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HEALTH BENEFITS FROM FEEDING FISH OIL AND FISH MEAL

THE ROLE OF LONG CHAIN OMEGA-3 POLYUNSATURATED FATTY ACIDS IN ANIMAL FEEDING

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by

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EXTENDED SUMMARY

Fish has long been recognised as a health promoting food. Increasing evidence points to the fat in fish, and particularly the long chain (C_{20} and longer) omega-3 fatty acids it contains, as being an important factor in the diet of man and animals contributing to good health.

In man and intensively reared animals it appears that diets have become unbalanced in terms of the make-up of fat - particularly polyunsaturated fatty acids. The content of omega-3 (n-3) fatty acids has declined and that of omega-6 (n-6) fatty acids increased. By supplementing with fish lipids which are rich in long chain omega-3 fatty acids the balance can be restored. **A ratio of n-6:n-3 fatty acids of around 5:1 is now regarded as optimal particularly where the n-3 fatty acids are supplied as EPA and DHA.** The latter are found mainly in fish oils and certain marine algae. They are also present in the lipids in fish meal. Where the n-3 fatty acids are provided predominantly as linolenic acid which is found in plant oils, this is of limited effectiveness which varies between animal species. Furthermore, as the ratio increases beyond 5:1 effectiveness reduces further.

Researchers have cited evidence that the oil (lipids) in fish, rich in long chain n-3 fatty acids may help reduce the incidence of the following diseases in humans:-

* Impaired development of brain and visual acuity
  - reduced intellectual capacity in infants
  - aggression and depression
* Neurological dysfunction, including visual symptoms
* Coronary heart disease:
  - restenosis
  - cardiac arrhythmias
* Mild hypertension (high blood pressure)
* Inflammatory and auto-immune disorders:
  - rheumatoid arthritis
  - psoriasis
  - ulcerative colitis
  - asthma

Fish Lipids to Improve Animal Health and Produce Healthier Food

In animals too there is increasing evidence that inclusion of fish lipids in the diet improves health. Both fish oil and fish meal supply lipids. For poultry they can improve disease resistance by moderating the immune reaction to disease challenge and improving

specific immunity. The long-chain n-3 fatty acids (EPA and DHA) were shown to be the active component of fish oil in terms of its effect on coccidia. Whilst flaxseed which also contains shorter chain (18 carbon) n-3 fatty acids (linolenic) has some benefit where birds are infected with coccidia, it is less effective than fish oil. Experimentally, benefits have been shown from feeding fish oil to birds challenged with coccidiosis and in those in which ascites (heart failure) was induced. Preliminary work in poultry shows improved bone formation also.

In pigs benefits were seen following a challenge with bacterial sepsis (E.*coli*). In cattle when lung tissue was infected with pneumonia, defence against this pathogen was increased with dietary fish oil.

In ruminants and pigs reproductive performance can be improved. Higher conception rates were obtained in dairy cows. Embryo implantation may also be improved.

Manipulating Fat Composition

Feeding the long chain n-3 fatty acids EPA and DHA leads to their deposition in intra-muscular fat and in eggs, particularly as phospholipids. There is some production by the animal of EPA and DHA from 18 carbon n-3 fatty acids (linolenic synthesis) which occurs in some vegetable oils such as linseed (flax) and fresh forages. Chain elongation, especially to DHA, tends to be limited. If dietary n-6 : n-3 ratios are high (over 10:1) there is evidence that chain elongation may almost cease. Consequently EPA and DHA deposition is more effective when these fatty acids are provided as such rather than in the 18 carbon (linolenic acid) precursor form.

Deposition of EPA and DHA in animal products such as meat and eggs provides a valuable source in the human diet. It tends to restore the n-6 : n-3 fatty acid balance in these products to levels closer to those in the animal's wild or extensively reared counterpart. Fish meal and oil provide the most cost effective source of EPA and DHA for animals. In the presence of adequate levels of vitamin E, up to 2% fish lipids can be incorporated in the diet without adversely affecting meat/egg flavour.

