IAFMM

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THE ROLE OF FAT IN FISH MEAL IN PIG AND POULTRY NUTRITION

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FISH MEAL SCIENTIFIC ADVISORY SERVICE

The International Association of Fish Meal Manufacturers (IAFMM) announces the establishment of a permanent Scientific Advisory Service mainly for Feed Compounders and Concentrate Manufacturers and Agricultural Institutions. The staff of the IAFMM, in conjunction with its Scientific Committee, representing an international group of experts in nutrition, bacteriology, engineering and product development, will provide up-to-date information on any aspect of Fish Meal and its uses. All enquiries should be directed to:

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SUMMARY

The composition of the main types of fish used to produce fish meal are discussed in terms of the effect this has on the residual fat in fish meal produced. The effects of processing, including use of antioxidants, on the composition of the residual fat in fish meal are also discussed. Antioxidant treatment helps maintain the fat content of the meal (as determined by diethyl ether or hexane), and also preserves the polyunsaturated fatty acid content.

The analytical determination of fat in fish meal is discussed and it is concluded that direct extraction with either diethyl ether or hexane is more meaningful in terms of the energy contribution of fish meal to livestock diets than attempts to extract all the fat material using more time-consuming methods.

The use of antioxidants can increase the energy content of fish meals by up to 15%, depending on the chemical characteristics of the residual fat. For the last five years antioxidants have been used in most commercial fish meals.

Determined energy values of fish meal for poultry and pigs are given.

Fish fat from stabilized fish meals has a low content of linoleic acid but is rich in polyunsaturated fatty acids, particularly those of the linolenic acid family. These acids can meet the bird's requirements for essential fatty acids.

Work has shown stabilized fish fat is equivalent to safflower oil (containing 74% linoleic acid) on a weight for weight basis in meeting the chick's requirement for essential fatty acids. To regard fish fat as containing at least 50% of its weight as essential fatty acids for feed formulation purposes allows some safety margin.

The nutritional significance of peroxide values and free fatty acid values are considered. It is concluded that the range of free fatty acids and peroxides found in commercial fish meal will not cause any nutritional problems to farm livestock.

A crude relationship between the level of fish fat in pig and poultry diets above certain "safe" levels and "fishy" taint in the carcass is established. From work with poultry it is recognised that there is a better correlation between the content of long chain poly-unsaturated fatty acids (22:6 etc.) in the diet and the flavour of the carcass meat. Fish fat in stabilized fish meal contains a higher quantity of long chain poly-unsaturated fatty acids compared with fish fat in unstabilized fish meal. Consequently if these two fats are fed at the same level, the unstabilized fish fat is less likely to cause taint than the stabilized fish fat. Feeding trials, with organoleptic evaluation of the livestock products, have led to the following recommendations for safe maximum levels of fish fat in diets:

DIET	UNSTABILIZED FISH FAT	STABILIZED FISH FAT
Pig finisher	0.6%	0.4%
Turkey finisher	0.8%	0.5%
Broiler finisher	1.5%	0.8%
Layers	No practical restrictions necessary	

These figures contain a good margin of safety and in practice many feed manufacturers have adapted higher maxima.

The fat in fish meal can make a significant contribution to the total fat content of the finished feed. Fat in finished feed helps to reduce dustiness, improves pelleting and reduces segregation of components of mixed feeds. In situations where fats are very expensive or their use is restricted because of the lack of handling equipment, fish meal offers a form of fat which will readily mix uniformly into the finished feed.

1. INTRODUCTION

Fish meal is generally manufactured from either demersal species (such as cod) or pelagic fish (such as anchovy, pilchard, herring, menhaden and capelin). In the former the fat is concentrated in the liver and there is little fat in the flesh. In the latter the fat is concentrated in certain parts of the flesh. The demersal fish normally have the livers removed before processing, resulting in the production of a white-fish meal with a low fat content (2-6%). On the other hand the pelagic fish result in the production of a "fatty fish meal" (7-13%) even though a considerable quantity of the fat is removed during processing. Furthermore, the fat content of the meal depends on the type of fish and the season during which it was caught, and processing.

The presence of fat in fish meal has considerable advantages in terms of energy contribution to the diet and the supply of essential fatty acids together with an improvement in the physical properties of the complete feed. These factors are reviewed in this bulletin. In the mind of some users, however, the presence of fat in fish meal may have a number of possible disadvantages such as the presence of peroxides and free fatty acids and the possibility of producing "fishy" tainted carcasses if fed to stock at high levels. These possible disadvantages are evaluated and their effects quantified.

2. EFFECT OF PROCESSING ON THE COMPOSITION OF FAT IN FISH MEAL

The few analyses performed on fat in fish meal have indicated that typically they contain about 70% neutral lipid and about 30% phospholipid. The main components of the neutral lipids are triglycerides with smaller amounts of free fatty acids and cholesterol esters. The phospholipids and triglycerides are characterized by their varying content of longer chain fatty acids with up to 24 carbon atoms (compared with 12 to 18 carbon atoms in almost all other oils). Moreover, the number of unsaturated linkages in some of the fatty acids, particularly the long chain ones, exceed the two or three in other oils and may be as high as six, rendering these oils highly reactive. These highly unsaturated acids can react exothermally with oxygen, resulting in the production of varying amounts of hydroperoxides, aldehydes, ketones and other low molecular weight compounds as well as high molecular weight polymerised compounds which are insoluble in diethyl ether and hexane.

Thus, after the manufacture of meal from fatty fish, a "curing" period may be necessary for unstabilized meals when the most reactive polyunsaturated part of the fat in the meal is allowed to oxidise. The need for and the duration (extent) of this period is greatly dependent on the nature of the raw material, especially the degree of unsaturation of the oil (iodine value) and processing conditions, particularly during the drying of the meal. The heat evolved is allowed to escape safely when the sacks are loosely stacked in such a way as to ensure continuous circulation of air around each bag. The curing may also be carried out by using semipermeable bags which limit the diffusion of oxygen and generation of heat. After the initial curing period, the meal can be stored in compact stacks. The oxidation process affects the chemical composition of the meal as well as the physical characteristics. The solubility of the fat in hexane decreases as does the iodine value (Table 1). The latter reflects the oxidation of the poly-unsaturated fatty acids.

TABLE 1:

STORAGE OF FISH MEAL FOR 4 YEARS – EFFECT ON FAT

ADDED ETHOXYQUIN ppm	FAT SOLUBLE IN HEXANE ON DRY BASIS			IODINE VALUE	
	AT START 1965	1969 (a)	1969 (b)	1969 (a)	1969 (b)
NIL	9.2	4.6	5.3	93	97
200	9.2	9.7	9.7	158	159
1000	10,1	9.8	10.0	167	166

1. Taken from reference No. 55.
(a) Stored in hessian sacks.
(b) Duplicates stored in plastic bags.

Stabilization of the fat in the meal with antioxidant (mainly ethoxyquin) has increased considerably on a commercial scale since 1968. This practice has the advantage of eliminating the necessity for a three or four week curing period, and can help maintain the energy value and vitamin and essential fatty acid status and may maintain protein quality of the meal compared with non-stabilized meals prepared from fish containing a large content of reactive fat. (Stabilization of meals containing less reactive fat is considered unnecessary by some producers). On the other hand, stabilization has one main disadvantage: the fat is more likely to impart a "foreign flavour" to the carcass meat of pigs and

poultry when fed at high levels, but more will be said of this later. The chemical effect of antioxidant treatment is to maintain the hexane solubility of the oil and preserve the poly-unsaturated fatty acid content and iodine value.

TABLE 2:

PERCENT FATTY ACID COMPOSITION OF FAT FROM MEAL MADE FROM DIFFERENT SPECIES OF FISH AND FROM DIFFERENT PROCESSES AND PERCENT FATTY ACID COMPOSITION OF FAT FROM MAIZE.

Fatty Acid %	White-Fish Meal[a] (Stored meal)	Capelin[b] (Fresh Meal)	Anchovy[b] (Stabilized)	Herring[b] (Fresh)	Herring[b] (Cured)	Herring[b] (Stabilized)	Sardinella/ Horse Mack-eral[a] (Stabilized)	Maize[c]
14:0	3	5	7	7	9	7	4	–
16:0	11	17	23	15	21	15	14	12
18:0	2	2	4	2	3	2	4	1
16:1	7	7	7	5	6	5	5	–
18:1	17	18	13	13	15	13	10	26
20:1	10	9	1	11	15	12	2	1
22:1	9	7	1	18	23	17	2	–
24:1	1	1	–	1	1	1	1	–
18:2	1	2	1	2	1	2	3	59
18:3	–	–	–	1	–	–	–	1
18:4	2	2	2	2	–	2	2	–
20:5	12	10	16	6	–	6	18	–
22:5	2	1	2	1	–	1	4	–
22:6	19	17	14	13	1	12	26	–

(a) Gunstone, *et al.* (1977). See Reference 81.

(b) Opstvedt, J. (1971) See reference 50.

(c) Opstvedt J. (1974) See reference 80.

Table 2 illustrates the fatty acid composition of the fat in freshly prepared meals, cured meals and stabilized meals. It can be seen from the samples of herring meal that the fatty acid composition in

freshly prepared meal and stabilized meal is similar. Oxidation of the fat during the curing process results in rapid disappearance of the poly-unsaturated fatty acids to less than 5% of the quantity in fresh or stabilized meals. White fish meal prepared from lean fish has a low oil content, but with a high proportion of poly-unsaturated fatty acids. Examining the proportion of poly-unsaturated fatty acids in the fat from stabilized anchovy meal, stabilized sardinella/horse mackerel meal and stabilized herring meal, it can be seen that anchovy and sardinella/horse mackerel fat contains higher proportions (above 30%) compared with herring fat (about 20%). This is reflected in the iodine values of the oils.

3. ANALYSES OF THE FAT IN FISH MEAL

Of all the common feedstuff analytical measurements, fat is probably the most widely divergent from country to country. The official IAFMM method proposes direct extraction of fish meal with diethyl ether, but it is known that a number of member countries of the IAFMM measure the fat level routinely using hexane. The latter is preferred by these countries because it poses less of an explosion risk, and the results obtained during this test do not differ appreciably from those obtained with diethyl ether (Table 3).

