidative rancidity. Such rancidity can influence the organoleptic characteristics of the fat and fat color, and can cause destruction of other diet and body reserves of both fats and fat-soluble nutrients. Oxidation is essentially a degradation process that occurs at the double-bond in the glyceride molecules (Sherwin 1978). Since the presence of double-bonds infers unsaturation, then obviously the more unsaturated a fat, the greater the chance of rancidity. The initial step is the formation of a free radical when hydrogen leaves the_-methylenic carbon in the unsaturated group of the fat. The resultant free radicle then becomes very susceptible to attack by atmospheric oxygen (or oxides) to form unstable peroxide free radicles (Sherwin 1978). These peroxide free radicles are themselves potent catalysts, and so the process becomes autocatalytic. Oxidative rancidity leads to a proportional loss in energy contribution together with the potential degradation of the birds' lipid stores and reserves of fat soluble vitamins.

Fortunately we have some control over these processes through the judicious use of antioxidants such as ethoxyquin. Most antioxidants are based on phenolic structures and essentially function as free radical acceptors - these radicals are, however, stable and do not cause autocatalytic reactions. Effectiveness of antioxidants, therefore, relies on adequate dispersion in the fat and incorporation during or immediately after manufacture.

There has been relatively little work carried out on the nature of so called non-saponifiables in fats. Impurities are most often referred to collectively as M.I.U. (moisture, impurities and un-saponifiables). Most of these compounds will have little nutritional value, and so obviously energy values must be adjusted relative to total fat content. During oxidation at both high and low temperatures, a vast range of unusual polymers can be produced, and Wiseman (1986) has extensively described polymer structure and formation and the adverse effect of feeding them in oxidized fats.

Wiseman (1986) cites evidence for the dramatic effect on energy value due to oxidation caused by overheating. (Table 1).

Since many organic molecules are soluble in fat, and often accumulate in the body of animals over time, there is a real concern about the level of these compounds entering feeds and the potential for continuous re-cycling through rendering. Products, such as dieldrin and DDT, have been most extensively studied, although it is hoped that renderers are assaying for other potential contaminants. The adverse effects of these contaminants on growth and reproductive performance are well established. A number of naturally occurring fatty acids can also adversely affect overall fat utilization, although their mode of action is most likely via general well-being of the animal rather than through any specific mode of action related to digestion or absorption etc. The two most

›mmon such components are erucic acid present in rapeseed oils and some other rassica sp., and the cyclopropenoid fatty acids in cottonseed meal.

ABLE 1 Effect of heating time on energy level of cottonseed oil

Temperature 182°C	Available energy (kcal/kg)
Time 0	9360
24h	8509
72h	7624
96h	6120
120h	6430
	(From Poling et al. 1962)

In subsequent discussion it is assumed that fats are adequately protected against oxidation and that they contain no unusual components or excessive quantities of impurities.

Factors affecting fat utilization

Fat digestion and absorption are affected by composition of the fat, type and age of bird, and the other diet ingredients with which fats are combined. In practice these three factors are intimately related and all should be considered in developing nutrient matrices for fats and oils.

Fat composition Fat composition can influence overall fat utilization since different components can be digested and/or absorbed with varying efficiency. It is generally recognized that after cleavage by pancreatic lipase, micelle formation is an important prerequisite to absorption into the portal system. Micelles are conjugates of bile salts, fatty acids, some monoglycerides and possibly glycerol. The conjugation of bile salts with fatty acids is an essential prerequisite for transportation to and absorption through the microvilli of the small intestine. Polar unsaturated fatty acids and monoglycerides form this important association. However, preformed mixed micelles containing unsaturates and bile salts have themselves the ability to solubilize non-polar compounds. Efficiency of fat utilization is, therefore, dependent upon there being an adequate supply of bile salts and an adeuuate balance of unsaturates:saturates. Consideration of the balance between unsaturated'fatty acids, provided by most oils, and saturates, found in tallows and lards, can therefore be used to advantage. For example, Muztar et al. (1981) indicate a significant synergistic effect from mixtures of tallow and soapstocks in terms of energy contribution (Table 2).

