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FISH LIPIDS IN ANIMAL NUTRITION

BY

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SUMMARY

Lipids in fish may be divided into neutral lipids (NL) and phospholipids (PL). The content of PL is relatively constant for different fish and species and throughout the year while that of NL varies depending on energy status (Fig.1). PL contain more polyethylenic and less monoethylenic fatty acids than NL (Fig.2). Fish oil is almost exclusively NL and, therefore, contains less polythylenic fatty acids than meal lipids which consist of a mixture of NL and PL (Tables 1, 2, 3). Hydrogenation of fish oil to partially hydrogenated fish oil (PHFO) reduces to content of polyethylenic fatty acids (Table 4).

Fish oil and fish meal lipids and their constituent fatty acids have high digestibilities and energy values in all animals tested (tables 5 to 9). The digestibility of PHFO is less than that of corresponding fish oil and decreases with the degree of hydrogenation (increasing melting point).

Fish lipids contain high levels of n-3 polyethylenic but low levels of n-6 polyethylenic fatty acids. The n-3 polyethylenic fatty acids may be essential for warm-blooded animals, and they may enhance growth and production in farm animals. In fish, n-3 fatty acids are essential, and the C_{20-22} n-3 polyethlenic fatty acids are either needed or have higher potencies than α-linolenic acid.

Fish meal lipids fed to diary cows at practical levels appear to have neutral effect on the content (percent) of milk fat (Table 11).

The oxidation of fish lipids is not of pratical importance in the feeding of farm animals. In fish feeding all measures should be taken to avoid oxidation and fish diets should contain an antioxidant in addition to adequate levels of vitamin E.

Content of free fatty acids is not a criterion for the quality of fish lipids.

Excess feeding of fish oil may cause off-flavour (fish taint) in animal products. At present levels of incorporation of fish meal in animal feeds this is not a problem.

CONTENTS

FISH LIPIDS IN ANIMAL NUTRITION

Fish lipids are consumed by farm animals and cultured fish in fish meal, raw and refined fish oil, partially hydrogenated fish oil (PHFO), partially hydrogenated fish acid oil (PHFAO), fish silage and in whole unprocessed fish. This bulletin summarises present knowledge of the lipids in fish meal and in raw and processed fish oil, PHFO and PHFAO as ingredients in the diets of mammals, birds and fish.

Fats affect the physical characteristics of the feed and may positively contribute to the palatability of the diet. Fats are sources of essential nutrients and energy, but may also contain possible undesirable substances. This bulletin examines in particular the value of fish lipids as a source of energy and of essential fatty acids, and discusses possible deleterious effects of fish lipids in feeding.

1. ORIGIN OF LIPIDS IN FISH MEAL AND FISH OILS

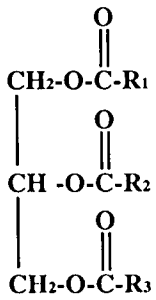
In order to understand and explain the properties of the lipids in fish meal and fish oil, it is necessary to consider the fish from which they are produced. The chemistry of fish lipids is reviewed by Reichwald (1976), El-Shattory (1979) Ackman (1980) and Ackman (1982). This bulletin will particularly focus its attention on those fatty acids of nutritional importance. Lipids consist of fatty acids esterified with an alcohol to which also other compounds may be bound (Fact route 1). Depending on the nature of the alcohol and the attached compounds, lipids are divided into

FACT ROUTE 1

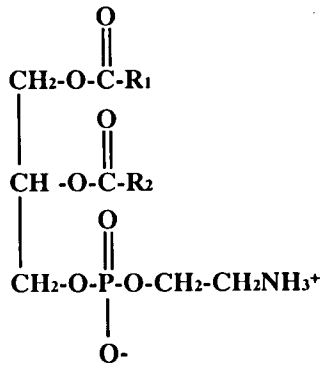
LIPID CLASSES:

LIPIDS CONSIST OF FATTY ACIDS ESTERIFIED WITH AN ALCOHOL TO WHICH ALSO OTHER COMPOUNDS MAY BE BOUND

NEUTRAL LIPIDS
(TRGLYCERIDES)



PHOSPHOLIPIDS
(PHOSPHATIDYL ETHANOLAMINE)



RCOO ARE FATTY ACIDS

different classes. Since it is the fatty acids which are of main importance in the diets, lipid classes are not of immediate concern in feed evaluation. It is convenient, however, to separate lipids into two groups, *phospholipids* (PL) and *neutral lipids* (NL): of the latter *triglycerides* (TG) constitute the main part in fish. The PL serve

structural and metabolic purposes in the body while the TG are used mainly for storage of energy as fat. Consequently, the content of TG may fluctuate depending on the energy status, while the content of PL remains fairly constant.

The ability to store fat varies between different fish species. Further, the anatomical location of the fat stores differ from one species of fish to another. Some species of fish have their fat stores located in the liver and their flesh contains little storage fat. In other fish species the fat is stored in the flesh. Despite the fact that fish cannot be divided into distinct and separate classes based on their ability to store fat in the flesh, it has become practice to separate between lean fish with a low content of fat in the flesh and fatty fish with a high content. To the latter group belong the pelagic species used for the production of fish meal, while the former group is the raw material for white fish meal. When the whole fish, including the liver, is utilised for meal production as is the case for blue whiting and Norway pout, the difference with regard to fat content between white fish meal and fish meal may be small.

Appendix table 1 shows the content of total lipids (TL) and of PL and NL in various tissues in different species of fish. A graphical presentation of the correllation between the content of TL on one hand and the content of PL or TG on the other in the tissues of different species of fish is shown in Figure 1. The content of total lipid varied from about

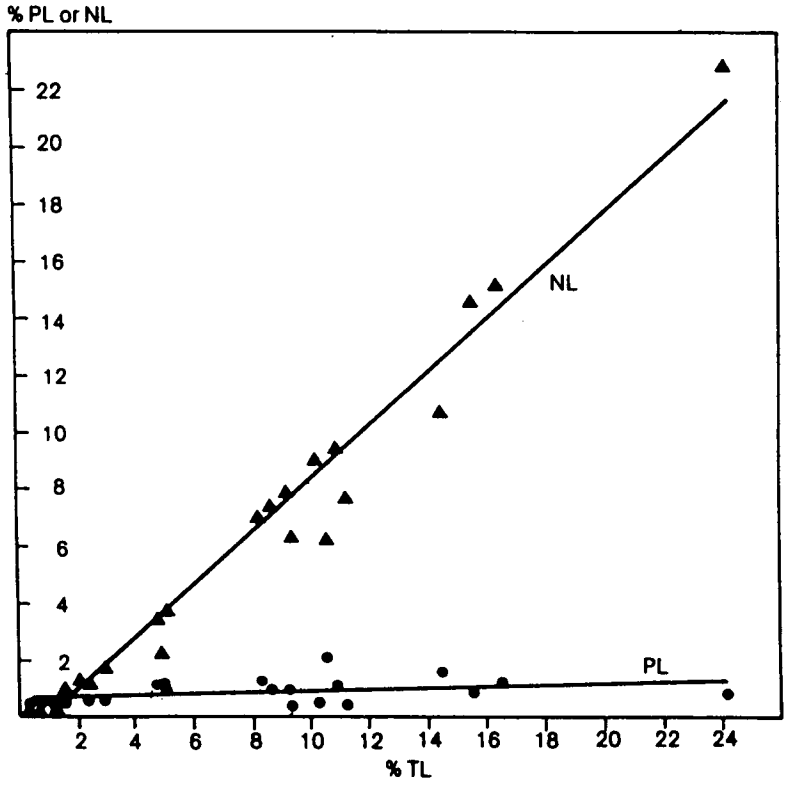


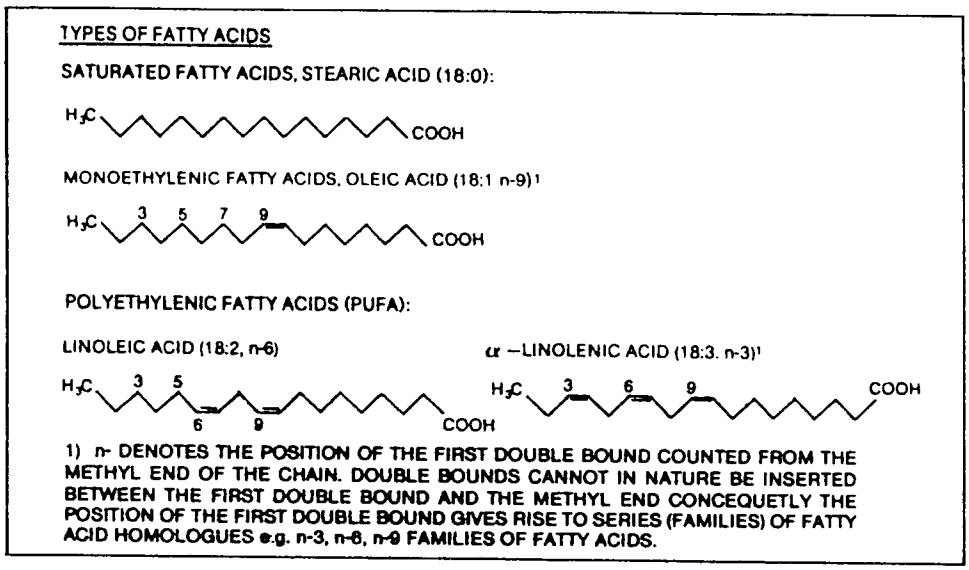
Figure 1. Correlation between TL and PL and NL in different species of fish.