TABLE 3:

RESULTS OF VARIOUS METHODS
FOR DETERMINING THE FAT CONTENT IN FISH MEALS[1]

SAMPLE OF MEAL		Fat Soluble in Diethyl Ether (A)			Fat Soluble in Hexane (B)	Difference Between (B) and (A)	Fat Soluble by E.E.C. Method (C)			Difference Between (C) and (A)
		Test 1	Test 2	Avg.			Test 1	Test 2	Avg.	
South African	1	9.75	9.76	9.76	9.7	0	11.39	11.45	11.42	+ 1.64
South African	2	11.38	11.29	11.34	11.2	– 0.14	12.92	13.10	13.01	+ 1.67
South African	3	8.69	–	8.69	9.0	– 0.31	10.77	–	10.77	+ 2.08
South African	4	5.85	5.31	5.58	6.1	+ 0.52	7.02	7.09	7.06	+ 1.48
South African	5	7.51	–	7.51	7.8	+ 0.29	9.58	–	9.58	+ 2.07
South African	6	3.43	3.54	3.49	4.1	+ 0.61	5.15	5.43	5.29	+ 1.80
German	7	6.71	–	6.7	–	–	8.2	–	8.2	+ 1.5
German	8	7.4	–	7.4	–	–	8.9	–	8.9	+ 1.5
German	9	9.3	–	9.3	–	–	10.8	–	10.8	+ 1.5
German	10	6.8	–	6.8	–	–	7.9	–	7.9	+ 1.1
German	11	7.6	–	7.6	–	–	8.9	–	8.9	+ 1.3
German	12	7.7	–	7.7	–	–	9.0	–	9.0	+ 1.3
German Factory Ship	13	6.6	–	6.6	–	–	7.6	–	7.6	+ 1.0
Peruvian	14	8.6	–	8.6	–	–	9.5	–	9.5	+ 0.9
Angolian	15	4.5	–	4.5	–	–	5.4	–	5.4	+ 0.9
Peruvian + A/O ...	16	9.53	9.59	9.56	8.92	– 0.64	8.81	8.83	8.82	– 0.74
Peruvian + A/O ...	17	9.59	9.33	9.46	8.62	– 0.84	8.94	8.70	8.82	–0.64
Peru	18	6.89	7.07	6.98	6.27	– 0.71	7.68	7.48	7.58	+ 1.31
Peru	19	7.55	7.34	7.44	7.12	– 0.32	7.50	7.56	7.53	+ 0.41
	Avg.					– 0.10				+ 1.16

1. Barlow, S.M. and Bellido A. (1972). See reference 82.

The official EEC method for determination of fat in fish meal consists of acid hydrolysis of the meal followed by diethyl ether extraction. This method is not one which is used by the feedstuffs industry in any country of the world. The argument for the method is that it gives a figure for *total* fat, i.e. including both freely extractable fat and the fraction of fat in fish meal which is in a bound form and can only be released by acid hydrolysis followed by ether extraction. It has been known for many years that varying proportions of the fat in fish meal are bound and can only truly be estimated by a total extraction with a mixture of chloroform and methanol. Since most of the fat in fresh non-oxidised fish meal is soluble in hexane or diethyl ether and since the decrease in the fat extractable by these solvents during oxidation of the meal occurs concomitantly with a decrease in energy value, the extraction by these solvents without prior acidification is probably more meaningful in terms of nutritional value of the meal compared with total fat extraction.

Indeed, Laksevela [1] extracted the fat from oxidized herring meal with petroleum-ether, which was discarded. The extracted meal was re-extracted with chloroform and the oxidized fat thereby obtained was mixed into a practical chick diet at a level of 8%. For comparison a further group of chicks was fed a diet containing 8% herring oil. Feeding was continued for seven weeks. It was concluded that the oxidized fat had no nutritive value.

Members of the IAFMM have compared the EEC method with the diethyl ether method and noted differences which can be seen in Table 3. On the grounds that the EEC method probably does not indicate nutritional value as meaningfully as values obtained by the direct use of either ether or hexane, together with the fact that the procedure is more complex, the adoption of this method is not recommended.

4. NUTRITIONAL PROPERTIES OF FAT IN FISH MEAL

4.1. Fish Fat as a Source of Dietary Energy — Energy Content of Fish Meal

Fish meal contains three major nutrients:

(i) protein
(ii) fat
(iii) minerals (ash)

All the energy in fish meal comes from the protein and fat content. The quantity of fat present in fish meal and its make-up depends on several factors:

(i) the species of fish
(ii) season of catching
(iii) the feeding of the fish
(iv) the method of processing and particularly the use of antioxidants.

Furthermore, the value obtained for total fat content will depend on the method of analysis (see section 3).

4.1.1 The effect of antioxidants on the energy value of fish meal

Meal from oily fish may contain over 10% fat with a relatively high content of unsaturated fatty acids. The rate and degree to which these acids are subject to oxidation during processing and storage depends mostly on the actual content of unsaturated (polyenoic) fatty acids in the fat and the content of antioxidant. During prolonged storage of fish meals in which the fat fraction has a high proportion of unsaturated fatty acids, the fat content, as determined by diethyl ether extraction according to the Soxhlet method, decreases by 1 to 6 per cent units, due to oxidation of these fatty acids. Concomitantly with the reduction of the ethyl ether extractable fat there is an increasing fraction of nitrogen-free extractives which is found to have no energy value [2]. This reduction in energy value of fish meal can be avoided by the use of antioxidants which stabilize the fat fraction.

However, before considering the effect of antioxidants on energy values, the system of expression of energy values must be considered.

The almost universal current practice in poultry nutrition is to use the metabolisable energy (ME) scale for expressing energy values. A comprehensive discussion of this and other energy scales is beyond the scope of the Bulletin, but certain limitations of the ME scale must be pointed out in order to facilitate interpretation of published ME values for fish meal. A full discussion of energy systems can be found elsewhere [3,4].

When the ME value is expressed as determined, i.e. the combustion value of the feed less the combustion value of the excreta, the term ME classical (ME_c) is applied. Hill and Anderson [5] proposed to correct the classical ME values for nitrogen retained in the body in order to place all experimental data on a common zero nitrogen base (nitrogen equilibrium). These corrected ME values have been commonly denoted ME_n or ME_n0. Although it is essential to correct for the nitrogen balance in the actual experiments in order to avoid the results being biased by protein level and amino acid balance in the experimental diets, the use of the ME_n0 in practical feed formulation is open to question. Erikson and Hartfield [6] pointed to the irrelevancy of using ME data based on zero nitrogen retention when from 30 to 40 per cent of the dietary protein is retained in meat or eggs. Accordingly, they proposed to correct ME values to 33.3% (weighted average for protein retention in broilers and layers) retention of the digestible nitrogen. This latter correction is preferred as it approaches practical

conditions. Under no practical feeding is all the protein oxidised to urea or uric acid and excreted, as would be implied by correction of ME values to zero nitrogen retention. However, most published ME values on fish meal are for zero nitrogen retention.

One of the first reports of the effect of antioxidant on the extractable fat material in fish meal was that of March *et al.*[7] who conducted experiments with Canadian herring meal. The effect of adding 700 or 1500 ppm of BHT (butylated hydroxytoluene) or 500 ppm EMQ (1.2–dihydro–6–ethoxy –2, 2, 4 – trimethylquinoline) as antioxidants to the meal to prevent oxidation was tested in two experiments. Since the two antioxidants were applied in separate experiments, they cannot be directly compared. Use of both types of antioxidant, however, resulted in an increase in the ME_{n0} value of 6 to 20 per cent in the different tests in favour of the antioxidant stabilized meals compared with the unstabilized meals after storage for one year. This is shown in Table 4 which contains some results from the experiment. Furthermore, diets containing 10 per cent of the fish meal lipids, extracted by chloroform-methanol from the antioxidant stabilized meal, tended to have higher ME values compared with those diets containing 10 per cent of lipids from the unstabilized meals. Unfortunately, the chemical composition of the various meals at the time of assay is not shown. Seven months after the meals had been assayed for ME values there was a difference in ether extractable lipids of 3 to 4 per cent units in favour of the antioxidant stabilized meal.

TABLE 4:

EFFECT OF ANTIOXIDANT STABILIZATION OF CANADIAN HERRING MEAL ON ME VALUE AND FAT EXTRACTABILITY (March *et al.* 1965[3])

	Unstabilized	B.H.T. 700 ppm	1500 ppm	E.M.Q. 500 ppm
ME_{n0} kcal/kg DM				
Test 1	3179	3377	3366	
Test 2	3187			3711[2]
Ether extractable lipids, % in DM	6.43[1]			10.16[2]

1) Average of 4 samples.
2) Average of 8 samples.
3) See reference 7.

The effect on energy value of anchovy fish meal of adding antioxidants has been studied by De Groote [8]. EMQ was added to an anchovy meal at a level of 400 ppm immediately after production. An untreated sample served as a control. Some of the results from this study are shown in Table 5. Fat in fish meal, extractable by acid hydrolysis and carbon tetrachloride was about 5 percentage units higher in the antioxidant stabilized meal compared with the unstabilized control. The GE (gross energy) of the stabilized meal was slightly higher than that of the unstabilized control while the antioxidant stabilized meal contained 543 kcal or 17% more ME_{n0} per kg of dry matter than that of the unstabilized control meal.

TABLE 5:

EFFECT OF ANTIOXIDANT STABILIZATION OF ANCHOVY FISH MEAL ON ENERGY VALUE AND FAT EXTRACTABILITY (De Groote, 1968)[1]

	Unstabilized	Stabilized
Fat, % of DM[2]	7.92	13.06
GE, kcal/kg DM	5055	5169
ME_{n0}, kcal/kg DM	3214	3757

1. See reference 8
2. For method of determination – see text.

The positive effect of antioxidant stabilization on the ME value of fish meal was also demonstrated in an American study comprising 36 samples of commercial meals made from menhaden in the U.S.A. and from anchovy in Peru[9]. The ME_n0 value of the antioxidant stabilized meal was 3,228 kcal per kg as compared with 2,689 kcal for the unstabilized meal. At the same time the variation between individual meals as expressed by the coefficient of variation decreased from 16.1 to 11.3%. The ME value found for unstabilized meal in this study agreed with the value found by Potter *et al.*[10] in a previous study.

The effect of stabilizing fish meal with antioxidant on ME values for chicks has been tested in several experiments at the Norwegian Herring Oil and Meal Research Institute [11, 12, 13]. In Table 6 some of the experimental results have been summarized. Herring, mackerel and capelin have been used in several experiments where different types and levels of antioxidants were added to the meals immediately after manufacture, while an untreated part of the meal served as a control. All meals were treated similarly during the period of storage of about one year, being held in open paper bags in an uninsulated storage room. The meals represented commercial meals as well as meals produced in a pilot plant. Since no significant differences were found between the different types or levels of antioxidants tested (i.e. 400 — 700 ppm EMQ and 1000 ppm BHT) the values for the various antioxidant treated meals are shown as averages when the test comprised more than one antioxidant treatment of each type of meal in each experiment. The ME values are corrected to zero nitrogen retention.

In the unstabilized meals ether extractable lipids decreased during storage while only minor changes were found in the antioxidant stabilized meal. One year after manufacture unstabilized meals had on an average 1.4 percentage units lower content of ether extractable lipids compared with the stabilized meals, but the variations in the differences between the individual meals varied from 4.5 to 0.3 percentage units. The GE value of the antioxidant stabilized meals tended to be higher than that of the unstabilized meals. The difference between the two sets of samples was on an average 65 kcal per kg dry matter in favour of the stabilized meals. In all meals tested, the antioxidant stabilization increased ME_n0 compared with the unstabilized control. The difference was on average 174 kcal per kg of dry matter or 5.1% higher in favour of the stabilized meal. For the individual meals the difference varied from 0.3% to 9.3%.