TABLE 2 ME of fat mixtures

Ingredient	ME (kcal/kg)	Expected ME	Δ
Tallow	8400		
Soapstock	7400		
50:50 Tallow:soapstock	8200	7900	+4%
		(Muztar et al. 1981)	

In this study, the ME of the fat mixture was improved by 4%, and assuming no effect on soapstock utilization within the 50:50 mixture, tallow utilization was in fact increased by 8%. The same type of effect is seen with pure fatty acids (Atteh and Leeson 1985, Table 3).

TABLE 3 Metabolizable energy value of diets containing 9% fatty acids fed to laying hens

Fatty acid	ME (kcal/kg)	Expected ME	Δ
Oleic	2920		
Palmitic	2500		
50:50 O:P	2850	2710	+ 5%

In this study there was a 5% improvement in diet ME related to increasing the unsaturated fatty acid profile of the fat mixture. This same type of synergism can influence the results of trials conducted to measure the metabolizable energy contribution of diets. In these assays, fat will be included at graded levels in a series of diets, and these fed to birds over a given time period. As fat inclusion increases in a diet, so diet ME will increase. In calculating the ME value of the fat per se, it is assumed that differences in diet ME are due solely to the test fat, since other diet factors are constant. However, if there is any effect of the test fat on utilization of other diet components (see later section), or an effect of basal diet nutrients on fat utilization, then there could be a corresponding increase in "apparent" ME of the fat. Following is an example of this type of study, where corn oil was assayed using various types of basal diet (Table 4).

TABLE 4 Variation in ME value of corn oil attributed to fatty acid saturation of the basal diet

Basal diet	Corn oil ME (kcal/kg)
1. Predominantly unsaturated	8390[a]
2. Predominantly saturated	9380[b]
3. Practical ingredients	8510[a]

When the basal diet contains saturated fatty acids, there is an apparent increase in the ME of corn oil. This effect is possibly due to the unsaturates in corn oil aiding in utilization of the basal diet saturates. However, because of methods of diet substitution and final ingredient ME calculation, such synergism is attributed to the test ingredient (corn oil). Leeson and Summers (1976) proposed this concept as a contributing factor to the so called extra-caloric effect of fats (Fig. 1).

As suggested by Robb (1976), in commercial diets the highly unsaturated components of cereals can be expected to improve the digestibility of saturated fats added at low levels. At high levels of fat inclusion, the beneficial effect of cereals (unsaturates) is diluted, and so under these conditions the composition of the added fat is more important. Contrary to these results, Summers and Leeson (1985) showed no synergistic effect in terms of weight gain or feed efficiency when graded levels of corn oil were added to a basal containing tallow.

Mateos and Sell (1980) clearly demonstrated a relationship between linoleic acid content of total dietary fat used in assays, and ME value attributed to yellow grease. Halloran and Sibbald (1979) quantitated such a relationship suggesting there to be a linear increase in fat ME with increase in linoleic acid content.