24% in a sample of flesh from mackerel to less than 1% in a sample of flesh from cod. Concomitantly the content of TG varied from about 23% to nearly nil. The content of PL on the other hand remained virtually unchanged at about 0.8% regardless of the total content of lipids. This presentation leads to the general conclusion that when *the content of fat in fish vary, as a consequence of fish species or season and energy status, this is due to variation in the content of TG while the content of PL is fairly constant throughout species and seasons.*

1.1 Fatty acid composition of phospholipids (PL) and neutral lipids (NL)

Although PL and NL are not used as separate entities in animal feeding, it will be shown later that they constitute different portions in different types of fats of fish origin. It is pertinent, therefore, to examine the fatty acid profiles of the two groups of lipids separately (Fact Route 2). Appendix table 2 shows the content of the major types of fatty

FACT ROUTE 2



acids in PL and NL from different species of saltwater fish including those used for commercial fish meal production. In Figure 2 the average content and variability of the major fatty acids in PL and TG are presented graphically.

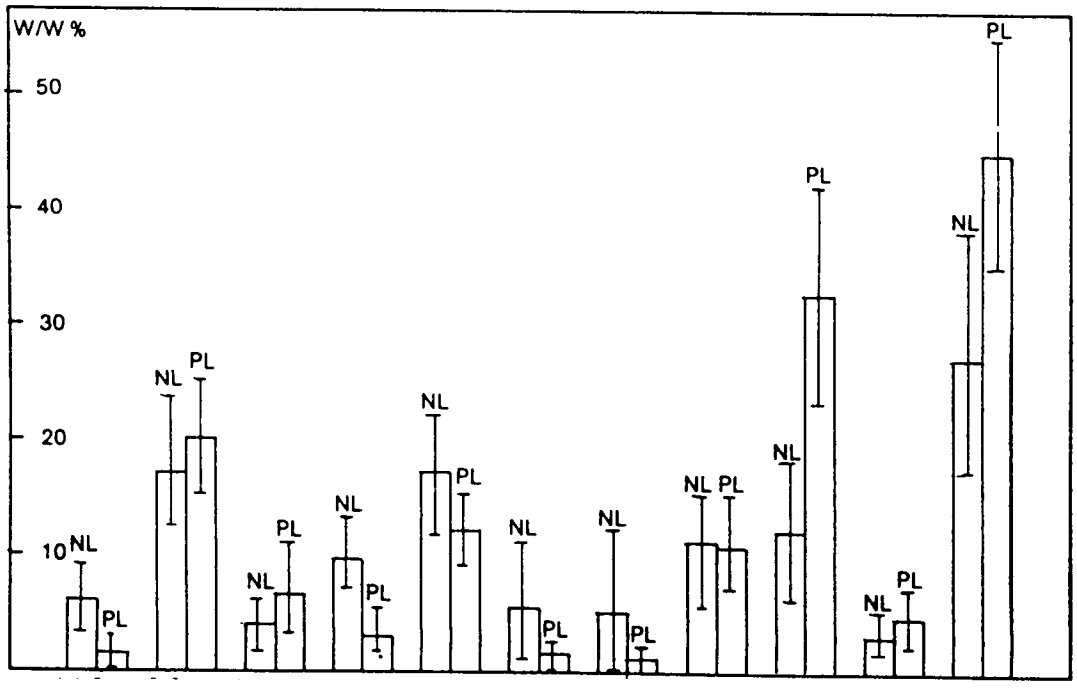


Figure 2 reveals some of the characteristics of fish lipids i.e. their *high content of long chain (more than 18 carbon atoms) polyethylenic fatty acids (PUFA) which mainly belong to the α-linolenic (n-3) family of fatty acids.* Furthermore, it is evident from Figure 2 that *the PL contains more polyethylenic and less monoethylenic fatty acids than TG. The variability in fatty acid composition is greater in the TG than in the PL.* This latter observation is due to the fact that the fatty acid profile of PL is less affected by dietary fat than is that of TG.

1.2 Partition of the lipids in fish on processing to fish meal and fish oil.

Processing of fish with a high content of fat provides fish oil in addition to fish meal. Separation of the lipids into oil is a heat-facilitated mechanical pressing operation. The pressing extracts mainly the TG in the fat cells, while the more strongly bound PL will follow the proteinaceous matter in the meal phase. The separation of the total lipids in the fish into meal and oil is illustrated by an example from capelin in table 1. In this case 40% of the total lipids followed the

TABLE 1

PARTITION OF LIPIDS IN CAPELIN INTO FISH MEAL AND OIL[a)].

	Capelin, whole	Meal	Oil
Total lipids (TL), % of dry matter	32	13	100
Percentage of TL in whole fish	—	40	60
Neutral lipids, % of TL	77	60	97
Phospholipids, % of TL	16	24	1
Fatty acid			
14:0	6.7	4.5	8.1
16:0	11.3	15.9	9.0
18:0	1.3	2.0	1.1
16:1	8.2	7.6	8.7
18:1	17.3	16.0	17.4
20:1	20.5	10.0	24.9
22:1	15.6	7.1	19.5
20:5 n-3	5.3	10.5	2.9
22:6 n-3	7.4	17.9	1.7
Total n-6	1.5	2.0	1.4
Total n-3	15.3	31.6	6.3

a) From Urdahl, N and Nygaard, E. (1970) (unpublished data)

proteinaceous matter in the meal, while 60% was pressed out as oil. The partition of the lipids into meal and oil will vary depending on the fish used as raw material and the type of processing applied. Using similar processing techniques, a fish with a high content of fat will yield relatively more oil than a fish with a low content of fat. Table 1 also shows that the oil was almost exclusively TG, which is in line with other findings (Ackman, Eaton and Hingley, 1976). In this case 24% of the TL in the meal was PL. Previous studies have found between 20 and 40 per cent of the TL as PL in fish meal from herring (Lea, Parr and Carpenter, 1958) and pilchard (Wessels *et al.*, 1971) Since the amount of lipids in fish meal is dependent on the efficiency of the oil pressing, and since the oil pressing only removes TG, *the lower the content of TL in the meal, the higher the proportion of PL in the TL.* In other words, since the content of PL in the meal is fairly constant, *the relative proportion of the PL in the TL is inversely related to the amount of TL in the meal.*

The partition of the fatty acids in the fish lipids between the meal and the oil, as shown in table 1, was a consequence of the partition of the PL and TG. Thus the higher content of PL in the meal resulted in a higher content of PUFA in the meal lipids compared with the oil. *Furthermore, the lower the amount of lipids in the meal the higher the proportion of PUFA.*

1.3 Fatty acid composition of different types of fish meal.

The major fatty acid components in the lipid of different types of commercial fish meals are shown in Table 2 by examples from published literature. For convenience, and in compliance with common practice, the fish meals have

TABLE 2

CONTENT (W/W %) OF NUTRITIONALLY IMPORTANT FATTY ACIDS IN SOME FISH MEALS:

Type	Anchovy						Herring						White fish
Reference	1	2	3	4	Average		1	4	4	4	Average		1
Species[a)]	N.S.	A	P	A		S.D.[b)]	N.S.	C	M	H		S.D.	N.S.
Fatty acid													
14:0	2.8	8.7	6.2	7.4	6.3	2.5	3.2	4.8	6.1	5.5	4.9	1.3	3.2
16:0	12.9	23.3	20.5	22.8	19.9	4.8	10.3	16.6	15.9	16.3	14.8	3.0	11.1
18:0	2.9	6.4	5.5	4.2	4.8	1.5	0.6	1.6	4.1	2.0	2.1	1.5	1.7
16:1	4.6	8.7	8.6	7.2	7.3	1.9	7.0	6.9	4.9	4.2	5.8	1.4	6.8
18:1	20.2	10.5	11.7	13.1	11.4	7.0	11.5	17.6	13.8	14.7	14.4	2.5	16.9
20:1	4.7	-	-	1.3	3.0	-	10.3	8.9	10.1	12.9	10.9	1.7	9.7
22:1	4.2	-	0.4	0.7	1.8	2.1	8.7	7.1	14.7	16.9	11.9	4.7	9.1
20:5 n-3	9.3	18.7	14.1	16.3	14.6	4.0	18.0	10.4	5.8	6.3	10.1	5.6	12.0
22:6 n-3	25.9	14.7	15.4	13.5	17.4	5.7	19.1	16.8	12.1	13.4	15.4	3.2	19.2
Total n-6	6.9	2.5	3.6	3.4	4.1	1.9	3.6	3.5	4.4	2.4	3.5	0.8	3.4
Total n-3	38.5	33.4	33.8	31.5	34.3	2.3	41.6	27.8	18.6	20.2	27.1	10.5	35.5

(a A = Anchoveta, P = Pilchard, C = Capelin, M = Mackerel, H = Herring, N.S. = not specified.

b) S.D. = Standard deviation.