Compared with the effect of antioxidant stabilization on the ME values found for Canadian herring meal by March *et al.*[7] and for anchovy meal by De Groote [8], the effect of antioxidant stabilization in

TABLE 6:

EFFECT OF ANTIOXIDANT STABILIZATION OF FISH MEAL ON ETHER EXTRACTABLE FAT AND ENERGY VALUE.

Experiment	Meal No.	Unstabilized				Stabilized			
		Fat (Soxhlet) %	GE kcal/kg	ME_{n0} kcal/kg in DM	corr. % of GE	Fat (Soxhlet) %	GE kcal/kg	ME_{n0} kcal/kg in DM	corr. % of GE
I	15	5.8	5000	2897	57.9	7.8	5082	3050	60.0
II	65	8.8	5320	3386	63.6	13.3	5389	3701	68.7
III	43	6.0	5110	3645	71.3	6.9	5202	3657	70.3
	47	9.2	5494	3746	68.2	10.2	5604	4004	71.4
	51	8.2	5616	3866	68.8	8.9	5595	3966	70.9
	53	4.0	5030	3374	67.1	4.5	5084	3501	68.9
	55	6.7	5213	3580	68.7	7.5	5362	3766	70.2
	57	5.6	5204	3478	66.8	6.7	5276	3654	69.3
	59	5.8	5374	3388	63.0	9.2	5374	3660	68.1
	61	6.0	5252	3301	62.9	6.5	5339	3496	65.5
	63	4.9	5182	3327	64.2	5.7	5274	3587	68.0
IV	28	7.8	5469	4030	73.7	8.1	5476	4082	74.5
Average		6.56	5272	3502	66.4	7.94	5338	3677	68.9

Norwegian experiments was less pronounced. This should be seen in connection with the relatively small decrease in ether extractable fat in the unstabilized meal tested in the Norwegian experiments. Evidently there exists a crude correlation between the reduction in extractable fat in fish meal during storage on one hand and the reduction in energy values on the other. Further, due to its fatty acid composition and content of natural antioxidants, the Norwegian fish meal is less subject to oxidation when stored without antioxidant addition compared to some other type of fish meal.

In Table 7 published ME_{n0} values determined for fish meals are given, along with the average analysis for dry matter, fat (ether extract) and crude protein. As virtually all commercial anchovy and menhaden meals and much of the herring meals are now antioxidant treated, the antioxidant treated samples of these meals in this table are more appropriate for practical use. Differences in ether extractable fat content and energy values between meals treated with and without antioxidant confirm data discussed earlier.

However, in the case of herring type meals the effect of antioxidants on energy value is less marked. Opstvedt compared herring type meal made with and without antioxidant. The energy value of the latter was 5% higher than the untreated meal, 3677 v 3502 kcal/kg DM[88]. In view of the small effect of antioxidants on herring type meal, and the greater effect of other factors such as fat content etc., a single energy value is given for herring type meals (3608 kcal/kg DM) in Table 7, which is considered appropriate for meals with or without antioxidant.

TABLE 7:

MEAN METABOLISABLE ENERGY VALUES OF VARIOUS FISH MEALS

TYPE OF MEAL	ME_{nO} Chick		Number of samples	C.V. + % –	Dry Matter	Ether Extractable Fat %	Proteins %	Ref.
	Kcals/Kg DM	Kcals/Kg as received						
ANCHOVY–PERU	3214	2886	1	–	89.8	7.9	61.5	8
ANCHOVY PERU (A.O. TREATED)	3757	3378	1	–	89.9	13.1	62.4	8
ANCHOVY	2772	2483	1	–	89.6	5.8	64.9	8
HERRING ICELANDIC	3412	3061	1		89.7	9.6	65.6	8
HERRING EAST COAST CANADA (A.O. TREATED)	3466	3233	7	4.7	93.3	8.9	73.6	83
HERRING –WEST COAST CANADA	3193	–	5	3.8	–	–	–	7
HERRING–WEST COAST CANADA (A.O. TREATED)	3623	–	6	5.5	–	–	–	7
HERRING TYPE-NORWEGIAN	3608	3251	40	–	90.1	7.7	71.4	14
MENHADEN (A.O. TREATED)	3370	3100	10	5.6	92.0	9.8	62.6	16

4.1.2 Energy values of fish meal as determined and as estimated by regression equation

Poultry

If a poultry diet is to be formulated to provide adequate energy to meet the bird's requirement for a given level of production, it is essential to have correct information on the energy values of the various feeds and to know the variation round the average figure.

A list of the results of published ME values determined on fish meals are given in Table 7.

In addition to *in vivo* ME determinations, attempts have been made to calculate ME on the basis of proximate analysis (protein and fat) using regression equations.

Ousterhout 1968[78] suggested a regression equation to calculate ME values which was based on the fat and protein content of the sample and also included a factor allowing for differences in protein digestibility.

TABLE 8:
CHEMICAL COMPOSITION AND ENERGY CONTENT OF NORWEGIAN HERRING FISH MEAL (Opstvedt, 1976) (14)

	In Dry Matter (DM)								
		g/100 g				kcal/kg			
Sample No.	DM	Protein	Fat (Soxhlet)[1]	Fat (Total)[2]	Ash	GE[3]	MEc[4]	MEnO[5]	MEn33[6]
15/68	88.7	78.80	5.75	10.60	13.53	5000	3298	2897	3208
16/68	87.1	78.99	7.81	11.14	13.32	5082	3375	3050	3362
65/68	94.6	76.53	8.77	15.33	10.89	5320	3727	3386	3688
66/68	96.0	77.71	13.23	15.52	10.94	5326	3956	3640	3947
67/68	95.9	77.69	13.45	15.43	11.05	5447	4191	3790	4097
68/68	95.7	77.53	13.27	15.36	11.08	5393	4009	3674	3980
43/68	86.7	78.43	6.00	11.02	13.15	5110	3969	3645	3954
47/68	90.4	80.20	9.18	13.55	12.17	5494	4262	3746	4062
51/68	89.5	78.10	8.16	15.49	9.83	5616	4270	3866	4174
53/68	87.9	81.34	3.98	8.26	11.38	5030	3766	3374	3695
55/68	87.6	80.71	6.74	13.54	11.42	5213	3872	3580	3898
57/68	87.4	80.21	5.61	11.95	11.56	5204	3909	3478	3794
59/68	90.0	81.56	5.78	13.69	9.11	5374	3737	3388	3710
61/68	88.8	80.74	5.97	10.93	11.60	5252	3646	3301	3620
63/68	89.1	82.74	4.94	10.63	11.45	5182	3796	3327	3653
44/68	86.0	79.19	6.86	11.02	12.91	5202	4054	3657	3969
56/68	87.5	80.91	7.54	13.54	11.31	5362	4139	3766	4085
54/68	87.1	81.52	4.48	8.26	13.66	5084	3964	3501	3623
58/68	87.6	79.91	6.74	11.95	11.30	5276	4137	3654	3969
62/68	88.7	80.83	6.54	10.93	11.27	5339	3883	3496	3815
64/68	89.2	78.56	5.72	10.63	10.99	5274	3974	3587	3897
48/68	89.5	81.79	10.17	13.55	9.94	5604	4415	4004	4327
60/68	89.4	82.44	9.17	13.69	9.17	5374	4077	3660	3985
46/68	87.9	79.64	8.19	12.88	10.92	5440	4057	3711	4025
52/68	89.2	79.48	8.86	15.49	8.74	5595	4373	3966	4280
45/68	89.2	78.59	7.85	12.88	11.32	5406	3661	3360	3670
3/70	95.3	83.84	8.08	12.91	12.91	5515	4527	4118	4449
5/70	87.1	83.58	8.38	12.63	10.33	5548	4516	4138	4468
28/68	88.0	83.86	7.84	12.16	10.34	5469	4316	4030	4361
29/68	89.1	82.27	8.08	12.12	9.88	5471	4424	4082	4407
78/72	90.7	75.52	10.47	16.98	12.35	5453	4002	3672	3970
81/72	93.8	76.33	10.45	15.88	12.05	5432	4062	3711	4012
84/72	91.6	75.55	10.59	14.19	13.54	5400	3722	3406	3704
88/72	92.4	75.76	9.74	15.15	12.99	5277	3801	3514	3813
91/72	90.6	73.73	12.69	17.33	11.15	5542	4125	3798	4089
10/72	91.2	77.30	8.77	14.47	12.17	5385	3781	3419	3724
55/72	92.7	76.91	10.14	14.78	11.65	5365	3546	3208	3513
59/72	93.0	76.13	11.29	15.05	11.51	5483	3956	3616	3916
69/72	91.8	75.06	13.62	18.19	11.11	5650	4298	3950	4246
71/72	91.6	77.29	10.59	14.63	11.90	5406	3546	3208	3513
Average	90.14	79.18	8.54	13.35	11.45	5360	3978	3609	3922
S[7]	2.77	2.64	2.55	2.30	1.21	164	299	287	290

1. Fat determined by ethyl ether extraction in a Soxhlet apparatus (see text).
2. Fat determined by chloroform/methanol extraction (see text).
3. GE = gross energy = combustion value.
4. MEc = metabolizable energy, classical, as determined without nitrogen correction.
5. MEnO = metabolizable energy, corrected to zero nitrogen retention.
6. MEn33 = metabolizable energy, corrected to 33% retention of digestible nitrogen (see text).
7. S = standard deviation.

In Table 8 the energy values of a series of 40 samples of Norwegian Herring meals are tabulated as nitrogen corrected ME determined in trials with chicks. These are expressed as ME_n0 and ME_n33 values. The energy value of the meals has also been calculated using the regression equation:

ME_n0 kcal/100g DM = 3.95 P + 6.45 F

where P is g of protein and F is g of ether extractable fat per kg of DM.

The average value was as follows:

ME_n0 as estimated using regression equation (kcal/kg of DM) = *3609*

This compares with an average determined value as follows:

ME_n0 as assayed (kcal/kg of DM) = *3678*

The above equation is based on Opstvedt's previously determined ME_n0 values for protein and residual fat in fish meal of 3948 kcal/kg and 6452 kcal/kg respectively [18]. The calculation assumes fish meal protein is 90% digestible and fish meal fat 91.5% digestible [17]. The latter value compares with a fish meal fat digestibility of 93.1% for antioxidant stabilized menhaden meals obtained by Cuppet and Soares [16], and digestibilities of 85% and 90% respectively for fish meal protein and fat given by Hoffman and Schieman [15]. In summary it can be concluded that the residual fat of present day fish meal is highly digestible in the chicken, with apparent digestibilities of about 90%.