$$\text{ME (kcal/kg)} = 6540 + 72\ (\%\ \text{linoleic acid})$$

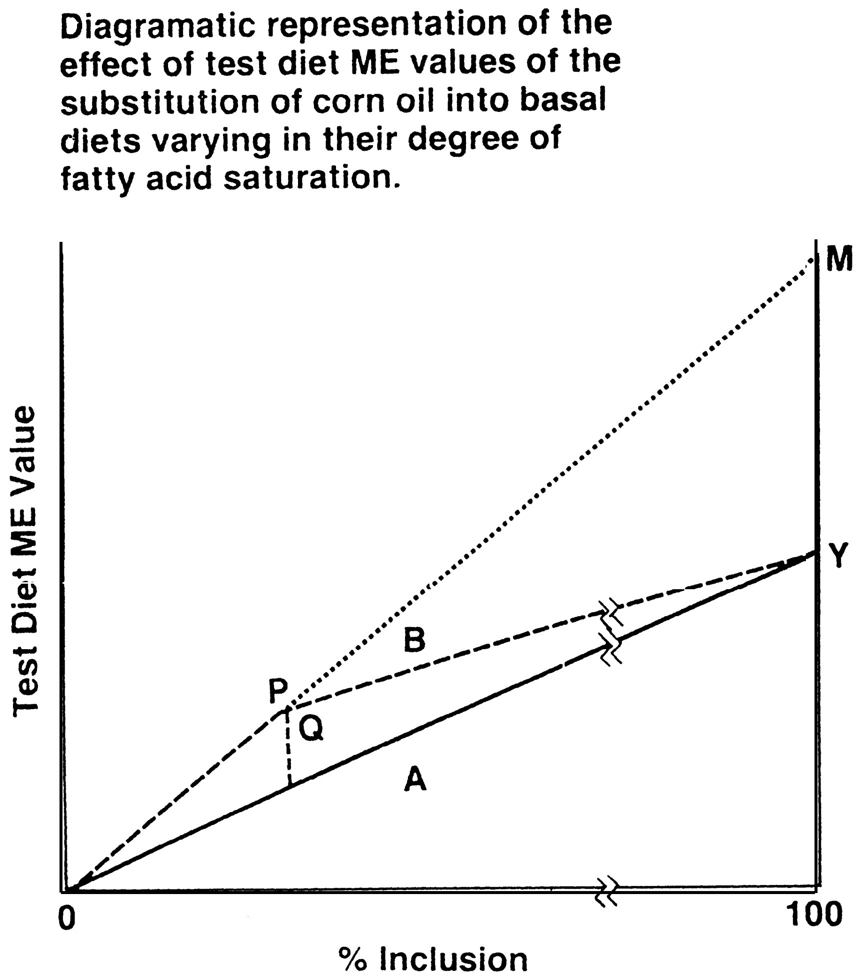


Fig. 1 Schematic representation of the effect of fatt acid synergism on Fat ME value. A - regression analysis with no fatty acid synergism. P represents point of maximum synergism (Q) and M is extrapolated ME taking into account such synergism.

These data suggest that fatty acid synergism is real, and that the effects are of economic significance. Recently there have been two reports outlining the potential of quantitating such effects. Lewis (1989) derived two equations for fat ME based on inclusion level:

1 $\text{ME (kcal/kg)} = 8530 + 630\,x$
Where x = fat inclusion of 1,2 or 3%

2 $\text{ME (kcal/kg)} = 10{,}065 - 277\,x_1$
Where x_1 = fat inclusion levels of 4-12% minus 3%
ie. @ 4%, $x_1 = 1$; @ 12%, $x_1, = 9$.

Lewis (1989) concluded that maximum synergism occurs with most fats at 3% inclusion level, and that ME values determined from digestibility studies rather than conventional (total collection?) ME studies are "not applicable in the real world". Similarly Ketels and DeGroote (1989) determined the optimum ratio of unsaturates:saturates in terms of overall fat digestibility and ME suggesting an optimum ratio of around 3:1 for unsaturates:saturates for maximizing ME. Contrary to the conclusion of Lewis (1989), Ketels and DeGroote (1989) show a similar ratio for optimum fat digestibility suggesting a relationship between this and ME.

While it is possible to define optimum ratios of fatty acids and optimum levels of fat with regard to ME, it is sometimes difficult to envisage how such information could be accommodated in a formulation matrix. Miller et al. (1983) outlined two methods for taking into account variable fat ME values related to inclusion level, suggesting overall savings of some 1% in total feed costs.