References:

1. Gunstone and Wijesundera (1978)
2. Bassler and Putzka (1975)
3. Wessels *et al.* (1971)
4. Opstvedt (1971).

been divided into anchovy (e.g. anchoveta and pilchard) and herring (e.g. herring, mackerel and capelin) types, in addition to white fish meal (e.g. white fish offal [cod, haddock etc.] blue whiting and Norway pout). The major difference between the different types of fish meal with regard to fatty acid composition is the somewhat greater content of PUFA in white fish meal and in anchovy type fish meal compared with that in herring type fish meal. All types of fish meal must, however, be regarded as good sources of long chain n-3 PUFA, but relatively poor sources of n-6 fatty acids. The oxidation of the lipids in fish meal may cause a substantial reduction in the content of PUFA (Opstvedt. 1971). This is nowadays prevented by the addition of an antioxidant.

1.4 Fatty acid composition of different types of unhydrogenated and hydrogenated fish oil

The fatty acid composition of unhydrogenated anchovy, pilchard, menhaden, herring and capelin fish oils is shown in Table 3. The general characteristic is a relatively high content of long chain n-3 PUFA and a relatively low content of

TABLE 3

CONTENT (W/W %) OF NUTRITIONALLY IMPORTANT FATTY ACIDS IN SOME FISH OILS

	Anchovy[a]	Pilchard[a]	Menhaden[a]	Herring[a]	Capelin	
Fatty acid	(Peruvian)	(South African)			Summer	Winter
14:0	7;5	7;8	10.5	6.1	7.0	8.2
16:0	17.5	15.3	21.5	10.8	11.2	11.3
18:0	4.0	3.7	3.4	1.4	1.2	1.2
16:1	9.0	8.5	14.2	7.3	8.3	8.2
18:1	11.6	9.3	10.3	10.3	12.5	20.2
20:1	1.6	2.5	1.2	13.4	15.0	19.8
22:1	1,2	3.1	0.1	21.3	16.4	16.7
20:5 n-3	17.0	19.3	15.1	7.5	8.0	3.8
22:6 n-3	8.8	6.5	6.5	6.8	7.0	2.7
Total n-6	2.1	1.8	3.7	1.3	2.6	1.8
Total n-3	33.7	33.2	27.8	21.4	21.8	13.8

a) Data from Ackman (1982)

n-6 fatty acids. The content of PUFA is about 30% greater in menhaden and anchovy oil compared with herring and capelin oils. However, oil from capelin caught in the summer season contains considerably more PUFA than oil from capelin caught in the winter season. Capelin and herring fish oils contain more 20:1 and 22:1 fatty acids than oils from anchovy and menhaden.

Table 4 shows the fatty acid composition of PHFO from capelin and herring and from menhaden. Table 4 also gives the fatty acid composition of partially hydrogenated fish acid oil (PHFAO). The hydrogenation reduces the number

TABLE 4

FATTY ACID COMPOSITION (W/W %) OF SOME PARTIALLY HYDROGENATED FISH OIL (PHFO) AND PARTIALLY HYDROGENATED FISH ACID OIL (PHFAO).

		PHFO[a]	PHFAO
Fatty acid	Herring type (herring, capelin) (melting point 30-40°C)	Menhaden (melting point 34-40°C)	(melting point 40°C)
14:0	7.4	9.4	7.6
16:0	14.2	22.1	12.9
18:0	5.0	7.6	8.4
20:0	3.5	2.1	4.7
22:0	3.7	0.8	3.9
16:1	7.4	13.1	5.6
18:1	14.1	15.6	13.3
20:1	13.9	7.5	13.5
22:1	15.4	2.6	14.6
18:X[b]	2.7	2.0	0.4
20:X[b]	4.9	9.7	2.9
22:X[b]	4.2	4.8	4.0

a) From: Anonymous (1977).

b) X denotes different geometrical and positional isomers with 2 to 4 double bonds.

of double bonds in the unsaturated fatty acids. If the hydrogenation is complete the resultant fatty acids are saturated. Common practice is to partial hydrogenate which, in addition to the original unsaturated fatty acids, gives different isomeric mono-, di-, tetra-, and penta ethylenic fatty acids (Ackman, 1982). The degree of hydrogenation is reflected in the melting point (MP), the more hydrogenated the oil the higher the MP. The main difference between the different types of PHFO, hydrogenated to the same MP, is the somewhat greater content of 20:1 and 22:1 fatty acids in PHFO from herring and capelin compared with that from menhaden and anchovy.

2. NUTRITIONAL VALUE OF FISH LIPIDS

2.1 Lipid and fatty acid digestibility in fish meal, fish oil, PHFO and PHFAO for different types of animals

Available data from lipid digestibilty studies in which lipids from fish meal, fish oil, PHFO and PHFAO were the sole dietary lipids are summarised in Table 5 for poultry and pigs, in Table 6 for ruminants and in Table 7 for fish and

TABLE 5

DIGESTIBILITY (%)OF DIFFERENT FISH LIPIDS IN POULTRY AND PIGS

	Fish meal residual lipids		Fish oil		Partially hydrogenated fish oil (PHFO), Melting point °C									Partially hydrogenated fish acid oil (melting point 40°C)	References[c] No.
					32		38		44	50		53			
Animal	D_A[a]	TD[b]	D_A	TD	D_A	TD	D_A	TD	TD	D_A	TD	D_A	TD	D_A	
Poultry	80	-	-	-	-	-	-	-	-	-	-	-	-	-	1
	-	-	-	94	-	85	-	-	70	-	50	-	-	-	2
	-	88	-	-	-	-	-	-	-	-	-	-	-	-	3
	93	-	91	-	-	-	-	-	-	-	-	-	-	-	4
	83	92	84	91	-	-	-	-	-	-	-	-	-	-	5
	-	-	-	-	-	-	-	74	-	-	-	-	-	-	6
	-	-	-	98	-	87	-	75	74	-	55	-	-	-	7
	-	-	-	94	-	-	-	-	-	-	-	-	-	-	8
Average for poultry	85	90	88	94	-	86	-	75	72	-	53	-	-	-	
Pigs	87	-	-	-	-	-	-	-	-	-	-	-	-	-	9
	92	-	-	-	-	-	-	-	-	-	-	-	-	-	10
	-	-	-	-	72	78	72	81	-	61	72	53	64	-	11
	-	-	-	94	-	-	-	-	-	-	-	-	-	54 to 75[d]	12-13
Average for pigs	90	-	-	-	72	78	72	81	-	61	72	53	64	54 to 75	

a) D_A = apparent digestibility.
b) TD = true digestibility e.g. corrected for metabolic fecal fat.
d) Highest value with added lecithin and monoglycerides.

c) References:
1) Potter *et al.* (1962)
2) Laksesvela (1966)
3) Hoffmann and Schiemann (1971)
4) Cuppett and Soares (1972)
5) Opstvedt (1973 *a*
6) Veen, Grimbergen and Stappers (1974)
7) Herstad (1975)
8) Ackman (1980)
9) Homb (1962)
10) Schiemann, Jentsch and Hoffmann (1969)
11) Sundsstøl (1974 *a*)
12) Lysø (1980)
13) Lysø (1983). Personal communication.

of double bonds in the unsaturated fatty acids. If the hydrogenation is complete the resultant fatty acids are saturated. Common practice is to partial hydrogenate which, in addition to the original unsaturated fatty acids, gives different isomeric mono-, di-, tetra-, and penta ethylenic fatty acids (Ackman, 1982). The degree of hydrogenation is reflected in the melting point (MP), the more hydrogenated the oil the higher the MP. The main difference between the different types of PHFO, hydrogenated to the same MP, is the somewhat greater content of 20:1 and 22:1 fatty acids in PHFO from herring and capelin compared with that from menhaden and anchovy.

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					32		38		44	50		53			
Animal	D_A[a]	TD[b]	D_A	TD	D_A	TD	D_A	TD	TD	D_A	TD	D_A	TD	D_A	
Poultry	80	-	-	-	-	-	-	-	-	-	-	-	-	-	1
	-	-	-	94	-	85	-	-	70	-	50	-	-	-	2
	-	88	-	-	-	-	-	-	-	-	-	-	-	-	3
	93	-	91	-	-	-	-	-	-	-	-	-	-	-	4
	83	92	84	91	-	-	-	-	-	-	-	-	-	-	5
	-	-	-	-	-	-	-	74	-	-	-	-	-	-	6
	-	-	-	98	-	87	-	75	74	-	55	-	-	-	7
	-	-	-	94	-	-	-	-	-	-	-	-	-	-	8
Average for poultry	85	90	88	94	-	86	-	75	72	-	53	-	-	-	
Pigs	87	-	-	-	-	-	-	-	-	-	-	-	-	-	9
	92	-	-	-	-	-	-	-	-	-	-	-	-	-	10
	-	-	-	-	72	78	72	81	-	61	72	53	64	-	11
	-	-	-	94	-	-	-	-	-	-	-	-	-	54 to 75[d]	12-13
Average for pigs	90	-	-	-	72	78	72	81	-	61	72	53	64	54 to 75	

a) D_A = apparent digestibility.
b) TD = true digestibility e.g. corrected for metabolic fecal fat.
d) Highest value with added lecithin and monoglycerides.

c) References:
1) Potter *et al.* (1962)
2) Laksesvela (1966)
3) Hoffmann and Schiemann (1971)
4) Cuppett and Soares (1972)
5) Opstvedt (1973 *a*
6) Veen, Grimbergen and Stappers (1974)
7) Herstad (1975)
8) Ackman (1980)
9) Homb (1962)
10) Schiemann, Jentsch and Hoffmann (1969)
11) Sundsstøl (1974 *a*)
12) Lysø (1980)
13) Lysø (1983). Personal communication.

