OPTIMIZING THE ROLE OF FATS IN DIET FORMULATION

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I. INTRODUCTION

Fats and oils are important components of compound poultry diets; they have approximately twice the dietary energy-yielding capacity of carbohydrates, they may contain essential fatty acids and fat soluble vitamins, their physical texture reduces dust in feed mills and they promote diet palatability; their influence on meat quality is also important. They are however extremely variable in terms of chemical composition and nutritional value.

Decisions on whether to use fats and oils will also be based upon other factors including their cost and the presence of appropriate milling technology which often limits the amounts that may be used. Fats and oils are frequently blends of a number of individual ingredients providing a final mixture with a melting point in the region of 40° to 50°C. Storage of blends is usually within this temperature range, requiring specialised facilities (which should be stainless steel or polymer based) and they are usually added in the liquid state. Most compound feeds are pelleted subsequent to mixing and this process is not effective if added fat levels are excessive (beyond approximately 40g fat/kg diet). Addition of further amounts of fat is through liquid fat spraying equipment post-pelleting. To overcome these technological problems, 'dry fat' products, where fats are absorbed on to a solid carrier, and spray-dried products are becoming increasingly available; the use of oil seeds prior to oil extraction (for example soya beans) is a well-established means of adding oil to poultry diets, a process which has the additional advantage of simultaneously providing other nutrients (for example amino acids).

II. UTILISATION OF FATS AND OILS BY POULTRY

The nutritional value of a raw material is governed primarily by its chemical composition (i.e. its ability to provide energy-yielding compounds and specific nutrients) and the degree to which it is digested. Fats and oils are of diverse origin and chemical composition - the animal feed industry is frequently the recipient of by-products from other processes which are often available as blends. A wide range of commodities is thus available including crude vegetable oils, soapstocks, hydrogenated materials, rendered animal tallow, recovered vegetable oils from human food production and even commodities from the refining of oils such as bleaching earths which are sometimes available as 'dry fat' products.

Whilst all these materials (with the exception of the last category) probably have similar total fat contents approaching 1000g/kg, there is considerable variability in chemical composition which has a pronounced influence on their digestibility. A number of reviews have considered both the physiological basis for the digestion and absorption of fats, and the factors which are responsible for the large differences in their subsequent dietary energy values (e.g. Freeman, 1976; Wiseman, 1984).

(a) Influence of chemical structure of fats and oils on digestibility and dietary energy value

There is considerable confusion relating to the apparent metabolizable energy (AME) value of fats primarily because descriptions of the products evaluated are confined to names and origins with no accompanying chemical characterisation of a more precise nature. Systematic studies on the influence of chemical composition of fats and oils on dietary

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energy values for poultry, in terms of the quantitative contribution of the variables involved, are limited. Thus tables of nutritional value of fats and oils are limited to descriptions such as 'beef tallow' and 'vegetable oil'. The need for greater precision in defining source materials in a chemical rather than descriptive manner is of particular importance as fats and oils are rarely fed as a single commodity but rather as blends of a variety of materials. The two chemical variables of most importance are the degree of saturation and content of free fatty acids, with chain length of the constituent fatty acids being of secondary concern.

(i) Degree of saturation and free fatty acid content. Physiologically, the mechanisms of fat digestion and absorption in non-ruminants are well documented (Freeman, 1976). The major site of fat digestion in poultry is the duodenum and this consists of emulsification of dietary fat by conjugated bile salts, followed by hydrolysis of triglycerides by pancreatic lipase into mixtures of 2-monoglycerides and free fatty acids. The subsequent absorption of these products is dependent upon their solubility in bile salt micelles. Polar solutes are more readily incorporated into micelles, and this explains the relatively higher absorption of unsaturated fatty acids compared to saturated fatty acids and the well-established observation that unsaturated fatty acids have a higher digestibility than those that are saturated. Thus oils have a higher AME value than the more saturated fats - this also explains why hydrogenation of oils (even partial) is associated with a reduction in AME value.

However this is an overly qualitative description and, to be of any value to assigning AME values to the wide range of commodities available, a quantitative measurement of the degree of saturation is essential. Whilst reference has been made to the digestion of individual fatty acids, some assessment of the overall commodity is more important. What has been utilised (e.g. Wiseman, 1990) is the ratio of unsaturated (U) to saturated (S) fatty acids (giving U/S). Increasing the degree of unsaturation of a fat through mixing a saturated fat with an unsaturated oil, which is associated with higher U/S ratios, is associated with a non-linear improvement in AME.