While unsaturated fatty acid content of a diet has a marked effect on overall fat ME level, there is often concern about the content of free-fatty acids. Such acids are more prone to rancidity and are more corrosive to some equipment. Although a large proportion of fatty acids are released in the lumen after hydrolysis, the presence of monoglycerides plays an important part in solubilizing non-polar long-chain saturates (Robb 1976). Sklan (1979) also showed that overall absorption of fatty acids was highest in chicks (3 weeks old) fed triglycerides and lowest when pure fatty acids were fed. This may be due to less efficient micelle formation, or less bile production. Sklan (1979) suggests that when products high in FFA content are used, such problems may be corrected by supplying a source of monoglyceride. This type of research data lead feed manufacturers to be wary of fats containing high levels of FFA. However, Alao and Balnave (1985) showed no difference in the ME and utilization of tallow samples containing 2 vs 16% FFA's. These authors concluded that the level of linoleic acid and/or unsaturates in tallow probably has a larger effect on its utilization than does the level of FFA's.

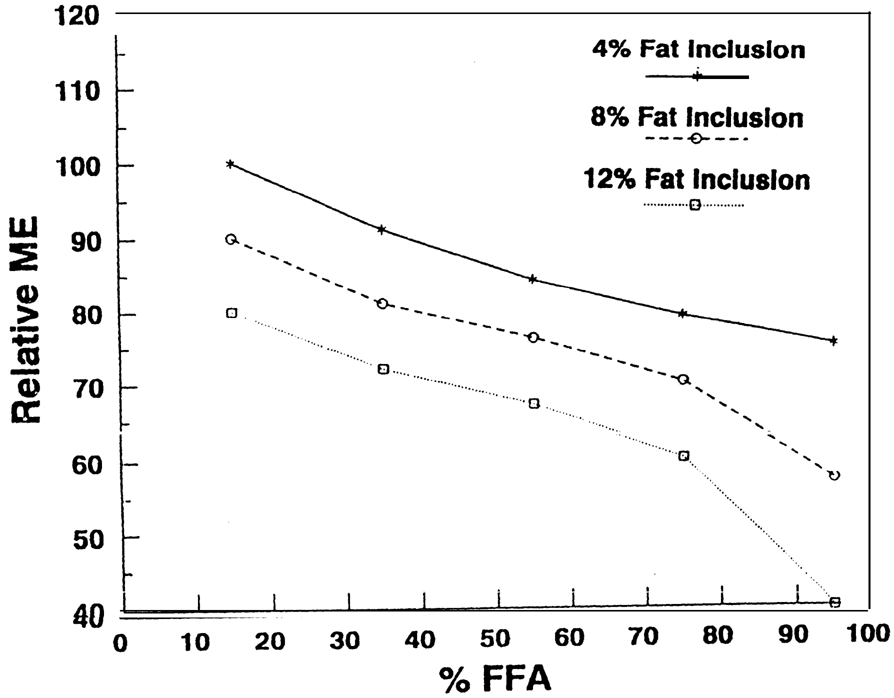
With higher levels of FFA's, however, as commonly occurs with by-product oils and restaurant greases, there is an indication of reduced digestibility. Wiseman et al. (1991) recently indicated marked reduction in ME of tallow and tallow acid oils blended to give a range of FFA's up to 95% of the added fat. As shown in Fig. 2, there was a clear trend for reduced ME as FFA level increased. In this trial involving very young birds (1.5 weeks) it appears that saturated fats containing appreciable quantities of FFA should be discounted in energy value.

Bird age and species Utilization of fat by birds is somewhat unique, in that there is a well defined dependence on bird age. This effect has been documented for many years, and yet this fact is rarely incorporated in formulation matrices. Sell et al. (1986) demonstrate the ability of young turkeys to metabolize various fat sources (Table 5).