The energy values calculated on the individual samples gave a correlation of 0.595 with the determined (assayed) energy values on the 40 samples (see Table 8). More than half of the total variation in the calculated ME_n0 values is unexplained and could be attributed to the variations in the fat and protein digestibility and experimental error. On average, the calculated values were 1.9% higher than the actually determined value, which was not significantly different. The calculated values were, however, a somewhat better prediction of true ME_n0 than using the average figure. A further approach to combining values calculated by regression equation and tabulated values is referred to later (section 4.1.3) and detailed in Appendix II.

Pigs

Whilst most feed formulators use the Total Digestible Nutrients (TDN) energy system (equivalent to GN in Germany) for commercial pig diets, many research workers use metabolisable energy or digestible energy. A comparison of these systems has been made by Morgan *et al.*[19], and these workers favour use of an ME system corrected for positive nitrogen balance. In view of current practice, however, energy values given here are expressed in several ways.

In studies at the Oscar-Kellner Institute the energy value of three samples of fish meal were tested (Table 9). The digestible energy contents of these samples were calculated from the data to be 3594, 3674 and 3894 kcal/kg. In the samples digestibility of fat was high (88.0%, 86.1% and 101.7%).

The energy values of white fish meal and herring fish meal were determined for pigs by Morgan *et al.* [19] using TDN, ME and DE systems. Results, including the fat and protein content of the meals are shown in Table 10. The white-fish meal had a low TDN value, possibly due in part to the unusually low protein content of the sample, though the TDN value appears low relative to the herring meal TDN, and also relative to the ME values on the white-fish meal relative to herring meal. McDonald *et al.* [20] quote a TDN value of 65 for white-fish meal which appears more realistic.

TABLE 9:
DIGESTIBILITY AND ENERGY CONTENT OF FISH MEALS FOR PIGS[1]

	Digestibility (%)		DE	ME
	Protein	Fat	kcal/kg	kcal/kg
FM 1[2]	86.1	88.0	3594	3051
FM 2	86.0	86.1	3674	3178
FM 3	93.5	101.7	3894	3411
M.B.M.[3]	80.9	96.9	3687	3138

1. From Shieman *et al* 1969[(2)] and Hoffmann and Shieman [(15)].
2. FM – Fish Meal
3. MBM – Meat and Bone Meal

4.1.3 Significance in feed formulation

Poultry

A further approach proposed to obtain more accurate ME values on fish meals for formulation purposes is to use determined values, and then correct for the actual protein and fat content of the consignment. For example, if the determined value refers to a herring meal with 7% oil and a consignment received has 10%, the determined value should be increased to allow for the additional 3% fat. A worked example is given in the appendix II, including the regression equation which might be used to correct the determined ME value. Using this regression equation incorporating the determined ME value for herring meals in Table 7 (Opstvedt, 1976) [(14)] to calculate ME_n0 for each of the 40 samples in Table 8, the values obtained were compared with the ME values determined for the individual samples (also in Table 8). A correlation coefficient of 0.71 was found. That is, the ME values calculated in this way accounted for about 50% of the variation in ME values. This compares with only 40% of the variation being accounted for when ME values were calculated from total protein and fat content for these 40 samples [(14)], the correlation of calculated with determined values being 0.595 (see above).

Pigs

In the absence of energy value determinations on fish fat or fish protein for pigs, it is not possible at this time to give factors to adjust fish meal energy values for pigs on the basis of the content of fat and protein, as was done for poultry. However, it would be desirable to carry out such an adjustment, and as soon as data are available, a procedure for carrying out the adjustment will be suggested.

TABLE 10:

ENERGY VALUES, PROTEIN AND FAT CONTENT OF FISH MEALS AND OTHER FEEDSTUFFS FOR PIGS[1,2]

Feedstuff	% Dry Matter	Fat % ether extr.	% Crude Protein	TDN	DE kcal/kg	ME_nO kcal/kg	ME_n30 kcal/kg
White-fish meal	88.7	5.1	61.6	61.0	3539	2794	3078
Herring meal	93.6	7.9	72.3	78.5	4334	3398	3744
Soyabean meal	88.1	1.4	46.8	75.2	3735	3110	3348
Meat and bone meal	91.2	4.3	50.6	34.7	1851	1322	1550
Dried Skimmed milk	91.2	3.5	32.5	84.4	3995	3529	3721
Barley	87.1	1.4	9.8	71.5	3144	2996	3049
Maize	87.5	4.2	9.4	81.0	3518	3360	3404

1. See reference 19.
2. Results expressed on samples as received.

4.2 Fish Fat in Fish Meal as a Source of Essential Fatty Acids

4.2.1 Fatty acid composition of the fat in fish meal

The fatty acid composition of the fat in fish meal depends on a number of factors outlined earlier (see page 6). By far the largest variation is caused by oxidation. This is illustrated in Table 2, which also includes data for the fatty acid composition of the fat in maize meal. Compared with maize meal fat, fat in fish meal has a much more complex fatty acid composition. Linoleic acid (C 18: 2ω6) which makes up more than half of the fatty acids in maize meal, is present at only low levels in fish fat. The majority of polyenoic fatty acids in fish meal belong to the linolenic acid (ω3) family. Table 11 clearly demonstrates the drastic effect of oxidation on the fatty acid composition of fish meal fat. Polyenoic fatty acids are almost eliminated in the oxidised meal.

4.2.2 The nutritional significance of fish fatty acids

There is now clear evidence that the fatty acids in fish fat can meet part of the requirement of poultry for essential fatty acids (EFA's). Animals are not able to interconvert fatty acids of the linoleic and linolenic families (the latter being found in fish fat), but there is evidence that acids of the linolenic family can substitute for the linoleic acid family to some degree in meeting requirements for essential fatty acids.

Houtsmuller [21] found that in rats, comparing the effectiveness of ω 3* and ω6 in preventing typical effects of essential fatty acid deficiency, namely body weight change, skin permeability and swelling of liver mitochondria, the former (ω 3) were less active than the latter (ω 6).

The findings of Neudoerffer and Lea [22] would indicate that the higher homologues of the linolenic acid family found in fish meal are interchangeable with fatty acids of the linoleic family as part of the lipoproteins in structural membranes. This is further substantiated by the work of Brockerhoff *et al.* [23]

TABLE 11:

FATTY ACID COMPOSITION (W%) OF RESIDUAL FAT IN DIFFERENT FISH MEALS AND IN VARIOUS OILS

Fatty Acid[2]	Anchovy Meal[1]		Anchovy [3]		Herring[1] Meal				Safflower oil[4]
	Unoxidized		Oil		Unoxidized		Oxidized		
14:0	7.4		8.7		7.0		9.4		0.2
16:0	22.8		16.5		15.4		20.5		12.3
18:0	4.2		2.8		2.4		3.4		1.8
16:1	7.2		9.8		5.1		6.2		–
18:1	13.1		8.4		12.7		14.6		11.2
20:1	1.3		8.3		11.5		14.5		–
22:1	0.7		5.7		17.4		22.8		–
18:2 ω 6 (linoleic)	1.0		1.1		1.6		1.0		74.3
18:3 ω 3 (linolenic)	0.4		0.4		1.1		0.3		0.2
18:4 ω 3	2.4		1.7		2.3		tr.		–
20:5 ω 3	16.3	35.3	14.5	28.2	6.0	23.1	0.2	2.3	–
22:5 ω 3	1.7		1.6		0.6		tr.		–
22:6 ω 3	13.5		8.9		11.5		0.8		–

1. From Opstvedt, J., 1974. See reference 85.
2. Carbon number: number of double bonds.

ω denote the site of the first double bond counted from the methyl end of the carbon chain

tr = traces

3. Ackman R.G. 1977 Personal Communication
4. Scott M.L. *et al*. See reference 86.

who showed that the long chain polyenoic marine fatty acids and arachidonic and linoleic acid were esterified in the same positions on the phospholipid molecule. Further, Mohrhaver and Holman [24] showed that fatty acids of the linoleic and linolenic fatty acids families compete for the same metabolic enzymes. Edwards and Marion [25] found that the increase in an eicosatrienoic acid (C20:3 ω9), which occurs during essential fatty acid deficiency, could be prevented by the feeding of ω 3 as well as ω 6 fatty acids. Crawford and Sinclair [26] postulated that the higher homologues of the ω 3 acids might be associated with special functions of the brain.

In the past there has been a tendency to fix the requirement for fatty acids in order to prevent dermal disorders, swelling of liver mitochondria etc., placing too little emphasis on the requirement for optimal growth. It is in meeting fatty acid requirements for growth that the fatty acids in fish fat can be particularly beneficial. This is summed up by Stansby [27] as follows:

> "Early research on essential fatty acids (EFA) overemphasized the curing of dermal symptoms even though recognizing that fatty acids of what are today described as of both the linoleic and of the linolenic acid families support growth. Knowledge of effects such as that on permeable membranes and cholesterol transport were completely lacking when EFA activity was first investigated. Since curing of dermal symptoms provided a specific assay procedure, the term EFA became linked more specifi-

*ω indicates the position of the first double bond counting from the terminal methyl group of the fatty acid.

cally to that aspect than to other effects of perhaps greater significance. Thus fatty acids of the linoleic acid family are now the only ones generally classified as having true EFA properties. If other effects, e.g. cholesterol depressant properties, had been discovered before dermal symptom curing properties, it is likely that we might today have a somewhat different concept of what constitutes an EFA. Certainly from a practical nutritional standpoint, support of growth and even probably cholesterol depressant effects have greater practical importance than do the curing of dermal symptoms. These facts are often overlooked and it is not uncommon to find statements expressing surprise that fish oils, low in classified EFA content, are useful in stimulating growth or in depressing serum cholesterol levels."

When considering EFA requirements of chicks for growth, it was found that chickens fed a diet virtually free from fatty acids responded in terms of growth as effectively when receiving supplements of acids of the linolenic acid family as with the linoleic acid family [28,29]. Menge [28] measured chick growth when feeding linoleic acid from safflower oil and coconut oil, and menhaden oil. Significant growth response was obtained when feeding 1.65% to 3.3% linoleic acid supplied by the safflower oil (2.07% or 4.19% by weight). Menhaden oil (2.58% or 4.19% by weight) containing relatively low amounts of linoleic acid but high amounts of polyunsaturated acids, particularly those of the linolenic acid series, promoted chick growth as effectively as safflower oil.

The growth of four-week old chickens on a virtually fatty acid free diet supplemented with either maize oil or herring oil was compared by Engster *et al.*[29]. Growth response for the two types of oil were similar, for a given weight of oil, indicating that the fish oil was as effective as the vegetable oil in meeting fatty acid requirements. In view of the fatty acid composition of these oils, this suggests, as with the work of Menge, that the polyunsaturated fatty acids in fish oil can effectively replace the linoleic acid family in meeting the chick's fatty acid requirement for growth. Indeed, the polyunsaturated fatty acids in stabilized fish oils (e.g. herring oil 22%) is lower than the linoleic acid content of maize oil (52%; see Table 12), suggesting that on a weight for weight basis the former are more effective.