The relative superiority of an intact triglyceride compared to hydrolysed fat in terms of AME is also well known (e.g. Young, 1961; Sklan, 1979). Increasing the proportion of FFA would appear to be associated with a linear reduction in fat digestibility (Freeman, 1976).

Systematic studies on the influence of U/S and FFA content of fats and oils on AME and DE values were undertaken by Wiseman and Salvador, 1991 and Wiseman et al., 1991. Materials and their blends of known U/S and FFA content, which covered the range employed in poultry feeding, were evaluated for AME. Chain length of constituent fatty acids was predominantly in the range 16 to 20 carbon atoms. Data generated confirmed that the response of AME to U/S was curvilinear, with the greatest improvement in dietary energy value occurring over the lower range of increase in U/S. The response of dietary energy to FFA was linear.

Evaluation through biological experimentation is a lengthy and costly procedure. Thus there have been many studies attempting to predict AME from chemical composition. Having identified the two major chemical components which have nutritional relevance and generated AME values, a subsequent procedure was regression analysis undertaken to relate AME (dependent variable) to both U/S and FFA content (independent variables).

Equations combining both independent variables are presented in Table 1. Separate functions were derived for both 'young' and 'old' birds as the ability to digest fats improves with age (Fedde et al., 1960; Carew et al., 1972; Wiseman and Salvador, 1989). The influence of both U/S and FFA, together with age, is presented in Figure 1. These functions do represent a considerable improvement, in terms of accuracy of prediction of AME, over those based upon rather more empirical approaches. An example of the latter would be
equations employing iodine value as the independent variable. Values for soya bean oil and rapeseed oil would be different (the former would be higher) whereas AME would be similar.

Table 1. Prediction equations relating AME; MJ/kg of fats/oils to U/S and FFA (g/kg fat) Age 1 and 2 to 1.5 and 7.5 weeks of age: AME = A + B x FFA + C x e^{D x U/S}.

PV is proportion of variance accounted for by regression.

<table>
<thead>
<tr>
<th>Constant</th>
<th>Age 1</th>
<th>PV</th>
<th>Age 2</th>
<th>PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>38.112</td>
<td>± 1.418</td>
<td>39.050</td>
<td>± 0.557</td>
</tr>
<tr>
<td>B</td>
<td>-0.009</td>
<td>± 0.002</td>
<td>-0.006</td>
<td>± 0.001</td>
</tr>
<tr>
<td>C</td>
<td>-15.337</td>
<td>± 2.636</td>
<td>-8.505</td>
<td>± 0.746</td>
</tr>
<tr>
<td>D</td>
<td>-0.509</td>
<td>± 0.186</td>
<td>-0.403</td>
<td>± 0.088</td>
</tr>
</tbody>
</table>

Figure 1. Influence of U/S and FFA on Fat AME Young and Old Birds

There are, however, problems with the equations derived as it may not be appropriate to apply them to those fats containing saturated fatty acids of shorter chain length (i.e. below 16 atoms of carbon) (Renner and Hill, 1961). This problem has been studied (Wiseman and Blanch, 1994) where a combination of coconut and palm kernel oils (together with the respective acid oil and with mixtures of the two to give blends of intermediate FFA content) were evaluated. Both combinations consist predominantly of saturated fatty acids, but of chain lengths shorter than 14 atoms of carbon. AME data indicate that content of saturated fatty acids used to calculate the U/S ratio should be based on the sum of myristic (C14:0), palmitic (C16:0) and stearic (C18:0) acids but not lauric (C12:0) which behaves like an unsaturated fatty acid.

(ii) Heat damaged fats and oils. It is likely that fats and oils have undergone some form of heat treatment, often in the presence of oxygen. They are relatively unstable (particularly if unsaturated) and are therefore prone to some form of degradation (which explains why
protection of fats and oils through the use of anti-oxidants, added as early as possible in the manufacturing process as oxidative degeneration is irreversible, is crucial). This has prompted numerous studies on the chemical commodities produced during heating and the nutritional implications (e.g. Artman, 1969; Wiseman, 1986).

A large number of modifications to the chemical structure of fats and oils following heating have been identified ranging from simple oxidation products through to dimerization and polymerization (linear and cyclic) of both fatty acids and triglycerides depending upon the substrate in question and the conditions.

The biological effects of feeding these modified structures are also extremely varied both in terms of the actual response in the animal and its severity. It should be noted that even minor adverse biological consequences would have serious effects on overall bird performance. Initially AME will be reduced, and an increasing amount of dietary fat will pass through the gastro-intestinal tract and be excreted. This may have serious implications for litter conditions which may deteriorate through becoming 'greasy', giving rise to a poorer environment and problems of both bird welfare and product quality. It is also possible that the presence of modified fat structures may interfere with the overall digestive process such that general nutrient uptake is impaired. Thus there may be overall nutrient deficiency. Furthermore an actively oxidizing fat or oil will destroy other nutrients present, e.g. vitamins.