TABLE 5 ME values of fats determined with young turkeys (kcal/kg)

	Age of turkey (weeks)			
Fat type	2	4	6	8
Tallow	6800	7700	8425	8550
Animal-vegetable blend	7100	7850	8540	8930

Fig 2. Fat Saturation and Relative ME Related to Fat Inclusion Level for Young Birds



From: Wiseman 1991

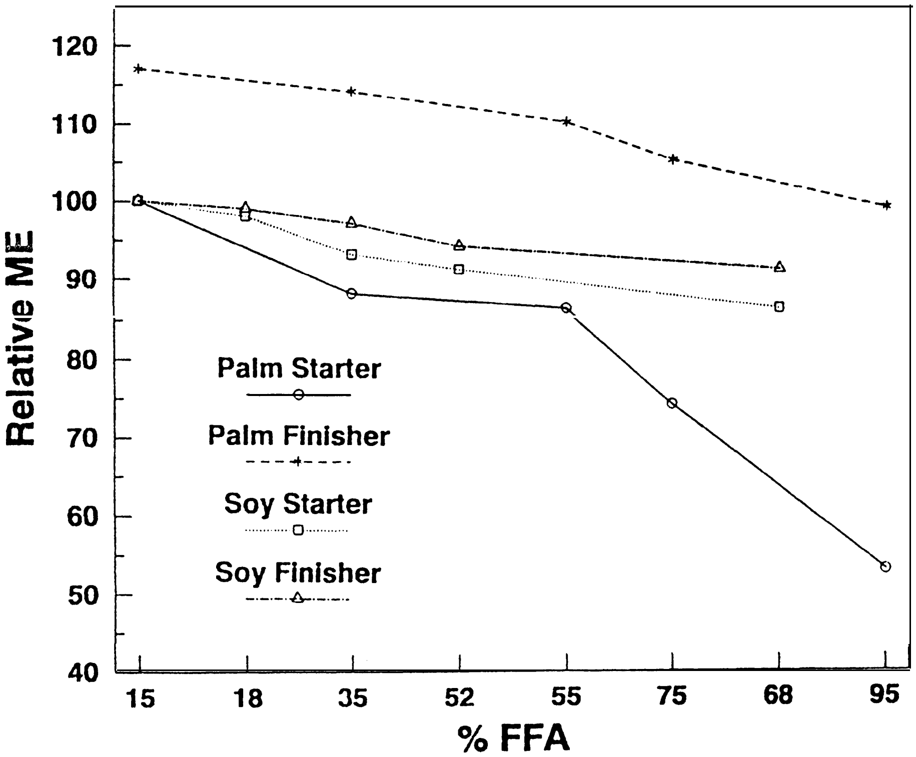
Katongole and March (1980) likewise show a 20-30% improvement in utilization of tallow for 6 vs 3 week-old broilers and Leghorns. The situation is most pronounced for fats containing saturated fatty acids. (Table 6, Whitehead and Fisher 1975) and does not seem to be of significance with other nutrients (Fisher and McNab 1987).

TABLE 6 Effect of bird age, fat saturation on fat digestion and diet ME (kcal/kg)

			Fatty acid					
Fat type	Weeks age	Fat digestion (%)	16:0	18:0	18:1	18:2	ME	Δ
Corn oil	2	96	90	-	95	95	9660	
	8	98	96	-	100	97	10,780	+ 11.6%
Tallow	2	57	51	49	94	-	7280	
	8	74	84	83	98	-	8030	+ 10.34

This overall effect is again confounded with FFA content of fats, and as can be imagined high levels of free saturates are not well utilized by young birds. Wiseman and et al. (1991) clearly indicate this concept in measuring the ME of starter and finisher diets containing predominantly unsaturates or saturates (Fig. 3).

Fig 3. Fat Saturation and Relative ME



From: Wiseman 1991

The reason why adult birds are better able to digest fats, and particularly saturated fats, is not clear. Young birds recycle bile salts less efficiently, and this may be a factor as described previously. Also there is an indication that fatty acid binding protein is not produced in adequate quantities by young birds. Both Sell et al. (1986) and Katongole and March (1980) cite evidence for up to 5 x increase in FABP with chicks from hatch through 8 weeks of age. However, bile salt availability may be the most important factor, and this can be clearly seen when synthetic bile acids are added to the diet. Using about 9% palmitate in the diet, or 9% of an oleic/palmitic acid mixture, Atteh and Leeson (1985) clearly show the advantage to be gained by adding cholic acid to the diet of broiler chicks (Table 7). Unfortunately the use of 0.2% cholic acid as used in this study, is not economically viable.