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1. INTRODUCTION

1.1 Fish as a Health Food

Fish has long been recognised as a health promoting food. Increasing evidence points to the fat in fish, and particularly the long chain omega-3 (n-3) polyunsaturated fatty acids (LC n-3 PUFA) it contains, as being an important factor in the diet of man and animals contributing to good health. More details of the polyunsaturated fatty acids and their metabolism and function are given in the Appendix (see Section 5)

1.2 The Fatty Acids from Fish - Omega-3 Polyunsaturated Fatty Acids

The human diet and that of intensively reared animals has become unbalanced in terms of the make-up of fat. Intake of omega-6 polyunsaturated fatty acids (n-6 PUFAs) has increased, whereas n-3 intake has decreased. Current evidence points to a ratio of around 5:1 n-6:n-3 in the diet being optimal (Table 1) (1,2,3). Formerly the ratio was 1:1 but it has risen to about 10:1 or higher (Figure 1) (4). The form of n-3 is also important. Long chain EPA (C_{20}:5) and DHA (C_{22}:6) are most effective. Vegetable oil forms (linolenic acid) are of limited effectiveness and this varies with species. When the n-6:n-3 ratio is above 5:1 the effectiveness of linolenic acid is further reduced (5).

1.3 Fish Fatty Acid Intake and Disease in Humans

The old wives' tale that 'fish is brain food' has been shown to have a scientific basis. The major component of the lipids in the brain is the fatty acid DHA. An unborn child needs an adequate supply of DHA if the grey matter in its brain and nerve tissue and cell membranes of the retina are to develop fully and properly (6,7,8).

There is now extensive epidemiological data showing that fish eating populations with high n-3 PUFA intake in the form of EPA and DHA, such as Greenland Eskimos (9) and the Japanese (10) have a lower incidence of cardiovascular disease and inflammatory diseases such as asthma and psoriasis. However, in the last two decades the Japanese have been changing to more Western diets containing more saturated fat and less n-3 but more n-6 PUFAs. Their incidence of these diseases is now increasing (10).

There have been several reviews of numerous clinical trials investigating fish/fish oil consumption and diseases (1,2,11,12,13). In these, researchers have cited evidence that shows potential health benefits of fish oil including reduced risk of the following:-

Impaired development of brain and visual acuity
- reduced intellectual capacity in infants
- aggression and depression

Neurological dysfunction, including visual symptoms

Coronary heart disease:
- restenosis
- cardiac arrhythmias

Mild hypertension (high blood pressure)

Inflammatory and auto-immune disorders:
- rheumatoid arthritis
- psoriasis
- ulcerative colitis
- asthma

In animals too there is growing evidence of the health benefits of balancing n-6:n-3 fatty acids through the use of fish lipids as fish oil or fish meal. Furthermore, the fat of the animal tends to reflect the composition of dietary fats. Meat and dairy products can provide n-3 PUFAs in the human diet.

NORDIC RECOMMENDATION ON BALANCE OF PUFA[1]
n-6 : n-3 = 5 : 1
TYPICAL N. AMERICAN ADULT CONSUMES **17g** DAILY **n-3 + n-6** PUFA THEREFORE REQUIRES **3g n-3** TYPICALLY CONSUMES **1.7g n-3 (90% C18:3 n-3)**
THEREFORE REQUIRES AT LEAST 1g n-3 (mainly EPA/DHA)
see reference (1)