TABLE 6

DIGESTIBILITY (%) OF DIFFERENT FISH LIPIDS IN RUMINANTS

Lipid	Melting point, °C	Animal	D[a] A	TD[a]	References
Fish meal residual lipids:					
		sheep	93	-	Breirem and Homb (1970)
Fish oil:					
		sheep	77	84	Andrews and Lewis (1970)
Partially hydrogenated fish oil, (PHFO),:					
		sheep			
	31 to 33		74	88	Sundstøl (1974b)
	38 to 40		72	86	
	43 to 45		73	80	
	48 to 50		68	82	
		preruminant calves			
	31 to 33		89	-	Flatlandsmo (1972)
	35		92	-	Bjørnstad and Hansen (1974)
	38 to 40		87	-	Flatlandsmo (1972)

a) For explanation of abbreviation see Table 5.

mink. The data show no consistent difference between digestibility of lipids from fish meal and oil in poultry, pigs and ruminants, although there is a tendency that fish oil may be more digestible than fish meal lipids. This could ari through oxidation of the fish meal lipids which reduces its digestiblity (Opstvedt, 1973b). The use of antioxidants to stabilise fish meals can be expected to maintain the high digestibility of the oil fraction. *Therefore, it appears that lipids in fish meal and oil have true digestibilities of 90% or more in all types of animals tested including fish and mink.*

TABLE 7

DIGESTIBILITY (%) OF DIFFERENT FISH LIPIDS IN MINK AND FISH

Lipid	Melting point °C	Mink D_A a)	Mink TD a)	Fish Rainbow trout D_A	Fish Carp D_A	References:
Cod-liver oil		94		89		Austreng, Skrede and Eldegard (1979)
Pollock-liver oil		-		96	89-91	Takeuchi, Watanabe and Ogino (1979)
Capelin fish oil		94		84	-	Austreng, Skrede and Eldegard (1979)
Capelin fish oil		-		86	-	Austreng and Gjefsen (1981)
Partially hydrogenated fish oil, (PHFO)	21	92	-	75	-	Austreng, Skrede and Eldegard (1979)
	32	81	91	-	-	Rimeslatten (1971)
	33	84	-	69	-	Austreng, Skrede and Eldegard (1979)
	≃38	-	-	≃73	≃73	Takeuchi, Watanabe and Ogino (1979)
	40	75	80	-	-	Rimeslatten (1971)
	41	67	-	48	-	Austreng, Skrede and Eldegard (1979)
	≃45	-	-	≃57	≃55	Takeuchi, Watanabe and Ogino (1979)
	46	24	37	-	-	Rimeslatten (1971)
	53	-	-	15	39	Takeuchi, Watanabe and Ogino (1979)

a) For explanation of abbreviation see Table 5.

The lipid digestibility of PHFO with melting point (MP) of 21°C or higher was lower than that of the corresponding unhydrogenated fish oil in all animals tested. The lipid digestibility of PHFO decreases with increasing MP in all animals tested, but the decrease appears to be greater in fish than in warm-blooded animals. Further, it has been shown (Takeuchi, Watanabe and Ogino, 1979) that the negative effect of hydrogenation on lipid digestibility in fish increases as the temperature of the water is reduced and is greater in small than in large fish. The addition of unsaturated fats to PHFO will increase its digestibility as compared to when fed as the sole fat (Takeuchi, Watanabe and Ogino, 1979).

Fatty acid digestibility in fish meal, fish oil and PHFO for different types of animals is shown in Table 8. *The digestiblity of the fatty acids decreases with increasing chain length and increases with increasing unsaturation.*

TABLE 8

APPARENT DIGESTIBILITY (%) OF FATTY ACIDS IN VARIOUS FISH LIPIDS FOR DIFFERENT ANIMALS

Fish Lipid	Melting point (°C)	Species	Fatty acid									References
			14:0	16:0	18:0	16:1	18:1	20:1	22:1	20:5	22:6	
Fish meal lipids		chicks	93	83	32	93	81	88	82	95	95	Opstvedt (1973b)
Whole sprat lipids		cod	68	62	56	86	80	67	58	-	-	Lied and Lambertsen (1982)
Fish oil		sheep	88	82	-	-	94	91	96	96	100	Andrews and Lewis (1970)
		chicks	94	86	78	93	85	85	78	92	86	Opstvedt (1973b)
		mink	96	89	77	91	94	99	99	100	100	Austreng, Skrede and Eldegard (1979)
		trout	89	79	59	86	81	92	95	100	100	Austreng, Skrede and Eldegard (1979)
Partially hydrogenated fish oil,	37	chicks	84	70	49	88	78	-	-	-	-	Veen, Grimbergen and Stappers (1974)
	32	calves	95	90	72	97	93	-	83	-	-	Flatlandsmo (1972)
	35	calves	98	94	88	98	97	95	94	-	-	Bjornstad and Hansen (1974)
	33	mink	93	76	70	82	78	92	96	-	-	Austreng, Skrede and Eldegard (1979)
	33	trout	59	49	43	81	73	76	82	-	-	Austreng, Skrede and Eldegard (1979)

No experiments have compared directly the ability of different animal species to digest fish lipid. However, it appears that the polyethylenic fatty acids (20:5 and 22:6) are highly digestible in all species. Further, 20:1 and 22:1 are generally better digested than 16:0and 18:0. The higher digestiblity of 20:1 and 22:1 in mink and trout compared with chicks has been attributed to an adaptation to their habitual diet (Austreng, Skrede and Eldegard, 1979).

2.2 Energy value of lipids in fish meal, fish oil and PHFO for poultry and pigs

The high digestibility of the fish lipids indicates a high energy value. This is generally confirmed in the literature although data on energy values of fish lipids are scarce. Table 9 contains those data which have been found. Despite the fact that the studies have been conducted at different centres over a considerable period of time and using different techniques, the agreement between the individual figures in relatively good. It appears that the energy value

TABLE 9

METABOLIZABLE ENERGY (M.E.) VALUE OF DIFFERENT FISH LIPIDS FOR POULTRY AND PIGS

Lipid source	Species	M.E. kJ/g	Reference
Fish meal, menhaden	Poultry	29.3	Potter *et al.* (1962)
" " unspecified	Poultry	31.0	Hoffman and Schiemann (1971)
" " herring	Poultry	28.0	Opstvedt (1973a)
" " anchovy	Poultry	32.2a)	Rojas and Arana (1981)
Fish meal, average	**Poultry**	**30.1 ± 1.9**	
Fish meal, unspecified	Pigs	33.7	Schiemann, Jentsch and Hoffman (1969)
Fish oil menhaden	Poultry	33.7	Hill (1964)
" " menhaden	Poultry	38.7	Artman (1964)
" " menhaden	Poultry	35.4	Cuppet and Soares (1972)
" " herring	Poultry	32.5	Opstvedt (1973a)
" " capelin Poultry	Poultry	36.9	Herstad (1975)
" " anchovy	Poultry	35.8	Rojas and Arana (1981)
Fish oil, average	**Poultry**	**35.5 ± 2.2**	
Partially hydrogenated fish oil (PHFO)			
Melting point 31 to 35	Poultry	33.1	Herstad (1975)
" " 37	Poultry	28.5	Veen, Grimbergen and Stappers (1974)
" " 38 to 40	Poultry	30.5	Herstad (1975)
" " 38 to 40	Poultry	34.5	Rojas and Arana (1981)
" " 43 to 45	Poultry	27.9	Herstad (1975)

a) Figure calculated by this author.

of fish oil is higher (about 15%) than that of fish meal lipids. Further, the energy value for pigs may be slightly higher than that for poultry. In line with what was observed for digestibility, the energy value of PHFO seems to be lower than that for the corresponding unhydrogenated oil, and to decrease with increasing MP.

2.3 Deposition of fish lipid fatty acids in the tissues of animals

The absorbed fatty acids may be deposited or catabolised. Comparison of deposited fatty acids with those absorbed does not usually take into account chain shortening and chain elongation or saturation or desaturation in the organism. Furthermore, fatty acids which may arise from *de novo* synthesis will dilute the absorbed fatty acids. Despite these limitations data for fatty acid deposition may give valuable indications to the extent that fish fatty acids are catabolised or deposited. Table 10 compares figures for deposition in a warm-blooded animal, the chick (Opstvedt, 1973b), with that of a cold-blooded animal, the trout (Yu, Sinnhuber and Putnam, 1977). In general the

TABLE 10

DEPOSITION OF FATTY ACIDS FROM HERRING OIL[a] IN THE CHICK AND THE RAINBOW TROUT

Fatty acid	Chick[b]	Trout[c]
18:1 n-9	31	50
20:1 n-9	21	29
22:1 n-11	11	18
18:2 n-6	16	40
18:3 n-3	14	60
20:5 n-3	5	25
22:6 n-3	9	48

a) As percentages of fatty acids consumed.

b) Data from Opstvedt (1973b).

c) Data calculated from Yu, Sinnhuber and Putnam (1977).

deposition was greater in the trout than in the chick, and this was particularly the case for the polyethylenic n-3 fatty acids. However, for both types of animals a larger fraction of the long chain fatty acids was catabolised or converted to other fatty acids in the body than that directly deposited.