Menge and his colleagues [31, 32] reported that chick pullets fed a linoleic acid deficient diet from hatching until 20 weeks of age had no detectable EFA in the muscle fat. These chemical changes were accompanied by poor egg production, low fertility and hatchability and increased susceptibility to lung infection. Adding linoleic acid to the diet alleviated all these symptoms. Although fertility was normal with an intake of 20mg. linoleic acid per day, the percentage of hatchability increased steadily as linoleic acid was increased up to 250mg. per day. Thus hatchability was the most sensitive index of EFA depletion in the chick. Later the same authors [33] observed that the polyunsaturated fatty acids of menhaden oil had stimulating effects on the reproduction of the hen that could not be attributed to linoleic acid alone in the fish oil.

In practice some herring type meals are not treated with antioxidant but allowed to "cure". This involves a controlled oxidation of unsaturated fatty acids. Consequently the residual fat in these meals would make a much smaller contribution towards EFA requirements than the herring oil used by Engster *et al.*[29]. Menhaden and anchovy type meals on the other hand are treated with antioxidant, and, therefore, the results of Menge with commercial menhaden oil would apply to the residual fat in menhaden fish meal. As this fat is similar to fat in anchovy meal in terms of content of polyunsaturated fatty acids both menhaden and anchovy fish meals can be regarded as having a fat equivalent to safflower oil in terms of meeting requirements for essential fatty acids for growth.

The possibility that acids of the linolenic family may have a sparing effect on the bird's linoleic acid requirement for egg production does not appear to have been investigated recently. However some years ago Edson [34] found that by adding fish oil to the diet of laying birds, the efficiency of egg production improved.

There does not appear to be information available for pigs concerning the extent the polyunsaturated fatty acids in fish meal will meet requirements for essential fatty acids. However, on the basis of existing information, it appears that conventional pig diets supply adequate amounts of essential fatty acids; there is no evidence of deficiencies occurring in commercial diets.

The salmonoid family of fish, e.g. trout, salmon, differ from warm blooded animals in that they have a requirement for fatty acids of the linolenic family which cannot be met by linoleic acid. Fish meal is a valuable source of these acids in the feeding of salmon and trout.

4.2.3 Significance in feed formulation

Fats and oils, either added to a feed as such or as a component of a feedstuff, e.g. maize oil in maize, are an important source of essential fatty acids. Many formulators now formulate finished feeds to a minimum linoleic acid content, each feed ingredient having been analysed (or tabulated values used) for linoleic acid content. The linoleic acid contents of typical feedstuffs are given in Table 12. The linoleic acid content of fish fat is low, but because the polyunsaturated fatty acids which predominate in stabilized fish fat can meet all of the growing bird's requirements for linoleic acid, using the linoleic acid content of fish fat is not the correct way of establishing its effectiveness in meeting a requirement for essential fatty acids.

TABLE 12:
THE LINOLEIC ACID CONTENT OF FEEDSTUFFS[1]

Feedstuffs	Linoleic Acid % (approximate)	Linoleic Acid Equivalent %
Maize	1.9	
Barley	0.8	
Wheat	0.6	
Milo	–	
Wheat Middlings	1.9	
Soyabean meal	0.4	
Corn gluten meal	1.2	
Meat and bone meal	0.3	
Maize, soyabean and peanut oils	52	
Stabilized poultry offal fat	22	
Stabilized animal tallow	2.5	
Fish oil	2.6	
Fish oil[2]		50.0[3]
Stabilized anchovy meal (12% fat)		6.0[3]
Stabilized menhaden meal (10% fat)		5.0[3]

1. from Scott, M.L. *et al.*(1971) See reference 86.
2. see text – based on results from Menge, H. (28)
3. Calculated as the 'equivalent essential fatty acid content' as assayed by chick growth response.

In general a stabilized fish fat appears to be at least as effective as corn oil and safflower oil on a weight for weight basis in meeting the bird's requirement for essential fatty acids. It is recommended that the fat fraction of antioxidant treated fish meals is taken as having an "equivalent essential fatty acid content" of 50% of the fat. As safflower oil contains 74% linoleic acid, a figure of 50% equivalent essential fatty acid content for stabilized fish fat gives a margin of safety.

The "equivalent essential fatty acid content" of stabilized fish meals can be calculated on the basis of the fish fat they contain. For example, a stabilized anchovy meal with 12% fat would give a value of 6% equivalent essential fatty acid content. (Table 12).

4.3 Peroxides

The concentration of peroxides in fat is measured in terms of millimoles (or alternatively as milliequivalents) of active oxygen per kilogram of oil. The latter gives twice the number of the former. All the figures quoted below are expressed in millimoles per kilogram of fat.

Figure 1 shows how peroxides (more correctly called hydroperoxides) form and breakdown during storage of fish meal. The peroxides, which are the first detectable oxidation products of the fatty acids, reach a peak value and then decrease, because their rate of breakdown is accelerated as the peroxide level increases whereas their rate of formation decreases as the more reactive fatty acids become oxidised. The peroxides reach a peak much more rapidly at room temperature than under cool or cold conditions, but eventually much higher peak values are reached at lower temperatures. This is explained by the slower rate of breakdown of peroxides rather than an increased rate of formation. The peak value may thus be reached in a few days or months, depending on many factors, including the reactivity of the fat, the antioxidants or pro-oxidants present in the fish meal and the temperature of storage.

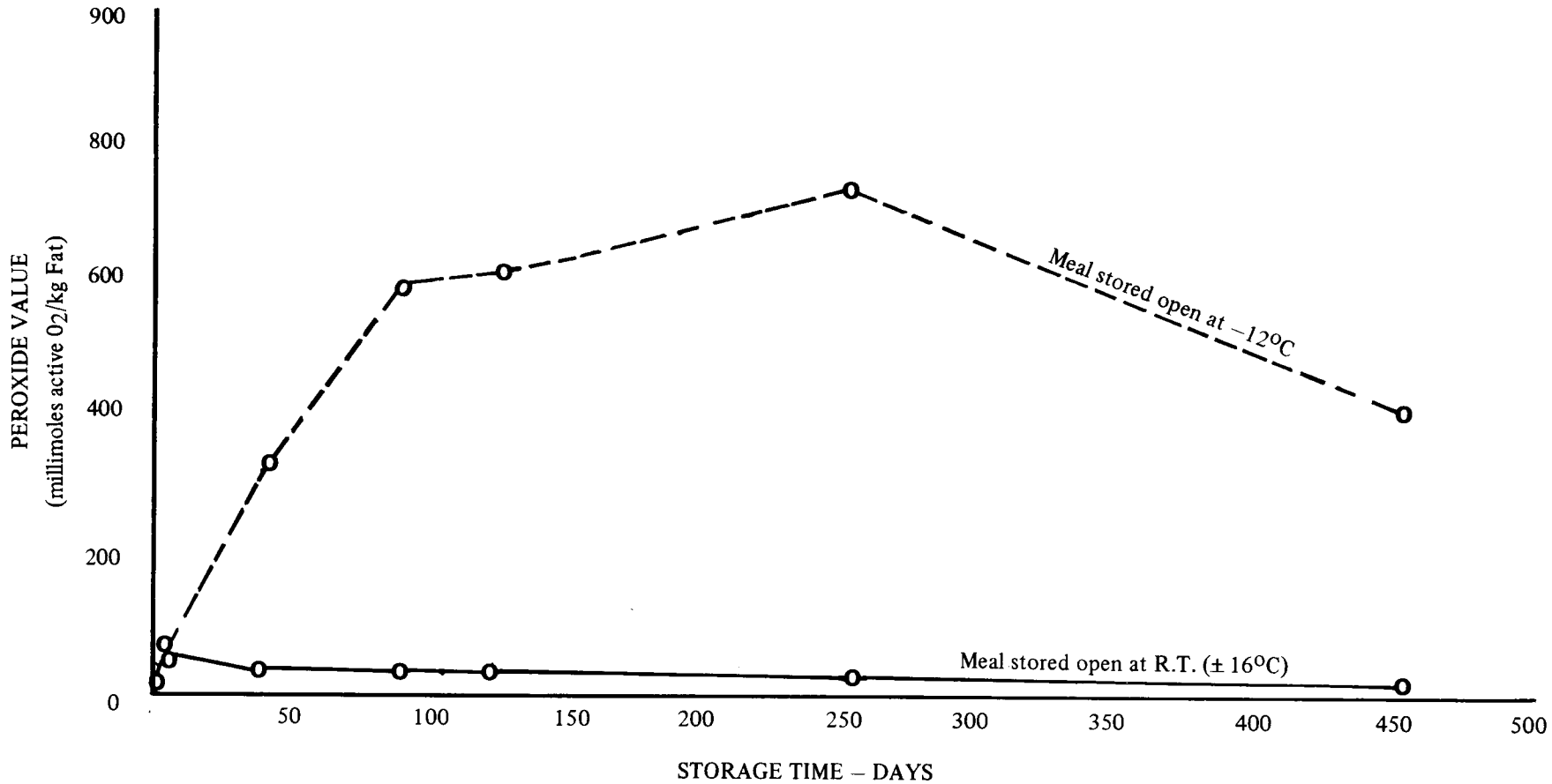
The formation of hydroperoxides is greatly reduced by the addition of antioxidants. With untreated anchovy and pilchard meals the maximum peroxide value (P.V.) is reached after about one week. These values are of the order of 100 to 125, whereas fish meals that have been treated with antioxidant have values at that stage of about 14 to 15 for anchovy meal, and 4 to 6 for pilchard meal. Thereafter, the peroxide values of the untreated meals decrease, whilst those for the treated meals increase. The maximum for anchovy meal in the latter case is of the order of 30 to 35 after about four weeks, and that for pilchard meal is 12 to 13 after about two and a half months [55].

Thus, it cannot be said that low peroxide values indicate a fresh meal, and high peroxide values an older meal. Indeed, the opposite could be the case.

Turning now to the problem of peroxide toxicity and possible adverse effects of oxidised fats in feed, some feed analysts set maximum peroxide values above which the feed is described as "unfit for feeding". Various maxima have come to the notice of the authors, ranging from 2.5 to 10 millimoles per kilogram of oil extracted from the feedingstuff. From the above discussion, fish meals are seen to have much higher values on occasions and one might wonder about their suitability for animal feed, if these limits are realistic.

Gray & Robinson [35] fed a series of meat meals to chicks, but concluded that although a P.V. of 10 corresponded to "rancidity", no adverse effect was observed in the bird's performance. L'Estrange *et al.* [36] oxidised in the laboratory a carefully prepared beef tallow of zero peroxide value to a P.V. of 109. Half of the oxidised material was then heated at 200°C under CO_2 to bring the peroxide level down to 2. (This was done to imitate what could be done industrially to treat an already oxidised tallow so that it would have an acceptable low level of peroxide). Each fat, supplemented with 0.02% BHT was included at a level of 5% in a practical type broiler diet. Three days after the diets had been prepared, they were fed to chicks from day old to eight weeks of age. Again, the birds receiving the oxidised (high-peroxide) fat consumed the ration and grew as well as the others.