TABLE 1

FAT AND FATTY ACID INTAKE AND HUMAN NUTRITION

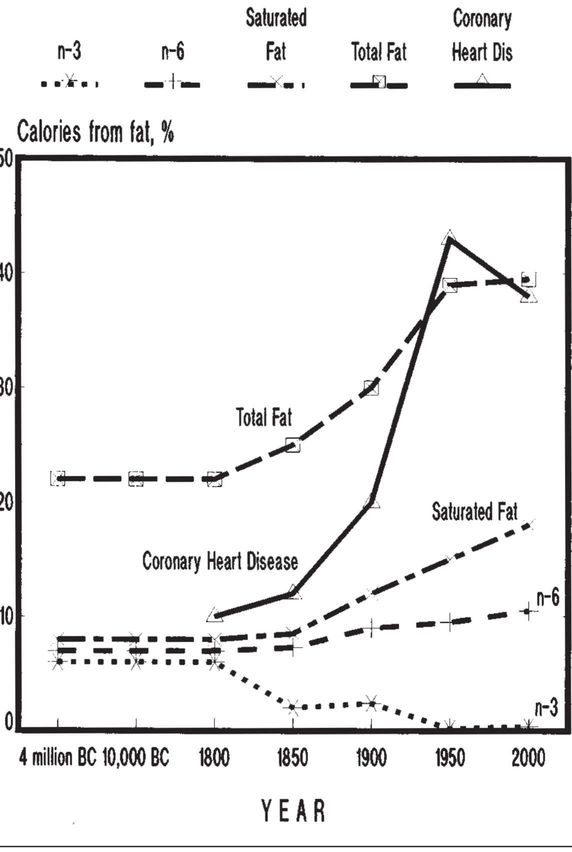


Figure 1

2. FISH OIL AND MEAL - THEIR USE TO IMPROVE ANIMAL HEALTH

2.1 Poultry: Improving Disease Resistance by Balancing n-6:LC n-3 PUFA Ratios

Because birds have evolved to travel large distances and be subject to sudden and sometimes dramatic changes in environment, they have a highly reactive immune system. A large part of the losses through disease in commercial flocks is due to an over-reaction of their immune system (see 'B' in Figure 2) (14). The physiologic response of animals to activation of the inflammatory response results in decreased appetite, feed consumption, lean tissue accretion, and increased degradation of skeletal muscle (15). The animal may also respond in this way to both invading pathogens as well as environmental immunogens such as dust and dander, even though these materials are non-infectious.

Immune responses which are targeted to specific antigens (specific immunity) typically result in very little diversion of nutrients from growth. This arm of the immune system may be the more desirable approach to pathogens whenever possible, minimizing the involvement of the inflammatory response and therefore the diversion of nutrients from growth. Dietary fish oil has been shown to improve certain indices of specific immunity (16), while lessening the production of pro-inflammatory messengers (17).

Adequacy of energy, protein, trace elements, especially iron and zinc, and vitamins A, C and E have long been recognised as important for proper functioning of the immune system. More recently the importance of the balance of fatty acids has been demonstrated to have an effect on immune response, having a greater impact than any other nutrient. Fish oil has been shown to improve the bird's immune system through its contribution of omega-3 fatty acids. Diet is one of several factors affecting the immune system (14,18).

Work at the University of California, Davis by Professor Kirk Klasing has established a model to challenge birds with disease in the absence of medication and monitor various reactions of the immune system (19,20). This involves injecting the bird with either *Salmonella typhimurium* lipopolysaccharide (LPS) or an extract of heat killed *Staphylococcus aureus* as antigens. Feed intake, growth, body temperature changes, changes in circulating levels of the cytokine interleukin 1 and acute phase proteins from the liver (hemopexin and metallothionein) were measured. Corn oil (high in n-6) was compared with fish oil (high in n-3) at 0.5, 1.0 and 2.0% of the diet. It was found that following the LPS challenge the best results (19) were obtained with the 2% fish oil. More details of these results are given in Appendix Figures 2a, b, c, d and e.

Specific immunity was also measured after challenging with infectious bronchitis (IBV) and measuring antibody titre. The titre values were highest with 2% fish oil; that is, these birds showed the highest specific immunity (Appendix Figure 2f). Fritsche (16) has also shown that fish oil gave the highest antibody titre in birds challenged with sheep red blood cells (Appendix Figure 3).