2.4 Fish lipids as sources of essential fatty acids

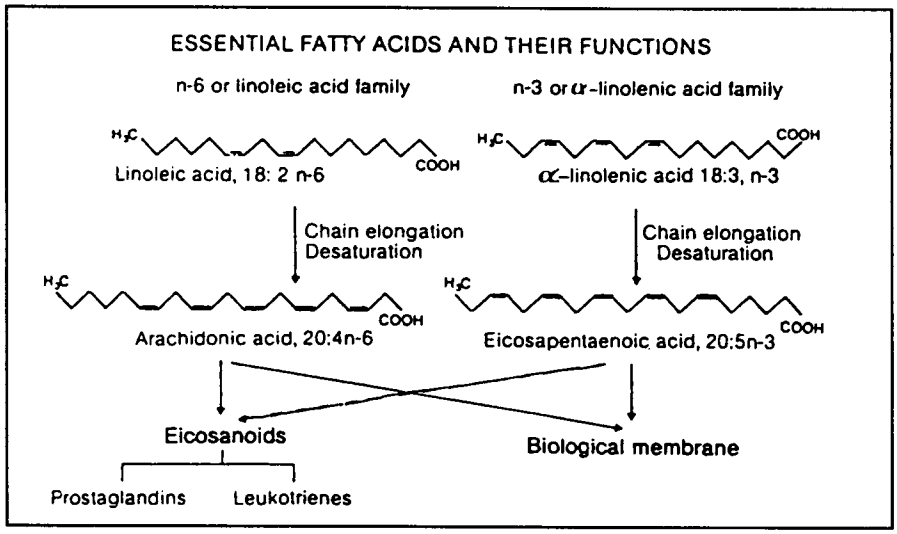
There are two types of fatty acids which are considered essential for animals, the linoleic or n-6 family fatty acids and the α-linolenic or n-3 family fatty acids.(Fact Routes 3 & 4).The parent fatty acids for these families of fatty acids,the

FACT ROUTE

ESSENTIAL NUTRIENTS

This term essential refers to a compound which is needed by animals in order to sustain life, i.e. reproduction growth and maintenance of body integrety, and which cannot be synthesized by the organism. A compound which in itself is not needed by the organism, but which may substitute for an essential compound is termed semi-essential. Besides of serving as essential compounds, nutrients may have positive effects on animal production over and above that due to their essential function by improving the utilization of other nutrients during absorbtion and in anabolism and catabolism.

FACT ROUTE 4



linoleic and the α - linolenic fatty acids respectively, cannot be synthesised by animals but are synthesised by plants. Linoleic and α - linolenic acid do not by themselves have essential functions in the organism, but they are parent substances for longer chain more unsaturated fatty acids which are synthesised in the body through desaturation and chain elongation and which serve essential functions. In some instances (see later) the capacity for chain elongation and desaturation is limited, and the animals have a nutritional requirement for the higher homologue fatty acids in the family.

2.4.1 Warm Blooded animals

The essentiality of linoleic acid for warm-blooded animals has been clearly demonstrated and its biological functions are fairly well known. The quantitative requirement for linoleic acid as an essential nutrient varies depending on species of animal and biological status. In general, the requirement is about 2% of the total energy intake. The extent to which linoleic acid at higher levels than that required to meet the demand as an essential nutrient may promote higher production in farm animals is still debated. Further evaluation on this point is beyond the scope of this bulletin.

The essentiality of α - linolenic acid for warm-blooded animals has been debated since the first discovery of fatty acid essentiality, and has recently been reviewed by Holman & Johnson (1982) and Tinoco (1982). It has been established that warm-blooded animals can have normal growth and reproduction over generations on diets containing very low levels on n-3 fatty acids. However, the fact that n-3 fatty acids are present in high concentrations in certain organs and organels (i.e. the brain, cerebral cortex, retina, testis and spermatozoa) which is built up against a great concentration gradient from the blood plasma has been taken as an indirect evidence of requirement for n-3 fatty acids in warm-blooded animals. Furthermore, n-3 fatty acids are involved in eicosanoid synthesis (Dyerberg and Anker Jorgensen, 1982). Recent observations in humans seem to support this view (Holman and Johnson, 1982). It is thus probable that n-3 fatty acids are nutritionally essential for warm-blooded animals, but the requirement is low.

The requirement for n-3 fatty acids in warm-blooded animals will evidently never exceed that naturally present in normal diets. It is, therefore, more fruitful to discuss their function in replacing n-6 fatty acids, i.e. as semi-essential nutrients, and their possible growth enhancing effects. In the rat it has been clearly demonstrated that α - linolenic acid (n-3) can be substituted for linoleic acid (n-6) for *pre* and *post* natal growth, but is unable to replace linoeic acid for maintenance of skin integrity, spermatogenesis and parturition (Cox et al., 1980, Leat and Northrop, 1981). It is, therefore, likely that the n-3 fatty acids can replace n-6 fatty acids in membrane structures, while they cannot replace n-6 as parent substances for particular eicosaniods.

In poultry, Edwards and colleagues (Edwards, Marion and Driggers, 1962; Edwards and Marion, 1963) showed that menhaden fish oil stimulated growth in chicks. This finding has later been confirmed by Engster, Carew and Foss (1975). Results from studies by Opstvedt (1981) are not entirely in agreement with these findings. Thus the replacement of partially hydrogenated coco-fat with fish meal lipids did not increase growth, while a comparable replacement with sunflower seed oil gave a growth improvement. However, in the study by Opstvedt (1981) the fish meal lipids did improve energy utilisation.

Menge and colleagues (Menge, Calvert and Denton, 1965) found that menhaden fish oil improved fertility in hens. However, a positive effect of n-3 fatty acids in fish oil compared with that on n-6 fatty acids in plant oil on the development of gonadal organs was not fully confirmed in experiments by Engster, Carew and Foss (1975).

Mundheim and Bergsronning (Opstvedt, 1981) using 750 laying hens for 56 weeks studied the effect of an addition of 1% soyabean oil (SBO) to an all vegetable diet and to diets containing 5.0% to 5.5% of ethoxyquin-treated fish meal from capelin or blue whiting (Appendix table 3). The addition of SBO increased the dietary content of linoleic acid (18:2, n-6) from about 1.1% to 1.7% and caused a significant increase in egg production, feed utilization and egg weight on the all-vegetable diet. The fish meal diets without SBO addition contained 1.35 and 1.43% of PUFA (n-6 and n-3), when based on capelin and blue whiting meal respectively, compared with 1.20% in the all-vegetable diet without SBO-addition. The effect of SBO addition to the fish meal diets was different for capelin and blue whiting meals. Thus, the addition of SBO affected egg production, egg weight and feed utilization in hens fed capelin meal in

a similar manner to that found for the all-vegetabel diet. Hens fed blue whiting meal without SBO on the other hand had similar production to those fed SBO. The different effects of SBO when the diets contained capelin meal compared with blue whiting meal cannot be explained by the fatty acid composition of the diets (Appendix table 3).

In conclusion it appears that a dietary supply of n-3 fatty acids in fish lipids enhances production in poultry, but the effect is less consistent than that found for linoleic acid in plant oils.

2.4.2 Fish

The essential fatty acid requirement of fish has recently been reviewed by Tinoco (1982) and Watanabe (1982). Studies conducted in the last two decades have shown the essential fatty acid requirement to vary between different species of fish and to be different from that of warm-blooded animals. It is, therefore, appropriate to discuss the role of fish lipids to meet the essential fatty acid requirement for different fish separately.

Trout: The essential fatty acid requirement is probably most comprehensively studied in the rainbow trout *(Salmo gairdneri).* It has been clearly demonstrated that the n-3 fatty acids are nutritionally essential (Lee *et al.,* 1967, Castell *et al.,* 1972, Yu and Sinnhuber, 1972 and 1975), and that satisfactory growth and reproduction can be achieved without a dietary supply of n-6 fatty acids (Yu, Sinnhuber and Hendricks, 1979). The requirement for α – linoleic acid (18:3 n-3) has been estimated as 1% of the diet (Castell *et al.,* 1972), or 20% of the dietary lipids (Watanabe, 1982). It has, however, been shown that the long chain polyethylenic n-3 fatty acids in fish lipids are more potent in meeting the essential fatty acid requirement for trout than α – linoleic acid (Yu and Sinnhuber, 1976, Watanabe and Takeuchi 1976). Thus *the requirement for n-3 fatty acids may be met when the diet contains 0.5%, or 10% of the dietary lipids, as long chain n-3 fatty acids from fish meal or fish oil (Watanabe, 1982).*

Salmon: The essential fatty acid requirement for species of salmonoid fish other than the rainbow trout has been less well studied. Experiments with chum salmon *(Oncorhynchus keta)* and coho salmon *(Oncorhynchus kisuch)* indicate that the requirement for essential fatty acids in these species may be as for the rainbow trout (Takeuchi, Watanabe and Nose, 1979; Yu and Sinnhuber, 1979). However, in the chum salmon linoleic acid (18:2 n-6) seems to promote growth when present in combination with n-3 fatty acids.