FIG. 1 PEROXIDE DEVELOPMENT IN FISH MEAL ON STORAGE



However, tallow is a relatively saturated and stable fat. This work was, therefore, continued with more reactive anchovy oil fed to young turkeys, considered to be the most sensitive of all classes of farm stock by U.K. compounders, and a higher level of fish oil was deliberately used than was thought would ever be encountered in practice. Three anchovy oil feed treatments were prepared as follows: Anchovy oil was mixed with a low-fat fish meal in the ratio of 15 to 100. The oil/fish meal mixture stored at 15°C for three months developed a P.V. of 110. Part of this mixture was then incorporated into a practical turkey diet at a level of 11.5% (i.e. contributing 1.5% anchovy oil to the diet) and the whole diet was stored for a further three months at 15°C (treatment 2 — table 13); the peroxide value of the diet fell slowly over this period by nearly one half. The remainder of the oil/fish meal mix was stored at low temperatures to preserve the hydroperoxides and portions were taken daily for preparation of fresh diet during the feeding trial (treatment 3). Since there might be disagreement as to whether oxidised or unoxidised fish oil would be the more desirable when stored in a mixed diet, a further diet was prepared. Freshly prepared anchovy oil/fish meal mix was added to the turkey starter diet and stored for three months at 15°C before the feeding trial began (treatment 1). In this case, the peroxide value of the total lipid (6.85%) of the diet only rose to 10. Assuming that all the peroxide production was due to oxidation of the anchovy oil, this would correspond to a P.V. of 45. Finally, a control treatment contained fresh tallow in place of anchovy oil.

The experimental treatments were continued from hatching to six weeks of age. There were no losses among the birds (21 per treatment). The results are summarized in Table 13. Although there was a tendency for performance to be slightly better in the control group, none of the differences was statistically significant. All the birds looked healthy throughout; the serum enzyme and aspartate amino transferase levels were in the normal range for all treatments, and inspection of their carcasses at slaughter failed to show any abnormalities.

Table 14 summarizes the effects reported by various authors on growth of chicks, pigs and rats of adding oxidised fat to the complete diet of young animals receiving adequate vitamins including vitamin E. It would appear that the results are consistent with one another, and that no experiment has shown any significant growth depression or other adverse effect from the inclusion or presence of five millimoles peroxide or less per kilogram of balanced diet. Moreover, it is the conclusion of Carpenter [37] that it is almost impossible to construct a practical pig and poultry ration from ordinary ingredients that will contain such high levels of peroxide.

If, for the sake of argument, it is assumed that fish meal contains 100 millimoles peroxide per kilogram of fat, and that fish meal is included in a poultry diet at a level of 10%, the fish meal will only contribute about 1 millimole of peroxide per kilogram of diet. The further addition of 5% high peroxide tallow will rarely cause the level of peroxides to exceed 5 millimoles peroxide per kilogram of diet.

Thus it is concluded that the range of peroxide values generally found in commercial fish meals will not cause any adverse effect on mortality, growth or feed conversation of poultry and pigs.

4.4 Free Fatty Acids

The free fatty acid (FFA) content of fish meal depends on a number of factors. Storage of the fish prior to processing can lead to increasing levels of FFA due to the action of hydrolytic enzymes, released from the fish gut during the breakdown of the tissue, digesting the fatty components. Cooking will probably also cause the formation of some FFA spontaneous hydrolysis. During the storage of the meal or the mixed feed, the glycerides will gradually release free fatty acids due to a complex interaction of oxidation.

TABLE 13:
PERFORMANCE OF TURKEY POULTS RECEIVING ANCHOVY OIL ALLOWED TO OXIDISE UNDER DIFFERENT CONDITIONS*

	Treatment			
	1	2	3	4
Type of fat used	Anchovy	Anchovy	Anchovy	Tallow
Estimated PV of anchovy oil (in m moles/kg)	45	55	110	-
Conditions of oxidation	3 months in whole diet	3 months in fish meal, followed by 3 months in diet	3 months in fish meal, then diet mixed daily	
Results of feeding trial – Liveweight gain gain/poult (kg)	0.87	0.84	0.84	0.89
Feed conversion efficiency	0.51	0.50	0.49	0.51
Aspartate amino-transferase in the serum (I.U.)	180	170	170	145

* See reference 87.

Analysts used to report that the ether extract fraction of diets had deteriorated so as to be "unfit for feeding" when its titratable acidity had reached a certain level, i.e. when it corresponded to a certain percentage of FFA. However, it came to be demonstrated that even grossly hydrolysed fat could be nutritious and harmless — which one would expect in view of the fat hydrolysing enzymes in the animal gut releasing free fatty acids from glycerides in the course of normal metabolism. In particular, Laksesvela [38] fed day-old chicks a diet containing 15% herring meal. Two herring meals with different levels of free fatty acids were investigated, together with a herring meal freed of fat by extraction. Even up to 40% FFA in the meal-fat did not result in any differences in liveweight gain, feed efficiency and mortality over a six-week feeding period. Similar results were obtained with pigs, feeding herring meal with up to 25% FFA in the fat. Furthermore, twelve commercial herring meals with FFA values ranging from 0 (extracted sample) to 47.8 were fed as a sole source of protein at a level of 10% to chicks. The net protein retention was calculated and these data are plotted against the FFA values in Figure 2. It can be seen that the FFA figures gave no indication of the quality of the meal which remained constant in spite of increases in FFA.

TABLE 14:

REPORTED EFFECTS ON GROWTH OF ADDING OXIDIZED FAT TO THE COMPLETE DIETS OF YOUNG ANIMALS RECEIVING ADEQUATE VITAMINS (INCLUDING VITAMIN B12)

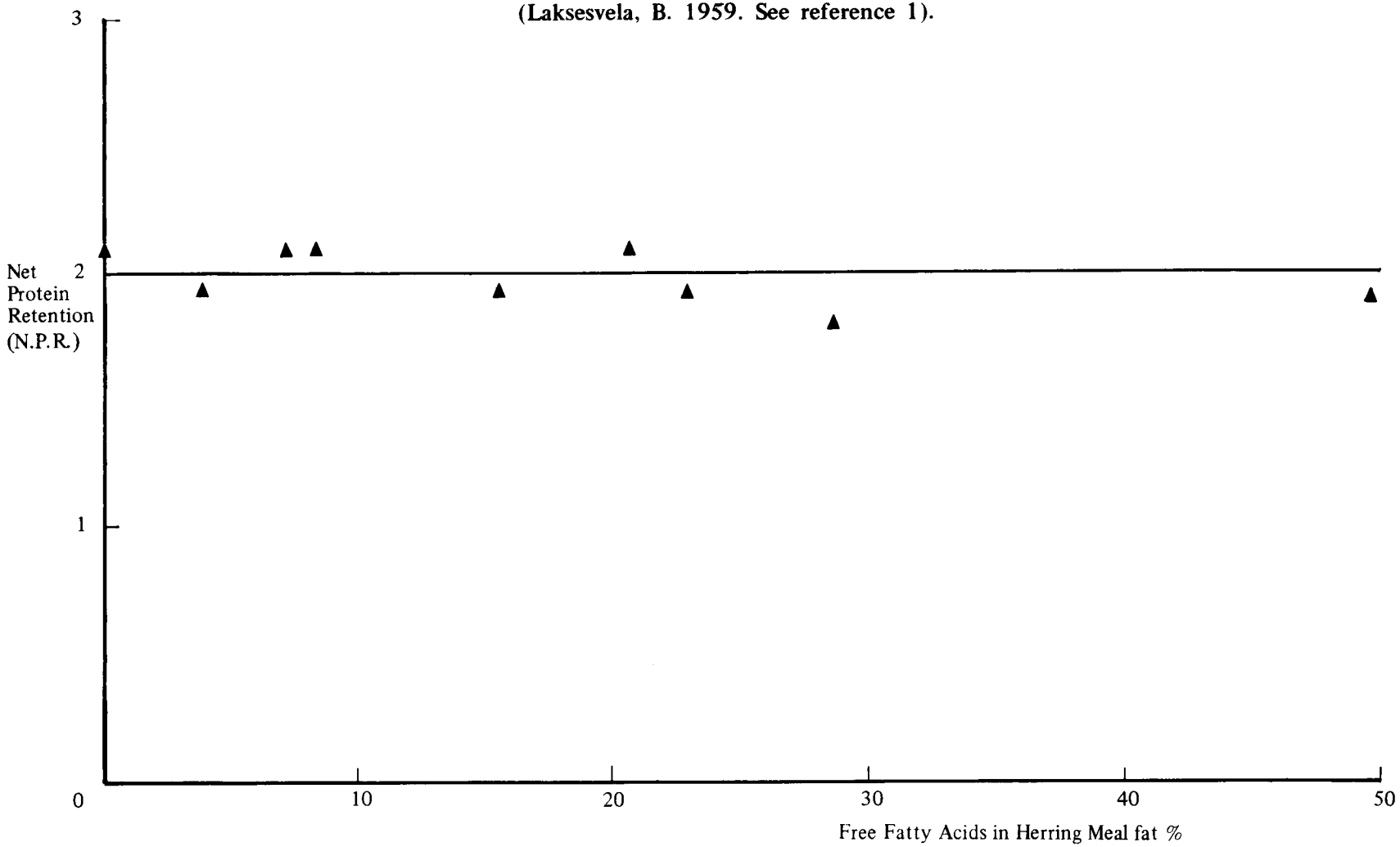
References[4]	Oxidised fat in diet	Peroxide in diet (m moles/kg diet)	Growth depression as compared with controls[1]
Chicks:			
Gray & Robinson (1941)	1.3% from meal of peroxide value 50	0.64	None
	1.5% lard of peroxide value 50	0.75	None
March *et al.* (1962)	10% oil extracted from herring meal	–2	None
Dangonmau *et al.* (1962)	8% from tallow of peroxide value 6	0.5 (then rising to 7)	None
Carpenter *et al.* (1963)	3.1% herring oil of peroxide value 142	4.3	None
L'Estrange *et al.* (1967)	5% tallow of peroxide value 71 (declining with storage of diet)	3.6 (then declining)	None
Pigs:			
Oldfield *et al.* (1963)	10% menhaden oil of peroxide value 61	6.1	None[3]
L'Estrange *et al.* (1967)	1.7% from meal of peroxide value 105 (declining with storage of diet)	1.8 (then declining)	None[3]
Rats:			
Graenberg and Frazer (1953)	10% soya oil of peroxide value 540	54	22%
Kaunitz *et al.* (1952)	10% lard of peroxide value 200 – 300	20 – 30	very slight
Andrews *et al.* (1960)	1.7 – 20% soya oil of peroxide value 600	10	None
		40	30%
		80	Complete
		120	Rats killed
Kreier *et al.* (1961)	20% tallow of peroxide value 258	52	18%
Lea *et al.* (1961)	5% tallow of peroxide value 93 (falling in mixed diet)	4.6 (falling with storage)	None

1. All experiments were for 6 – 12 weeks.
2. The peroxide value of the oils was not reported, but the oils were extracted from herring meals after 2 – 10 months of storage in air.
3. In these experiments the growth of an oxidized-fat diet including supplementary tocopherol acetate has been compared with that on the only "control" diet, i.e. with the same fat in fresh condition, which contained no such supplement.
4. For details of references, see original (Carpenter, 1968) (37).