The role of fibre in fat utilization may likewise relate to availability of bile salts, since various sources of fibre are known to complex with bile acids.

TABLE 7 Broiler response to dietary cholic acid

	56 d body wt. (g)		Fat retention (%)		Diet ME (kcal/kg)	
Diet	Control	+Cholic acid	Control	+Cholic acid	Control	+Cholic acid
1. Non fat basal	1800[a]	1750[a]	77[e]	79[f]	3000[a]	3000[a]
2. + Palmitate	1830[a]	1960[b]	32[a]	42[b]	3125[b]	3200[c]
3. + Oleic/palmitate (50/50)	2180[c]	2300[d]	53[c]	69[d]	3300[d]	3500[e]

Since most fat utilization studies have involved broiler or Leghorn birds, there is ittle information available across bird strain or type. Recently Soto-Salanova et al. (1981) ● dicated that young turkey poults inefficiently metabolized high-fat diets, with ME values some 500-700 kcal/kg less than anticipated. This same effect was seen with a number of fat sources. We have found similar results with young turkeys, where reduced diet ME related to poor fat utilization (Basha and Leeson 1992, unpublished observation, Table 8).

TABLE 8 Diet ME and fat utilization by young poults and broiler chicks

Bird type	Diet fat (%)	Diet ME (kcal/kg)	Fat digestibility (%)
Turkey strain A	4.2	2810[b]	48.2[c]
	12.5	2490[c]	46.3[c]
Turkey strain B	4.2	2830[b]	55.1[b]
	12.5	2518[b]	48.0[c]
Broiler chicken	4.2	3090[a]	67.3[a]
	12.5	2825[b]	64.3[a]

The diet containing 12.5% fat was well utilized by chicks, yet the turkey poults exhibited an extremely low metabolizable energy value when fed this diet. If these data are confirmed, then we should question the practice of adding fat to turkey prestarter diets

Intestinal factors and general diet composition Status of the intestinal lumen will obviously have an effect on the digestion and/or absorption of any nutrient. Freeman (1969) indicates that digesta pH can influence fat utilization, where acidic conditions reduce micellar solubilization. In rats, it has been shown that fat digestibility is reduced when the diet contains lactic acid. This concept warrants further study considering the use of organic acid mold inhibitors and the availability of various feed additives to modify gut pH.

Freeman et al. (1969) indicate that in the pig that the capacity of the small intestine to absorb micellar lipid is far in excess of normal flow into the intestine, suggesting absorption per se is not a rate-limiting process. However, Katongole and March (1980) indicate that mechanisms of absorption may be affected by an age-related availability of so-called fatty acid binding protein (FABP). Dror et al. (1976) likewise conclude that pancreatic lipase output is little affected by diet fat concentration. A fatty acid-albumin complex has been shown to be absorbed less efficiently than micellar FA's (Sklan 1979) and the formation of a complex of these FA's with undigested protein may be partly responsible for the poorer fat digestion seen when animals are fed improperly processed soybean meal.

Birds infected with coccidiosis exhibit inferior fat digestibility (Sharma and Fernando 1975) where the steatorrhea may result from the loss of reconstituted fat globules following the rupture of parasitized epithelial cells. Fat per se and linoleic acid in particular may also affect the microbial populations in the intestine. Groneuer and Hartfiel (1975) indicate reduction in coliform bacterial population in layers fed corn oil.