Marine fishes: Studies with red sea bream (Chrysophrys major), black sea bream (Mylio macrocephalus) opaleye (Sirella nigricans), turbot (Scophthalmus maximus) and yellow tail (Seriola quinqueradiata) have shown that these species of fish have a nutritional requirement for the long chain polyethylenic n-3 fatty acids in fish lipids which cannot be met by α – linoleic acid (18:3 n-3) due to limited capacity for chain elongation and desaturation (Cowey et *al.,* 1976; Deshimaru, Kuroki and Yone, 1982; Yone and Fujii, 1975a, 1975b; Fujii and Yone, 1976).

Shellfish: The shellfish prawn (Marcrobrachium rosenbergii) has been shown to have a requirement for n-3 fatty acids (Kanazawa *et al.,* 1977), which is better met by the long chain polyethylenic n-3 fatty acids in fish lipids than by α - linoleic acid (Kanazawa, Teshima and Tokiwa, 1977). Evidently, these fishes have limited metabolic capacity for chain elongation and desaturation of α – linoleic acid to the long chain polyethylenic fatty acids.

Carp, catfish and eel: Carp (Cyprimus carpio), channel catfish (Ictalurus punctatus) and eel (Anquilla japanica) are the most common species of fish cultured in warm fresh water. These species of fish seem to have a requirement for both n-6 and n-3 fatty acids (Arai *et al.,* 1971; Dupree, 1969; Takeuchi and Watanabe, 1977; Watanabe, Takeuchi and Ogino, 1975; Watanabe *et al.,* 1975), but their requirements seem to be less than for trout. Also in these species the polyethylenic n-3 fatty acids in fish lipids seem to be more potent than α – linoleic acid (18:3 n-3) as sources of essential fatty acids.

Tilapia: Tilapia, another warm fresh-water fish, on the other hand do not seem to have a requirement for n-3 fatty acids according to experiments conducted by Takeuchi, Satch and Watanabe (1983) with Tilapia nilotica.

Thus for several fish species the quantitative requirement for n-3 fatty acids is not fully known until comprehensive expert data have been compiled. It may be prudent to use those amounts found to be appropriate for the rainbow trout.

2.5 Effects of fish lipids on milk fat secretion in ruminants

Fish lipids containing polyethylenic fatty acids have been used as model substrates for studying milk fat secretion and the "low-milkfat syndrome" in ruminants. Recent interest in the use of fish meal as a source of low-degradable protein in milking cows has focused attention on the effect of fish lipids as a natural ingredient in dairy cow rations. The metabolism of the polyethylenic fatty acids in fish lipids in ruminants and their effect on milk fat secretion have been extensively reviewed elsewhere (Van Soest, 1963; Christie, 1981; Storry, 1981). It is established that feeding or infusion of polyethylenic fish fatty acids in large amounts (i.e. 300g per day or more) causes a depression of milk fat secretion. The reduction in milk fat secretion is accompanied by physiological changes similar to those found when milk fat secretion is reduced due to large amounts of concentrate (Opstvedt and Ronning, 1967; Opstvedt, Baldwin and Ronning, 1967; Brumby, Storry and Sutton, 1972) (i.e. reduced concentration of acetic acid and increased concentration of propionic acid in the rumen, increased fat synthesis in adipose tissue and reduced fat synthesis in the mammary gland).

Feeding 300g cod liver oil a day in a protected form of formaldehyde-treated casein-oil powder abolished the milk fat depressing effect observed with unprotected oil (Storry, Brumby, Hall & Tuckley, 1974). Similarly the milk fat depressing effects of plant oils rich in linoleic acid were obviated when the rumen was bypassed, either by post-ruminal infusion or use of well protected dietary preparations (Storry 1981).

The $C_4 - {}_{14}$ fatty acids and approximately half the C_{16} fatty acids of milk fat are synthesised in the mammary gland; the remaining C_{16} and all the longer chain fatty acids are derived from the very low density lipoprotein (VLDL), the low density lipoprotein (LDL) and the non-esterified fatty acid (NEFA) fractions of circulating plasma lipids. When 300g cod liver oil were fed in a single meal to lactating cows 93% of the plasma C_{20-22} fatty acids, approximately half of which were polyunsaturated, were found in the cholesteryl ester and PL fractions, 6% in the NEFA and only 1% in the TG fraction of plasma lipids (Brumby *et al.*, 1972). Consequently, the transfer of C_{20-22} dietary fatty acids to milk fat is relatively low (Brumby *et al.*, 1972; Storry *et al.*, 1974) compared with that of C_{18} fatty acids which can be as high as 100% (Storry, 1981).

It is commonly accepted that the effect of polyethylenic fatty acids on milk fat secretion is mediated mainly via their effects on the rumen metabolism, although additional effects at a tissue level cannot be ruled out.

Table 11 summarizes 20 sets of results on feeding fish meal to dairy cows in different countries and over a period of more than 50 years. The studies cover different feeding practices and milk yield varied from 8 to 30 kg per cow and day. The levels of fish meal lipids consumed varied also, from 16 to 128g per cow and day, but were in most instances below 100g, i.e. normal fish meal fed at practical levels.

TABLE 11

EFFECTS OF FISH MEAL WHEN INCLUDED IN THE DIETS, ON THE SECRETION OF MILK FAT IN COWS

References	Fish lipid consumed	Fish meal treatment		Changes compared with control animals			
	(g/cow/d)	Milk yield (kg/d)	Milk fat %	Milk fat %	Significance P	Milk fat (g/cow/d)	Significance P
Isaachsen &Ulvsli (1971)	128	10.7	3.48	-0.11	†	8	†
Isaachsen & Ulvsli (1972)	16	10.9	3.40	0.01	†	-20	†
Hvidsten *et al* (1971)	approx. 50	12.9	3.90	-0.11	N.S.	82	N.S.
	approx. 100	8.4	4.34	0.11	N.S.	5	N.S.
Ekern (1961)	50	14.5	4.07	0.01	N.S.	-8	N.S.
Christiansen *et al* (1970)	approx. 80	22.2	3.39	-0.44	†	-87	†
Miller *et al* (1981)	approx. 50	27.2	3.96	0.15	0.08	79	†
Ørskov, Reid & Macdonald (1981)	approx. 60	20.9	4.4	0.11	<0.05	96	<0.05
	approx. 45	24.9	4.8	0	N.S.	-5	N.S.
	approx. 60	28.5	3.9	-0.10	N.S.	-20	N.S.
Vik-Mo & Thuen (1982) (personal communication)[1]	approx. 39	24.0	3.99	0.07	N.S.	73	N.S.
	approx. 60	24.8	4.17	0.25	<0.05	137	<0.05
Thuen (1982)	approx. 66	20.3	4.07	0.01	N.S.	12	N.S.
Miller *et al* (1983)[2] (and personal communication)	approx. 40	29.9	3.60	-0.18	N.S.	22	†
		26.9	3.78	0.04	N.S.	58	†
	approx. 40	29.9	3.61	-0.16	N.S.	27	†
		27.6	3.91	-0.32	<0.05	-48	†
	approx. 25-45	22.8	4.45	0.31	N.S.	183	†
		20.8	4.39	-0.23	N.S.	95	†
Bergsrønning, Opstevdt & Rodt (unpublished data)	45	27.2	3.70	-0.04	N.S.	-15	N.S.

†= statistical calculations not presented

N.S.= not significant

1.= the control diet also contained a low level of fish meal (supplying 12g of fish lipid) and supproted milk yield of 22.7 kg/d with milk fat of 3.92%.

2.= values relate to trials on three farms and cows in lactaton weeks 10 to 13, 14 to 17, 9 to 12, 13 to 16, 12 to 15, 16 to 19 respectively.

The general impression from Table 11 is that feeding fish meal at this level has little effect on the content (percent) o milk fat. The observed differences in milk fat percentage between fish meal fed cows and cows fed without fish meal (-0.44 to 0.32 percentage units) are small and appear to follow a random pattern. Thus in ten cases cows fed fish meal had higher milk fat percentages (0.01 to 0.31) compared with the control cows without fish meal. In two of these experiments the positive effect of fish meal on milk fat percentage was statistically significant while a third approached significance. In nine experiments milk fat percentages were lower than without fish meal (-0.04 to -0.44); only one of these differences was shown to be statistically significant. No statistical assessment was carried out by Christensen, Klausen and Anderson (1970) who reported the greatest decrease in milk fat percentage. In one experiment the milk fat percentage was similar with and without fish meal. When lower milk fat percentage was observed on fish meal feeding this was usually accompanied by an increase in milk yield, resulting in either little change or even an increase in milk fat production (g/day).

Breirem (1949) concluded that although feeding of marine lipids may tend to reduce the percentage of fat in the milk, the effect will be insignificant if the daily supply is below 100g to 150g per cow and day. Later studies with high

yielding cows have generally confirmed this conclusion, though it appears that the improvement in protein supply brought about by fish meal feeding may exert a positive effect on the yield of milk fat in addition to that found on milk yield.

However, the possible interaction between low roughage — high starch concentrate intake and fish lipid consumption in precipitating the "low milk fat syndrome" deserves further study, although there are no indications from either experiments or practical experience of such an interaction.