From this work the following conclusions can be drawn regarding fish oil addition to diets of birds subject to a challenge with extracts from pathogens:

-The immune reaction was moderated towards better growth and feed conversion

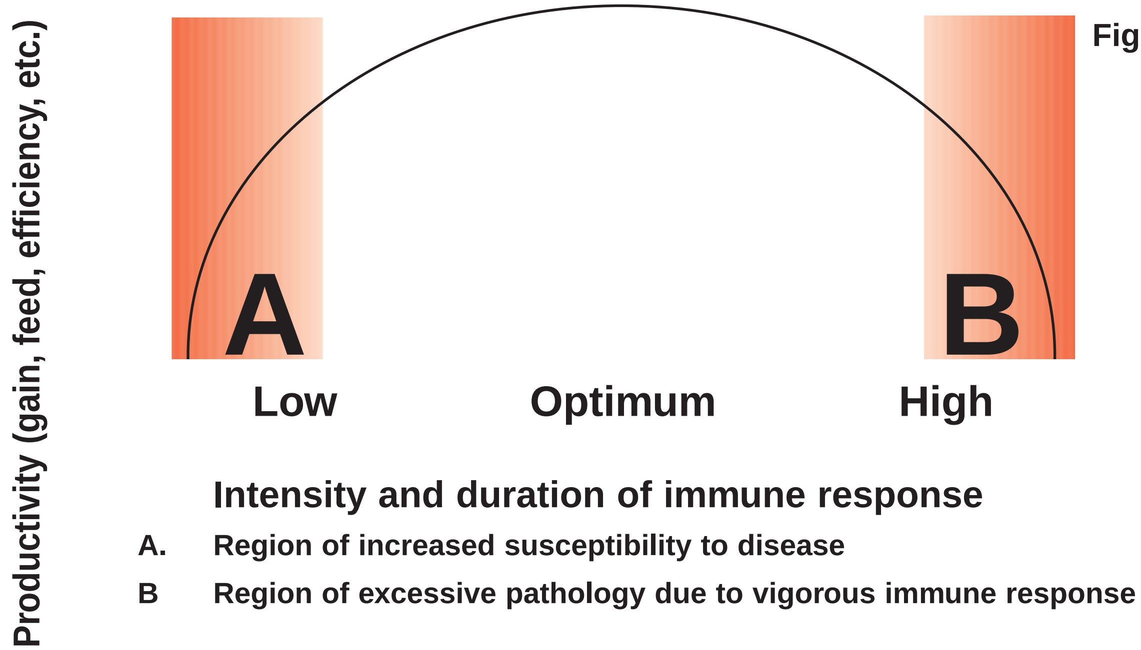
-Specific immunity was increased

-The optimum level of fish oil was 2%

-Lower levels of fish lipids may be effective provided the n-6:n-3 ratio is 5.1

RELATIONSHIP BETWEEN IMMUNITY AND PRODUCTIVITY

Figure 2



Relationship between optimum immunocompetence and the incidence of infectious disease vs. impairments in productivity due to immune responses of excessive intensity or duration.

TABLE 2

COMMERCIAL BROILER TRIAL - USA

Facilities used:

* 48 houses
* 28,000 birds per house
* 1.3 million birds
* 2 treatment diets:

	% Fish Meal	
Starter	8	0
Grower	4	0

Results	**With Fish Meal**	**Without Fish Meal**	**P=**
Mortality %	6.14	6.78	0.03
Final wt. kg	4.69	4.54	0.06

Reduction in mortality with fish meal	**9.4%**
Increase in growth with fish meal	**3.3%**

Total condemnations from sepsis, inflammatory processes and cellulitis significanlty lower with fish meal (p<0.05).

2.2 Broiler Chicks: Fish Oil Reduces Performance Loss due to Coccidiosis

When chicks were challenged with coccidiosis (the parasite E. *tenella*) in the absence of coccidiostats, incorporation of omega-3 fatty acids in the diet reduced the adverse effects on growth and reduced gut lesion scores (21,22). The optimum response with fish oil was seen with 5% inclusion (23) whereas a higher level of an n-3 rich vegetable oil (flax) was needed (22). Lower levels of fish oil (2.5%) give lower yet significant improvements (24). It was demonstrated that the main long chain omega-3 fatty acids in fish oil (EPA plus DHA) accounted for most of the fish oil's activity (22).