FIGURE 2

CORRELATION BETWEEN F.F.A. AND NUTRITIVE VALUE OF HERRING MEALS

(Laksesvela, B. 1959. See reference 1).



N.P.R. = G.wt. gain of chicks fed herring meal as sole protein source plus g.wt. loss with protein free control diet divided by g. protein eaten.

5. FLAVOUR COMPOUNDS DERIVED FROM FISH MEAL FAT

5.1 Effect of Composition and Quantity of Dietary Fish Fat on Flavour of Pig and Poultry Products

It is now generally acknowledged that the "fishy" flavours in pig and poultry meat caused by feeding excessive amounts of fish meal are due to the fat in the meal. It is, therefore, of interest to review some of the published evidence which has led to this assumption.

In 1945, Vestal *et al.*[39] noted that pig rations containing 2.5% and 10% menhaden fish meal produced pork without a fishy flavour. However, addition of 0.5% or 1.5% of fish oil to the latter ration resulted in fishy flavour, which was more pronounced in the fat than in the lean tissue of the meat. Kifer *et al.*[40] noted that meat from pigs fed diets containing about 1% of menhaden oil had a fishy flavour. Fish oils fed to broilers have produced "fishy" and "off" flavours [41,42,43,44,45,46]. On the other hand, fat extracted fish meal fed to broilers at levels up to 30% resulted in better carcass quality than birds receiving similar levels of antioxidant and non-antioxidant treated meals [47]. Experiments were performed in South Africa in which the fat in the meal was replaced by stearic acid, hydrogenated fish oil, or more saturated vegetable and animal fats. The flavour of the chicken carcass improved with this procedure compared with direct feeding of 20% anti-oxidant treated fish meal [48].

There is a substantial body of evidence indicating that the fatty acid composition of the diet is reflected in the fatty acid composition of the tissue in pigs and poultry reared on it [40,42,43,44,49,50,51,52,53,54]. Recent work has indicated a correlation between the degree of off-flavour or fishy flavour in carcass meat and the tissue content of polyunsaturated fatty acids.

In the U.S.A., Miller *et al.*[42] fed three different menhaden oil preparations at a level of 5% together with a glucose and soyabean diet to broilers. Two control rations were fed: one containing corn oil and the other tallow. There was a positive correlation ($p<0.05$) between the organolepic score and quantity of four fatty acids in the muscle fat. The fatty acids were C18:4, 20:4, 20:5 and 22:5. No correlation was found between 22:6 and the organoleptic score. Later, the same group confirmed these results using levels of 1.5% and 2.5% herring, menhaden and sunflower oils in a corn/soyabean diet. However, on this occasion, a significant correlation with the organoleptic score was noted for C22:6 [43].

In Norway, Opstvedt *et al.*[49] observed a strong correlation ($p<0.01$) between the content of specific fatty acids (C 22:6, 22:5, 20:5, and 22:1, 20:1, 18:1) in broiler carcass and the number of remarks on "fishy" flavour made by a taste panel. The diets consisted of various levels of stabilized and unstabilized mackerel meals fed at up to 26.5%. The correlation between poly-unsaturated fatty acids and the degree of off-flavour confirms the U.S. work.

Dreosti of South Africa [55] also reported a correlation between the content of C 22:5 and 22:6 in chick flesh and the organoleptic score.

Furthermore, two reports [50,53] have been published showing a direct correlation between the quantity of poly-unsaturated fatty acids *eaten* by poultry to slaughter weight, and the decrease in flavour score of the meat. Removal of the fatty acids from the diet for a few weeks before slaughter resulted in increased flavour score.

Wessels *et al.*[56,57] of South Africa have confirmed the high correlation between flavour score and the level of certain highly unsaturated fatty acids in the chicken carcass. However, it was noted that although the phospholipids and triglycerides extracted from fish meal contained similar levels of the highly unsaturated fatty acids, the triglyceride fraction of fish fat (at a level of 2.0%) in the diet invariably produced carcasses with a "fishy" taint, whereas the phospholipid fraction had no effect on carcass flavour when fed at the same level. The reason for this is not known, and further investigation is desirable.

From the above evidence it would seem that the polyunsaturated fatty acids in fish meal play a decisive role in the production of tainted meat. Consequently, stabilization of the fat in the meal by antioxidants which maintains the high level of polyunsaturated fatty acids, increases the risk of taint when the meal is fed at high levels of incorporation, compared with unstabilized meal. It would be valuable to know if the polyunsaturated fatty acids *per se* impart the undesirable flavour to the meat, or rather the oxidation products of the highly reactive fatty acids, or an unknown factor which in some way correlates with the quantity of polyunsaturated fatty acids in the diet or animal flesh. Such aspects are discussed in the following section.

5.2 Tainted Pig and Poultry Products — Possible Causes

Dreosti and Atkinson [58] added pilchard oil to minced chicken (before and after steam cooking) and presented the samples to a taste panel. Although the treatment produced a strong taint, it was not described as fishy. Thus, it would seem that polyunsaturated fatty acids in the oil are not responsible for the fishy taint. Trimethylamine hydrochloride, however, added to the meat gave a typical fishy taint, but feeding trimethylamine to broilers does not appear to produce a fishy tainted carcass [59] or had little effect [57].

Oxidation products of polyunsaturated fatty acids could produce the fishy taint, and, there is a certain amount of circumstantial evidence indicating that this is a likely mechanism. Various workers have noted that feeding high levels of Vitamin E and other antioxidants together with fish meal or oil to pigs and poultry, result in improvement of flavour score [49,60,61,62,63,64,65]. These antioxidants could prevent the oxidation of the polyunsaturated fatty acids in the carcass flesh and, thus, the formation of oxidation products responsible for the off-flavour. It should be noted that ethoxyquin used for stabilizing fish meal is either poorly absorbed by the animal gut or not biologically active and therefore would not afford protection against oxidation of polyunsaturated fatty acids in the flesh.

Meijboom and Stroink [66] have reported the isolation of an oxidation product from fish oil which has a "fishy" flavour; it is the aldehyde, 2-trans, 4-cis, 7-cis-decatrienal. Scientists at the Food Research Institute in Norwich, U.K. have isolated 4-cis-heptenal from oxidised fish oil which is claimed to have a fishy odour [67]. This compound has also been associated with the "cold storage flavour" of white fish [79]. These reports indicate that oxidation products of fatty acids in fish oil are probably responsible, in part at least, for fish flavours.

However, there are still a number of important questions which remain unanswered. Do the aldehydes mentioned above occur in fishy tainted carcasses? Are the polyunsaturated fatty acids precursors to tainting substances? Does the rest of the diet contain factors which might retart or accelerate the production of fishy tainting substances from their precursors? What role do animal genetics play in producing tainted flesh? There is a further question of considerable importance. Do national tastes differ, such that a panel in one country might describe the flesh as "fishy" whereas in another country the meat would be regarded as "acceptable"?

Some of these questions have been raised during trials conducted at the Food Research Institute in U.K. in co-operation with the IAFMM.

The purpose of this work was to isolate and identify the "fishy" compounds from broiler meat produced by feeding very high levels of stabilized, high-fat fish meal. In order to do this effectively, it was desirable to produce excessively tainted meat and, therefore, 15% and 20% fish meal was fed to slaughter weight of broilers in six experiments (Table 15). These diets were designed to include well in excess of 1% stabilized fish fat which is regarded as a maximum in practical broiler feeding. Taste evaluations were done by the Food Research Institute taste panel and on occasions by a commercial panel [67].

TABLE 15:
DIETS FED TO BROILERS AT THE FOOD RESEARCH INSTITUTE, U.K.

INGREDIENTS	DIETS		
	1, 2, 3	4	5, 6
FISH MEAL	15.0	15.0	20.0
SOYABEAN MEAL	11.0	20.0	–
WHEAT	60.75		59.3
MAIZE	7.25	63.0	20.0
MILO	5.0	–	–
LIMESTONE	0.325	1.0	0.7
DICALCIUM PHOSPHATE	0.3625	0.5	–
MINERAL/VITAMIN etc.	0.3125[a]	0.5[b]	0.088[c]

(a) MO - 78mg: I - 1.0 mg. Zn – 64 mg: Vit A – 8920 i.u.: Vit D_3 – 990 i.u.:
Menadione Na bisulphite – 1.2 mg: d – tocopherol acetate – 6.56 mg:
Riboflavin – 8.92 mg 1 Pantothenic acid – 12.7 mg: Folic acid – 0.595 mg:
Payzone – 450 mg: Pancoxin – 558 mg: Nicotinic acid – 19.8 mg: Zinc bacitracin – 10 mg.

(b) Commercial mix.

(c) Rovimix A – 50 (50,000 i.u./g) – 15*: Rovimix D_3 (100,000 i.u./g) 1.5*:
Rovimix E (100 mg DL – toc acetate/g) – 8.0*: Vit. K – 0.2* Vit B_1 – 0.2*:
Vit B_{12} – 3.1* Riboflavin – 0.5*: Ca Pantothenate – 1.7: Folic Acid - 0.1*:
Nicotinic acid – 2.5*: Choline Cl – 4.8*: Ki – 0.5*: Fe So_4 $7H_2O$ – 44.0*:
ZnO – 7.0*: $CuSO_4 5H_2O$ – 2.0*.

*g/100 kg diet.

In experiments using 15% white-fish meal (unstabilized) and 15% herring meal (unstabilized) no significant differences were noted from the control birds which is not unexpected and confirms the comparatively high levels of unstabilized meals which can be fed to slaughter without risk to the flavour of the meat. In further experiments, 15% stabilized anchovy meal in the diet produced some remarks from the trained taste panel of "fishy" or "oily" in the leg meat of the birds, but no obvious differences in the breast meat were noted. The general conclusions of the panel were that the overall flavour was probably acceptable. In the final experiments the level of stabilized anchovy meal in the diet was increased to 20% (fed through to slaughter). The taste panel noted occasional "fishy" characteristics in both breast and leg meat. Samples of the meat were sent to two large retail organisations with a reputation for quality, requesting flavour evaluation. Both the organisations regarded the meat as acceptable for the retail market. Thus, although the level of stabilized fish fat in the diet exceeded the practical maximum by more than 100%, the carcass quality was still regarded as acceptable for the retail market in U.K.

Why was this? Is the breed of bird critical for producing obviously fishy carcasses? Are components other than fish fat in the diet important for producing the flavour (the vitamin levels were examined and considered to be normal, and only excessive levels of vitamin E and choline have been known to improve the flavour)? Do consumer tastes differ from country to country, causing one group of people to be sensitive to a slight suggestion of a "fishy" taint, and other groups to be insensitive?