Diet fat affects rate of passage of digesta, and this can influence overall diet ME. Sell and co-workers at Iowa State have used this argument to account for the so called "extra-metabolic" effect of fat. Mateos et al. (1982) suggest that fats and oils likely inhibit stomach emptying and intestinal digesta movement. However this phenomena is affected by diet constituents, the rate of passage being more affected when the diet contains sucrose vs starch (Mateos and Sell 1980). Delayed rate of passage suggests that digesta spend more time in contact with digestive enzymes, carriers or co-factors and absorptive sites, etc. Addition of fats to the diet may therefore lead to increased utilization of non-fat components of the diet. As previously described, increase in utilization of basal diet ingredients other than the test ingredient, leads to unexpectedly high ME values (contributing to the extra-metabolic effect).

Perhaps the most significant fat-nutrient interaction that can occur in the lumen, is the complexing of fatty acids with minerals, to form soaps. If insoluble soaps are formed, there is the possibility that both the fatty acid and the mineral will be unavailable to the bird. Atteh and Leeson (1984) indicate substantial soap formation in the digesta of broiler chicks and that this is most pronounced with saturated fatty acids where high levels of diet minerals are used (Table 9).

TABLE 9 Fat digestion in broilers fed up to 1.6% dietary calcium

	Diet Ca (%)		
Predominant diet fat source	0.8	1.2	1.6
Control	77[e]	78[e]	75[e]
Oleic acid	90[f]	87[f]	78[e]
Palmitic acid	32[b]	26[b]	18[a]
Oleic/Palmitic mix	56[d]	54[d]	39[c]

These differences in fat digestibility are mirrored by changes in fecal soap formation (Table 10).

TABLE 10 Proportion of fecal fat present as soap

	Diet Ca (%)		
Predominant diet fat source	0.8	1.2	1.6
Control	13[ab]	19[bc]	21[c]
Oleic acid	7[a]	8[a]	9[a]
Palmitic acid	56[e]	74[f]	84[f]
Oleic/Palmitic mix	35[d]	40[d]	51[e]

In other studies Atteh and Leeson (1983) indicated such increased fecal soap production to be associated with reduced bone ash and bone calcium content of broilers. Soap production seems to be less of a problem with older birds. This is of importance to laying hens that are fed high levels of calcium. In addition to calcium, other minerals, such as magnesium, can also form soaps with saturated fatty acids. In older birds and with some other animals, there is an indication that while soaps form in the lower digestive tract, they are subsequently solubilized in the lower tract due to changes in pH.

Jnder these conditions both the fatty acid and mineral are available to the bird. Control ›ver digesta pH may, therefore, be an important parameter for control of soap formation

CONCLUSIONS

Fats provide essential fatty acids and a concentrated source of available energy. Utilization of fat is affected by:

1. Type of fat. Fat ME value correlates with linoleic acid content. Saturated fatty acids are less well utilized.

2. Inclusion of a correct ratio of unsaturates:saturates is important for optimum utilization. This ratio appears to be around 4:1.

3. Young chicks are not able to utilize saturated fatty acids. As such, different ME values should be used for birds < 3 weeks age and > 3 weeks age.
4. Fats can influence the utilization of other diet nutrients, and fat utilization can itself be adversely affected by fibre and minerals.

5. At low inclusion levels (< 3%) fat ME value can be greatly influenced by the composition (fat, CHO and protein) of the other diet ingredients. At high inclusion levels, fat ME value is most affected by fat composition.

6. Fat ME values used in formulation should be varied depending upon fat saturation and bird age. Leeson and Summers (1991) recently suggested such a range of values to be used in diet formulation.

	Metabolizable energy (kcal/kg)	
Fat type	Birds up to 21 d age	Birds > 21 d
Tallow	7400	8500
Lard	7600	8400
Poultry fat	8200	9000
Fish oil	8600	9000
Vegetable oil	8800	9200
Coconut oil	6000	7500
Palm oil	7100	7300
Vegetable soapstock	7800	8100
Animal-vegetable blend	7700	8000

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