Perhaps more concern has been expressed over whether any toxic products are generated following fat and oil heating / oxidation. It does appear however that the majority of these products are only sparingly absorbed and are thus harmless. However, in the case of oxidized fats and oils, defence mechanisms in the gut mucosae to prevent absorption may be stretched such that overall nutrient absorption might be reduced. Death in laboratory animals fed heated fats and oils has been recorded (Andrews et al., 1960) but these are extreme cases.

Because of the potential adverse effects of feeding heat damaged / oxidized fats and oils, there has been considerable interest in developing chemical methods to detect such damage. It is important to note that any method adopted has to be one that measures all products collectively if it is to have any practical application. Peroxide value (PV) has been employed widely for this purpose, but it is an unsound method. In tracing the change in PV over time (Poling et al., 1962) an increase followed by a reduction was observed. Thus a low PV value may indicate on the one hand a commodity that had not undergone any degradation but, on the other hand, one that had been seriously denatured. The rate of production of oxidized fats may also equal their subsequent degradation. The PV under these circumstances may not change significantly, suggesting a stable situation. Measurement of oxidized fat has been employed but the evaluation is solvent dependent and would not measure those complexes which would not be soluble in polar solvents.

FFA content has been employed frequently to assess damage to oils used in the human food industry but is inappropriate for fats and oils for animal feeding. This is because soapstocks, for example, are perfectly acceptable ingredients for blends (whilst being of lower AME than the original triglyceride) although the FFA content is high. This also explains why assessments of molecular weights or sizes are inappropriate. Thus a fatty acid trimer (zero AME) would generate similar data to a triglyceride (of high value).

One promising technique is based upon estimating the total non-esterifiable material (NEM) through quantitative gas-liquid chromatography (Walting et al., 1975; Edmunds 1990). Whilst this method only measures total degraded structures within a fat or oil, it does at least provide guidance as to whether the commodity has been damaged and has proved useful in identifying those commodities (for example some recovered vegetable oils) which are liable to have been excessively heated.

In a trial designed to examine the reduction in dietary energy value likely to result from damage (Wiseman et al., 1992)), a refined sunflower oil was extensively heat damaged. From analysis of the data it was evident that the AME of the NEM fraction, in this material,
was of the order of zero. This indicates the problems identified with heat damaged fats, although no account was taken of associated issues of the presence of the NEM fraction (e.g. reduction in general nutrient uptake).

The experimental program conducted at the University of Nottingham described above had employed the same basal diet to which experimental fats and oils were added. The major raw materials were wheat 300g, maize 275g, soya bean meal 440g and fish meal 125g/kg and, accordingly, the levels of cereal non-starch polysaccharides (NSP) were deliberately kept very low to avoid any possible confounding effects they might have (it had already been established that data generated on AME of fats and oils were no different from those when a synthetic diet was employed). This precaution has, subsequently, proved to have been important.

Recent data have demonstrated that there may be significant interactions between fat digestibility and the nature of the basal diet attributable to high levels of cereal NSP. Thus, both Danicke et al., (1997) and Langhout et al., (1997) have established that basal diets containing high levels of cereal NSP (achieved in the former with 610g rye and in the latter with 500g wheat and 100g rye/kg diet) reduced the digestibility of added fat, the more so with fats that were more saturated. Improved responses were obtained with additions of various exogenous NSPases. The probable reasons for these responses were considered to be linked to the increase in viscosity of intestinal digesta (associated with NSPs) and greater microbial activity which may de-conjugate bile acids, thus reducing their effectiveness in promoting digestion and absorption of fats. It remains to be established whether similar responses would be obtained in the absence of rye (which contains considerably greater levels of NSP than wheat).

(iii) Contaminants within fats and oils. In addition to the products arising from heat damage and oxidation, fats and oils may contain contaminants which are fat soluble. Perhaps the most important group of contaminants are pesticides. Whilst they are potentially damaging to the animal itself, residues within the product are also of concern to the human consumer. Furthermore many of these commodities are rendered even more dangerous following the action of heat (e.g. Metcalfe 1972). Levels within diets should be strictly controlled. Other contaminants found in fats and oils include unsaponifiable matter (plant waxes) which acts as a diluent, water (a diluent but which also has a role in the oxidation process) and polythene (which would compromise fat spraying equipment). These would also cause a minor reduction in total fat content. Finally it is of interest to note that, in any process designed to purify a fat or oil, the materials employed in such purification will themselves become contaminated.