These questions illustrate the complexities of working in the field of flavour research. Until these questions are resolved, it is difficult to proceed with experimental work on flavour components.

5.3 Recommended Maximum Levels of Fish Fat in Pig and Poultry Diets

Until 1969 most compounders producing BROILER rations regarded 1.5% of fish fat in a finisher ration as the maximum, beyond which there was a risk of producing fishy tainted meat. With the advent of antioxidant treated fish meal, a revised figure of 0.8% fat was recommended by the IAFMM when feeding stabilized meal. This figure provides a good margin of safety and in practice many feed manufacturers have adopted a maximum of 1% fish fat in the diet as an easier figure with which to work. These levels are for broiler finisher diets, and more fish meal, stabilized or not, is permissible in starter diets, if the level in the finisher diet is low. For example, Atkinson *et al.*[57] fed 15% stabilized fish meal to broilers until 5 weeks of age and completed the feeding period of 9 weeks by reducing the level to 8% stabilized fish meal resulting in carcasses with an acceptable flavour.

TURKEYS tend to be more susceptible to flavour problems than broilers. Consequently a maximum level of 0.5% stabilized fish fat is recommended right through to slaughter weight. Higher levels can be fed in starter and grower diets provided that there is a complete withdrawal of stabilized fish meal prior to slaughter. For example, 10% stabilized fish meal (contributing approximately 1% fat to the diet) can be fed satisfactorily provided that there is a withdrawal period of four weeks [68,69].

LAYERS are far less sensitive to the presence of fish fat in the diet than are broilers and turkeys. To the author's knowledge no practical level of fish fat incorporation in the diet has resulted in tainted eggs. Koehler and Bearse [70] claimed that feeding 10% fish meal resulted in undesirable egg flavour, but the taste panel results with "hidden controls" were unreliable, making interpretation of the results ambiguous. There have been recent commercial problems of "fishy" eggs from certain strains of brown egg layers. However, fish fat has been shown not to be the cause of the problem, but rather certain components of rapeseed meal [71].

For PIG FINISHER diets, the maximum figure would seem to be 0.6% and 0.4% fish fat in the diet for non-stabilized and stabilized fish meal respectively. These figures provide a good margin of safety. Indeed Shearer *et al.*[72] fed 0.45% fish fat (by including 6% fish meal) in pig finisher diets without producing fishy tainted meat, and Smith *et al.*[73] fed diets with 1% unstabilized fish fat to pigs from 30 to 90kg (from fish silage) without carcass taint.

However, these figures can only be regarded at best as a useful "rule of thumb" guide for they take no account of the differing quantities of poly-unsaturated fatty acids within fish meals of different origins produced at different times of the year, and no account is taken of the complex interactions which can occur when the fish meal is added to a mixed diet [74].

Opstvedt of Norway [74] has attempted to do this by studying the effect on fatty acid composition and flavour quality of broiler meat of adding different types of fat at various levels to diets high in stabilized fish meal, namely hydrogenated coconut oil, peanut oil, animal fat and oleic acid. Some of the results are presented in Table 16.

The fat additions reduced the *concentration* of polyunsaturated fatty acids in the dietary fat and carcass fat and there was a parallel improvement in flavour scores to a level higher than that of an all-vegetable diet.

The concentration of poly-unsaturated fatty acids in the carcass fat was related to the concentration of polyunsaturated fatty acids in the dietary fat rather than to the total intake of the unsaturated fatty acids, which was practically the same on all diets. Based on all the data in the experiment, it seems as if the concentration of polyunsaturated fatty acids in the carcass fat varied from 50 to 65% of that of the dietary fat. An exception to this trend was found for diets containing high levels of added oleic acid which reduced the carcass concentration of polyunsaturated fatty acids to values below those predicted from the dietary concentrations.

TABLE 16:

EFFECT OF FAT ADDITION ON THE POLY-UNSATURATED FATTY ACID CONTENT AND FLAVOUR QUALITY OF BROILER MEAT.

DIET	ALL VEGETABLE	20% ANTIOXIDANT STABILIZED FISH MEAL					
TYPES OF ADDED FAT	NONE	NONE	HYDROGENATED COCONUT OIL	GROUND NUT OIL		ANIMAL FAT	OLEIC ACID
LEVEL OF ADDED FAT	–	–	4	4	8	8	2.2
PUFA[a]) IN DIETARY FAT	0	7.8	4.6	4.6	3.2	3.2	5.6
PUFA[a]) IN CARCASS FAT	0	4.1	2.4	2.1	1.4	2.1	2.1
FLAVOUR SCORES POINTS[b])	6.8	5.7	6.1	6.2	7.4	6.1	6.4

a) PUFA – Polyunsaturated fatty acid e.g. 20:5 + 22:5 + 22:6

b) 2-10 points with improving flavour quality.

These observations on the effect of fat addition on flavour quality might conceivably be applied under practical conditions to reduce the risk of fish flavour when high levels of fish meal or fish oil are to be fed. Let us assume for the sake of discussion that an antioxidant stabilized fish meal contains 12% total fat, that this fat contains 20% of polyunsaturated fatty acid, and that the fish meal is fed at 7% with other ingredients. Mixed feed contains an average of 4% fat, and the fish meal contributes 0.84% fat and 0.16% polyunsaturated fatty acids to the diet. The concentration of polyunsaturated fatty acids in the dietary fat is 4.2%. Based on the experiemental data, it is assumed that 55% of this concentration of polyunsaturated fatty acids will be found in the carcass fat. Thus 2.3% of polyunsaturated fatty acids would be found in the carcass fat. Previous experimental data have indicated that a concentration of about 2.2% of polyunsaturated fatty acids may be accepted in broiler carcass fat without serious flavour deterioration. Thus it can be calculated that in this situation up to 7% of fish meal may be fed throughout the life of the broiler without serious flavour deterioration.

However, if higher levels of fish meal are desirable it might either be necessary to increase the total amount of dietary fat in order to maintain the concentration of polyunsaturated fatty acids in the dietary fat at a level of 4.2% or to lower the level of fish fat in the finisher feed.

It is acknowledged that the above considerations are based on only a few experiements and many more practical trials will be required before these calculations can be confirmed and considered helpful in every circumstance. However, situations may arise whereby high level usage of fish meal or fish oil in broiler finisher rations is economically attractive and justifies experimental attempts at adding, for example, additional dietary tallow in order to compensate for the presence of fish meal or oil.

It would also be interesting to see if similar effects are found with pig feeding.

6. EFFECT OF FAT IN FISH MEAL ON THE PHYSICAL PROPERTIES OF FINISHED FEEDS

With the fat in fish meal contributing up to 1% fat in the finished feed, it can have a significant effect on the total content of fat in the finished feed. Fat in finished feed plays an important role as a source of nutrients (a concentrated source of energy and also a source of essential fatty acids) and also as an improver of the physical characteristics of the feed, including palatability.

Fat improves the physical characteristics of a feed in the following ways:

(i) less feed waste and greater comfort to feed mill operators through reduced dustiness;

(ii) easier pelleting and better pellet durability;

(iii) less wear on the mixing, pelleting and handling machinery;

(iv) less segregation of components of the mixed feed, and easier handling of bulk feed;

(v) improved feed appearance (colour, texture, etc.)

6.1 Use of Fat to improve pelleting of Feeds

Pelleting feeds not only improves feed utilisation for many types of stock but can also reduce feed wastage including dust loss and improve conditions for the mill operatives.

The production of pellets can be improved by increasing the fat content of the feed. Fats and oils are good lubricants and they can effectively decrease the power requirements of pelleting equipment. It has also been reported that fats and oils added to feeds increase life of pellet dyes and rollers.

6.2 Use of Fat to prevent Feed Ingredients in Finished Feed from segregating

Segregation of certain ingredients in finished feeds, particularly vitamin and mineral supplements, can create feeding problems. Pfost *et al.*[76] found that ingredients with large differences in particle size were difficult to mix, and segregate easily when discharged from vertical screw mixers. For such ingredients, addition of fat or molasses were found to reduce segregation. A similar beneficial effect of added fat was found using a horizontal mixer [77].

6.3 Significance in Feed Formulation

In view of the physical advantages fat imparts to the finished feed many formulators specify that diets should contain a minimum total fat content. This will be achieved by adding fat to the feed. Where feed ingredients contribute significant quantities of fat, e.g. fish meal, the minimum content specified in the finished feed will be met by a smaller quantity of added fat. Fats for use in animal feeds are often expensive, and some feed mixing companies do not have the equipment required for direct addition. In these situations, the contribution of fat by the feed ingredients assumes even greater importance.

In conclusion, fat in fish meal can make a significant contribution to the total fat and oil in a finished feed which in turn can impart marked benefits to the physical characteristics of the feed.

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*FIRI = Fishing Industry Research Insitute, University of Cape Town.

APPENDIX I

STRUCTURAL RELATIONSHIPS BETWEEN UNSATURATED FATTY ACIDS

Linoleic acid (9,12-octadecadienoic acid) C18:2 $\omega 6$

$CH_3\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH=CH\text{-}CH_2\text{-}CH = CH\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}COOH$

Arachidonic acid (5,8,11,14-eicosatetrienoic acid) C20:4 $\omega 6$

$CH_3\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH=CH\text{-}CH_2\text{-}CH = CH\text{-}CH_2\text{-}CH=CH\text{-}CH_2\text{-}CH=$
$CH\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}COOH$

Linolenic acid (9,12,15-octadecatrienoic acid) C18:3 $\omega 3$

$CH_3\text{-}CH_2\text{-}CH=CH\text{-}CH_2\text{-}CH=CH\text{-}CH_2\text{-}CH = CH\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}COOH$

APPENDIX II

Adjustment of Tabulated ME values of Fish Meal using its Protein and Fat Contents

For formulation purposes the energy values ME_n0 given in Table 7, which are regarded as the most appropriate for application to current day commercial meals might be used and corrected to the fat and crude protein content of a particular consignment of fish meal, using the formula:

$$ME_n0_{\text{adjusted}} = ME_n0_{\text{tabulated}} + \left[\frac{(F_a - F_t)}{100} \times 6452\right] + \left[\frac{(P_a - P_t) \times 3948}{100}\right] \text{ kcal/kg}$$

where ME_n0 tabulated is taken from Table 7, F_t and P_t are the fat and protein contents of the tabulated samples respectively, and F_a and P_a are the actual fat (ether extractable) and crude protein of the consignment.

For example, the adjusted energy value of an anchovy fish meal with 10% fat and 65% crude protein would be as follows:

$$ME_n0_{\text{adjusted}} = 3378 + \frac{(10-13.1)}{100} 6452 + \frac{(65-62.4)}{100} 3948$$

$$= 3280 \text{ kcal/kg}$$

where the unadjusted energy value in the Table is 3378 kcal/kg. This value relates to an antioxidant treated anchovy meal referred to in Table 7. As mentioned earlier, it is the practice now for virtually all commercial anchovy fish meal to be antioxidant treated.