3. TOXICOLOGICAL EFFECTS OF OXIDISED FISH LIPIDS

Toxicological effects in warm-blooded animals of oxidised lipids from fish meal have been reviewed by Barlow and Pike (1977) who concluded "that the range of peroxide values generally found in commercial fish meals will not cause any adverse effect on mortality, growth or feed conversion of poultry and pigs". Later literature supports this conclusion.

Since large amounts of fish meal and fish oil are used in fish feeding, oxidation and rancidity of fish lipids have been of greater concern in this instance. Effects of oxidised fish oil in the diet for rainbow trout (Salmo gairdneri) have been studied in Canada. Hung and Slinger (1980) fed in two experiments "slightly" oxidised (Peroxide value [PV] =26 meq/kg oil) or "moderately" oxidised (PV =51 meq/kg oil) fish oils to 150g trout and "highly" oxidised (PV=120 meq/kg oil) or "extremely" oxidised (PV = 314 meq/kg oil) fish oil to 258g trout, respectively. A fresh, unoxidised fish oil (PV = 6 meq/kg oil) was used as control. The oils were added at a level of 7.5% to pelleted, practical diets containing 20% of capelin fish meal, and 33 mg of added α - tocopheryl acetate per kg of diet, except for the diet containing "extremely" oxidised fish oil to which no α – tocopheryl acetate was added. After 24 weeks of feeding no difference was found between trout fed fresh and oxidised fish oils with added α – tocopheryl acetate with regard to live weight gain, efficiency of feed conversion, mortality, haematological values or ascorbate concentration in the liver. Trout fed the "extremely" oxidised fish oil without added α - tocopherol acetate had increased mortality and reduced haematological values and liver ascorbate content compared with the control-fed trout, while the oxidised oil did not affect growth rate and efficiency of feed conversion.

In a different study Hung, Cho and Slinger (1981) fed fresh (PV = 7 meq/kg oil), "slightly" oxidised (PV =25 meq/kg oil) or "moderately" oxidised (PV = 50 meq/kg oil) fish oil to 1.5g trout for 24 weeks. The oils were added at a level of 7.5% to pelleted practical diets containing 20% of capelin meal, and 33, 66 and 99mg of α – tocopheryl acetate per kg of diet, respectively. The results revealed no significant differences between fresh and oxidised oil with regard to liveweight gain, efficiency of feed conversion, carcass composition, haematological values and plasma gluthathione peroxidase activities. However, the moderately oxidised oil reduced liver α – tocopherol concentration which apparently was due to a reduction of the vitamin E content of the diets after pelleting and storage.

In a third study Silas *et al.*, (1981) fed fresh (PV = 5 meq/kg oil) or oxidised PV = 120 meq/kg oil) fish oil to 2g trout for 24 weeks, with two levels of added α - tocopheryl acetate (0 and 33 mg/kg diet) or two levels of added ethoxyquin (0 and 120 mg/kg diet) in a factorally designed experiment. The fish oil was added to pelleted, practical diets containing 20% of capelin meal. The addition of oxidised oil reduced the content of basal α – tocopherol and PUFA in the diets after 24 weeks of storage. Trout fed oxidised fish oil without added α - tocopheryl acetate had increased mortality and reduced vitamin E status, which were not counteracted by the addition of ethoxyquin except for a slight improvement in mortality. The addition of 33mg of α – tocopheryl acetate prevented the toxicological effects of the oxidised fish oil. The feeding of oxidised fish oil had no effect on growth rate, efficiency of feed conversion or plasma gluthatione peroxidase activity regardless of addition of α – tocopheryl acetate or ethoxyquin.

The effect of oxidised fish oil in the feeding of *channel catfish* (ictalurus punctatus) was studied by Murai and Andrews (1974). Fish oil, oxidised to a PV of 60 meq/kg oil, was added at levels of 0, 1.0 or 10.0% to semi-synthetic diets containing varying levels of added α–tocopheryl acetate (o, 25 and 100 mg/kg diet) or ethoxyquin (0 and 125 meq/kg diet) in a factorially designed experiment. Catfish fed oxidised fish oil, even at a rate of 1%, without added α - tocopheryl acetate or ethoxyquin had reduced growth rate, efficiency of feed conversion, and increased mortality and exhibited symptoms of vitamin E deficiency. The toxicological effects of the oxidised oil were fully prevented by the addition of 25mg α – tocopheryl acetate plus 125mg ethoxyquin or by 100mg or α - tocopheryl acetate alone, but not by 125mg ethoxyquin alone.

The effect of oxidised (saury) fish oils on carp (Cyprinus carpio) has been studied in Japan. Hashimoto *et al.*, (1966), Watanabe, Matsuura and Hoshimoto (1966) and Watanabe, Tsuchiya and Hashimoto (1967) fed carp fingerlings (3g to 5g) 10% of oxidised (PV = 150 meq/kg oil) fish oil with and without added α - tocopheryl acetate or synthetic antioxidants in an otherwise low-fat diet for 120 days. Carp fingerlings fed the oxidised oil without added α - tocopheryl acetate had reduced growth rate and increased mortality which were counteracted by the addition of 25mg of α - tocopheryl acetate per kg of diet, but not by the addition of synthetic antioxidants. It thus appears that fish lipids which are oxidised (i.e. PV higher than 50 meq/kg lipid) are toxic to fish even when fed at low levels when the diets contain no added α - tocopheryl acetate. However, when the diets contain added α - tocopherly acetate (i.e. 25mg α - tocopherly acetate/kg plus added antioxidant) even extremely oxidised lipids (i.e. more than 100 meq/kg lipid) do not seem to show deleterious effects. *Consequently, fish meal and fish oil used for fish feeding should contain antioxidants to avoid oxidation and fish diets should be supplemented with α - tocopheryl acetate.*

3.1 The effect of free fatty acids (FFA) on the nutritive value of fish lipids

The content of FFA has been used as a quality criteria for fats and oils without much experimental evidence. Gjefsen and Lyso (1979) compared PHFO with less than 1% and 8% FFA added to the diet of growing, finishing pigs. The diet contained 8% PHFO. The level of FFA had no effect on growth and feed conversion or on carcass quality. These results were confirmed and extended by Lyso (1980) who did not observe deleterious effects from the feeding of 4% PHFAO to growing, finishing pigs. Similar results have also been obtained by Austreng and Gjefsen (1981) feeding fish oil with graded levels of FFA to rainbow trout and salmon parr. In that study increasing levels of FFA from 0.1 to 11% in the oil showed no consistent effects on either type of fish when the oil was added at levels up to 15% in the diets. *Thus, the FFA content is not a useful criterion of the quality of fish lipids.*

3.2 Effects of fish lipids on the quality of meat, eggs and milk

It has long been recognised that high intakes of fish lipids may cause off-flavours in meat and eggs. The subject has been extensively reviewed by Lineweaver (1970), Opstvedt (1971), Hartfiel and Tuschy (1973) and Barlow and Pike (1977). It appears to be commonly accepted that the off-flavour (fishy flavour) originates from the n-3 fatty acids in the fish lipids, which when deposited in carcass and egg fats oxidise when the products are stored and cooked. It is further commonly accepted that the degree of off-flavour is related to the level of intake of fish lipids, and that intakes under a certain level commensurable with practical feeding of fish meal to poultry in most situations, does not create off-flavour. Based on experimental data it was postulated that the risk of off-flavour is correlated to the proportion of n-3 fatty acids in the total dietary fat (Opstvedt, 1974). Thus the risk of fishy off-flavour may be reduced by the addition to the diet of fat that does not contain n-3 fatty acids.

The question of fishy off-flavours in milk and dairy products as a consequence of fish meal feeding to dairy cows has been raised. Experimental data on this problem are extremely meagre. Hvidsten, Mehlum and Simonsen (1952) found no effect on the oxidative stability (by sensory evaluation) of the milk due to the feeding of 0.5kg to 1.1kg fish meal (50g to 108g fish lipids) per day, while the addition of 120g to 150g cod liver oil per day led to increased susceptibility to oxidation. This finding with fish meal is in agreement with recent results from dairy goats (Ekern, Skjevdahl and Opstvedt, unpublished) in which feeding fish meal did not have any detrimental effect on the flavour quality of the milk or the cheese made therefrom. Contrary to these results, the feeding of fishmeal at a level to provide 70g of fish lipids per cow per day in Danish experiments (Christiansen, Klausen and Andersen, 1970) resulted in a tendency for a numerical decrease in flavour score in the milk and in the fresh but not in the stored (1 month) butter made therefrom, compared with milk and butter from cows on diets without fish meal. It appeared that butter made from milk from cows fed fish meal had better consistency than butter from cows without fish meal in their diets.

Fish meal has in the recent years been used to an increasing extent in the feeding of dairy cows in many countries, and this has not been associated with a flavour problem of milk or milk products.