(b) Effect of dietary fats and oils on meat quality

An important feature of poultry production is increasing interest in quality of the product. Carcass fatty acids in poultry can arise from two discrete sources, being de novo synthesis or direct deposition from dietary sources - the latter is the route by which polyunsaturated fatty acids (principally linoleic acid) appear in the carcass.

The degree to which dietary factors influence the fatty acid profile of carcass fat is controlled by a number of factors, including the actual fatty acid profile of the dietary fat and AME (direct deposition of dietary fat is more likely the higher the AME). The basic effects of dietary fat have been recognized for some considerable time. Carcass linoleic acid levels, specifically, have been identified as perhaps the major determinant of the degree of softness of carcass fat. Investigations into the role of linoleic acid have led to recommendations that concentrations above 150g linoleic acid/kg body fat are to be avoided if excessive softness is to be prevented (Whittington et al., 1986), although these studies were with pigs; the lack of a
discrete subcutaneous layer makes it more difficult to comment on softness of carcass fat in broilers.

(i) Effect on physical texture and on keeping / eating quality. The increased use of diets with high AME (particularly as this has been associated with including significant amounts of relatively unsaturated dietary fats) is accompanied by a risk of a negative effect on the keeping quality of the carcass because of the risk of oxidative breakdown of unsaturated fatty acids resulting in development of peroxides and rancidity (Darling et al., 1998). This is because oxidation products, being volatile, give rise to off-odours which will reduce the shelf life of meat. However, the evidence that carcass fatty acid profiles influence the eating quality of meat is less conclusive, although it would appear that the more unstable the fatty acid, the greater the risks. Certainly feeding oils with high levels of long chain polyunsaturated fatty acids (for example fish oil) is not advisable.

Although current recommendations appear to suggest that the polyunsaturated fatty acid content of poultry adipose tissue should be limited (on both textural and eating quality grounds), an opposing viewpoint is occasionally put forward by human nutritionists. A UK Government report (COMA, 1991), in recommending that total dietary fat should represent no more than 33% of total energy intake of the national diet, also proposed that the proportion of this total fat that was saturated should be no more than one third. Recommendations were also established in connection with unsaturated fatty acid intake, which represents an increasing awareness of the importance of different classes of unsaturated fatty acids in human nutrition. The proposed cis mono-unsaturated fatty acid: cis polyunsaturated fatty acid ratio was 2:1 and, furthermore, the ratio of cis ω-linoleic acid (of the n-6 or ω-6 essential fatty acid family) to cis ω-linolenic acid (n-3 or ω-3 essential fatty acid family) was 5:1.

These recommendations apply to the total diet and should not necessarily be used to define optimum fatty acid ratios for individual food items in the human diet. Nevertheless, there is growing interest in modifying fatty acid profiles of animal products, which is comparatively easy in poultry, because of the somewhat negative reputation that these products have of being high in saturated fatty acids which have been implicated in consumer avoidance of these food items. It is possible that broiler meat which was aligned better to the 'optimum' would have a significant impact upon consumer acceptance of them. Nevertheless such a development should not proceed unless there is clear evidence that such modifications to carcass adipose tissue levels are not accompanied by deteriorations in meat quality as defined by technological and organoleptic criteria. In this context the protective function of dietary α-tocopherol acetate has recently been studied (Bartov and Frigg, 1992) where it was considered that, whilst it would not improve performance, it had an important effect on meat stability.

(ii) Rate of change of carcass adipose tissue fatty acids. Problems of unsaturated fatty acids within adipose tissue need to be placed alongside the higher dietary energy values associated with more unsaturated fat blends. Such, seemingly mutually exclusive, objectives might be more easily reconciled if the speed with which carcass fatty acid profiles respond to changes in dietary levels could be established.
Figure 2 Pattern of change of carcass fatty acids following dietary change

The more rapid these changes, then the later the introduction of the more saturated lower dietary energy fat. The responsiveness of carcass fat to dietary fat has been studied (University of Nottingham, unpublished) employing diets based upon tallow and safflower oil; data indicate that the rate of change of carcass fatty acid profile is comparatively rapid (Figure 2).

III. CONCLUSIONS

Fats and oils have an important role in contributing to the AME of compound diets for broilers although they also have other beneficial effects including provision of essential fatty acids, reducing dust in mills and improving diet palatability. It is evident that the chemical composition of the various commodities which are available is extremely variable and this will have a major impact on bird performance and carcass quality. Classification of fats and oils simply in terms of their origin is no longer valid. Quantitative relationships between AME and chemical composition are now available and should contribute significantly to the efficiency of diet formulation.

IV. REFERENCES