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APPENDIX TABLE 1

TOTAL LIPID (TL), PHOSPHOLIPID (PL) AND NEUTRAL LIPID (NL) CONTENT (%) IN TISSUES FROM VARIOUS SPECIES OF FISH

Species/tissue	TL	PL	NL	References
Cod (Gadus morhua), white muscle	0.59	0.52	0.07	Addison, Ackman and Hingley (1968)
flesh	0.70	0.55	0.10	Jangaard *et al.* (1967)
fillet	0.75	0.65	0.06	Bligh and Scott (1966)
Hake (Merluccius capensis), muscle	1.55	0.46	1.00	de Koning (1966)
Rockfish (Morone saxatilis), fillets	2.14	0.67	1.36	Wood and Hintz (1971)
Capelin (Mallotus villosus), whole	2.89	0.56	1.99	Ackman *et al.* (1969)
Pilchard (Sardinops ocellata),whole	5.00	0.91	3.90	de Koning and McMullan (1966)
Menhaden (Brevortia tyrannus) flesh	8.20	1.23	6.97	Ackman, Eaton and Hingley (1976)
Herring, Baltic (Clupea harengus), fillet	4.60	1.10	3.31	Linko (1965)
Herring Atlantic (Clupea harengus), whole	16.40	1.13	15.20	Drozdowski and Ackman (1969)
Mackerel (scomber scombrus), dorsal muscle	2.10	0.85	1.23	Viviani *et al.* (1967)
flesh June	9.10	0.88	7.93	Hardy and Keay (1972)
flesh Dec.	24.10	0.84	22.70	Hardy and Keay (1972)
light muscle	10.20	0.50	9.10	Ackman and Eaton (1971)
dark muscle	14.40	1.60	10.70	Ackman and Eaton (1971)
Mackerel (Scomber japanicus), flesh Aug.	10.80	1.10	9.40	Ueda (1976)
flesh Jan.	15.50	0.99	14.40	Ueda (1976)
Horse Mackerel (Trachrus japanicus), dorsal muscle	1.10	0.39	0.18	Toyomizu, Nakamura and Shono (1976)
dorsal muscle	11.20	0.35	7.81	Toyomizu, Nakamura and Shono (1976)
Scad, Black Sea (Trachurus mediterraneus ponticus), light muscle	4.90	1.15	2.20	Shchepkin *et al.* (1974) (cited by Ackman (1980)
dark muscle	10.50	2.07	6.10	Shchepkin *et al.* (1974) (cited by Ackman (1980)
Mackerel scads (Decapterus pinnulatis), dorsal muscle	9.30	0.36	6.27	Toyomizu, Nakamura and Shono (1976)
Sardine (Sardinops sagax)	8.60	1.09	7.53	Melva, Tsukuda and Okada (1982)
Average	7.59	0.87	6.07	
$CV_{a)}$,%	81	48	95	

a) CV = coefficient of variation = (standard deviation/average) x 100.

APPENDIX TABLE 2A

FATTY ACID COMPOSITION (W/W%) OF NEUTRAL LIPIDS (TRIGLYCERIDES) IN DIFFERENT FISH SPECIES

Fish species and tissue	Fatty acid 14:0	16:0	18:0	16:1	18:1	20:1	22:1	20:5 n-3	22:6 n-3	Total n-6	Total n-3	References[a)]
Anchovy (Engraulis ringens)	11.2	20.4	6.8	7.9	12.2	2.8	2.3	10.1	9.2	3.3	22.8	1
Menhaden (Brevortia tyrannus), eviscerated	8.1	25.5	4.3	8.4	17.9	1.8	-	10.1	8.3	2.2	25.0	2
Horse mackerel (Trachurus japanius), muscle	4.7	21.4	7.7	8.6	22.4	0.5	1.0	6.9	12.9	4.5	24.6	3
Mackerel scads (Decapterus pinnulatus), fillets	3.4	24.2	7.4	8.4	25.7	1.2	trace	6.0	13.2	3.8	22.7	3
Herring (Clupea harengus)	5.6	12.5	1.1	13.6	15.5	13.7	19.4	6.8	3.1	1.4	11.6	4
Capelin (Mallotus villosus) eviscerated	8.0	9.4	1.1	16.1	8.2	17.4	15.6	7.1	4.8	2.6	13.9	5
Mackerel (Scomber japanicus) eviscerated	4.7	19.6	4.0	7.5	19.3	4.3	0.8	16.4	13.6	2.3	33.1	6
Sardine (Sardinops sagax)	8.1	18.6	3.3	8.3	12.3	4.0	0.1	15.7	17.4	2.6	36.9	6
Cod (Gadus morhua), flesh	3.4	12.3	2.7	9.3	18.8	7.7	6.3	15.4	15.6	2.1	34.0	7
Cod (Gadus morhua),liver	1.8	8.7	1.8	6.5	17.6	4.7	3.0	16.2	23.7	6.2	45.5	8
Average	5.9	17.3	4.0	9.5	17.0	5.8	5.4	11.1	12.2	3.1	27.0	
SD	2.9	6.1	2.5	3.0	5.2	5.6	7.2	4.4	6.1	1.4	10.4	

SD Standard Deviation

APPENDIX TABLE 2B

FATTY ACID COMPOSITION (W/W %) OF PHOSPHOLIPIDS IN DIFFERENT FISH SPECIES

Fish species and tissue	Fatty acid 14:0	16:0	18:0	16:1	18:1	20:1	22:1	20:5 n-3	22:6 n-3	Total n-6	Total n-3	References[a)]
Anchovy (Engraulis ringens)	4.5	25.2	5.7	7.0	15.0	2.6	2.0	7.4	15.0	3.2	24.8	1
Menhaden (Brevortia tyrannus), eviscerated	1.6	24.6	9.5	3.6	18.5	0.7	0.1	7.5	23.2	3.9	32.2	2
Horse mackerel (Trachurus japanicus), muscle	-	19.4	11.0	1.9	9.6	trace	-	7.6	39.9	5.0	50.5	3
Mackerel scads (Decapterus pinnulatus), fillets	-	18.1	12.4	1.5	9.6	trace	-	6.7	40.6	6.4	49.8	3
Herring (Clupea harengus)	1.8	21.4	3.2	4.6	13.0	2.4	1.6	12.2	32.7	2.5	46.2	4
Capelin (Mallotus villosus) eviscerated	2.0	18.3	2.7	5.7	11.2	3.0	2.6	12.2	29.3	3.1	44.4	5
Mackerel (Scomber japanicus) eviscerated	0.6	16.2	10.7	1.9	11.8	1.0	0.4	13.4	35.9	3.7	52.3	6
sardine (Sardinops sagax)	0.5	22.3	5.1	0.2	7.3	0.5	0.3	10.6	46.7	3.1	58.9	6
Cod (Gadus morhus), flesh	1.1	20.8	4.0	3.6	12.7	1.9	0.2	17.9	30.0	4.1	48.1	7
Cod (adus morhus), liver	2.0	9.9	2.5	4.5	13.9	3.7	2.4	12.9	33.1	8.6	51.1	8
Average	1.8	19.6	6.7	3.5	12.3	1.6	1.2	10.8	32.6	4.4	45.8	
SD	1.3	4.4	3.8	2.1	3.2	1.3	1.1	3.6	9.1	1.9	10.1	

SD Standard Deviation

a) References:

1. Masson and Burgos (1973)
2. Ackman, Eaton and Hingley (1976)
3. Toyomizu, Nakamura and Shono (1976)
4. Addison, Ackman and Hingley (1969)
5. Ackman *et al.* (1969)
6. Melva, Tsukuda and Okada (1982)
7. Addison, Ackman and Hingley (1968)
8. Gunstone, Wijesundera and Scrimgeour (1978)

APPENDIX TABLE 3

DIET COMPOSITION AND NUTRIENT CONTENT (%) IN LAYING HEN STUDY BY MUNDHEIM AND BERGSRØNNING (OPSTVEDT, 1981)

	DIET					
	1	2	3	4	5	6
Barley	39.1	39.1	46.7	46.7	46.7	46.7
Wheat	15.0	15.0	15.0	15.0	15.0	15.0
Sorghum	15.0	15.0	15.0	15.0	15.0	15.0
Soybean meal	12.8	12.8	2.8	2.8	2.8	2.8
Capelin meal	-	-	5.0	5.0	-	-
Blue whiting meal	-	-	-	-	5.5	5.5
Soybean oil	-	1.0	-	1.0	-	1.0
PHFO, M_p = 32°C	4.7	3.7	2.7	1.7	2.8	1.8
Grass meal Minerals, Vitamins and amino acids		to 100				
Metabolizable energy, Kcal/kg	2699	2699	2700	2700	2700	2700
Protein,	14.2	14.2	14.2	14.2	14.2	14.2
Lysine,	0.67	0.67	0.67	0.67	0.67	0.67
Methionine & Cystine,	0.52	0.52	0.52	0.52	0.52	0.52
Ca,	3.09	3.09	3.07	3.07	3.07	3.07
P (avail.),	0.62	0.62	0.61	0.61	0.61	0.61
Fat,	6.3	6.3	5.0	5.1	5.1	5.1
Fatty acids[a)]						
18:2, n-6	1.07	1.70	1.13	1.61	1.22	1.71
18:3, n-3	0.11	0.20	0.12	0.18	0.14	0.21
Total n-3	0.12	0.21	0.20	0.33	0.20	0.29
Total n-6	1.07	1.70	1.13	1.61	1.22	1.71
Total n-3 + n-6	1.20	1.91	1.35	1.94	1.43	1.99

a) Analysed in diets.

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