One mode of action postulated is that the omega-3 fatty acids infiltrate tissues of the parasite where they become more susceptible to oxidative attack by phagocytic cells. It is believed that E. *tenella* may be particularly susceptible (22). In addition the effects of omega-3 fatty acids may be via the immune system, reducing the effect of inflammation (23).

Where coccidiostats are not used and a coccidiosis challenge is likely to be high - a high level of fish oil in the diet (5%) would be required but perhaps only for a few days between 14 and 21 days of age. Where a coccidiostat is used and/or the challenge is small - lower levels (1% to 2%) should be effective.

Vegetable oils such as flax (linseed) which are high in 18 carbon chain omega-3 fatty acids are less effective, even when used at high dietary inclusions (e.g. 15% flaxseed) (21,25).

2.3 Poultry: Fish Oil and other Diseases

In a trial at the PARC Institute in Maryland broilers were challenged in such a way that the condition of ascites[1] developed. Mortality feeding fish oil or mixed fat was 0.85% and 3.41% respectively (26); weight gain was 3.6% higher with fish oil. (The oil/fat was fed at 3% in starter and 2% in grower feeds.)

A report from Purdue University in the USA showed dietary n-6:n-3 ratios affected bone morphometry in chicks. By including fish oil to reduce this ratio, bone development was improved (27).

2.4 Broilers: Fish Meal Improves Broiler Performance - Large Scale Trial

Turning to commercial experiences, a large broiler producer in the USA compared diets with and without fish meal. This involved 1.3 million broilers in 48 houses (Table 2) (28). Dietary fish lipids were relatively low. They were supplied by 8% fish meal in starter and 4% in grower feeds giving an estimated 0.8% and 0.4% in the diet. There was a positive effect of these lipids on mortality and weight gain. Also, it was found that condemnations of carcasses from sepsis, inflammatory processes and cellulitis were significantly lower with fish meal.

2.5 Pigs: Sows - Better Litters with Fish Oil Feeding

Feeding fish oil from day 95 of pregnancy to parturition to provide 12% of the dietary energy (approximately 4% to 5% of diet) produced significantly heavier piglets at birth (1.46 v 1.29kg) compared with a standard diet of similar energy content (29). Similarly it was found that as a result of including fish oil in the diet, average birth weight was increased by 0.13kg and by 0.33kg at 21 days (30). Milk fat content increased by 0.2% and mortality at weaning by 5.7%.

[1] Cardiopulmonary insufficiency which is believed to be due to birds growing beyond the capacity of their ciculatory system - characterised by the accumulation of lymph in the peritoneal cavities.

Feeding fish oil at 4% of dietary energy (approximately 1.5% in diet) for the 21 day lactation resulted in larger litters (10.0 v 9.2kg) at 21 days and 42 days post-partum (10.0 v 9.0kg). Average weaning weight was higher (6.3 v 5.6kg) (31). The fat content of the sow's milk was increased by 1.2%.

2.6 Growing Pigs: Improved Resistance to Disease with Fish Meal and Oil

In baby pigs (under four weeks of age) dietary proteins other than sow's milk protein are antigenic and can cause an inflammatory response. The antigenicity of fish protein is low; coupled with the anti-inflammatory properties of fish lipids this makes fish meal and fish oil useful components of these feeds (32).

When **pigs** were challenged with sepsis (E. *coli*) the effects were less severe with those receiving a fish oil containing diet (33). The fish oil was compared with corn oil added at approximately 10% of the diet.

2.7 Ruminants: Improved Resistance to Disease and Parasite Challenge when Fish Oil Fed

Using **bovine** lung cells infected with para influenza-3 virus *in vitro* and enriching with EPA and DHA, their ability to kill this respiratory pathogen was enhanced, compared with non-enriched cells (34).

Production losses in **sheep** challenged with nematodes were substantially reduced in the presence of fish meal and egg concentrations in faeces were significantly lower (35). This response may be due to the lipids in the fish meal.

2.8 Effects of Fish Oil and Meal on Health - Conclusion

The correct balance of PUFAs in animals in terms of n-6 : n-3 ratios can improve health particularly where the main source of n-3 is from EPA and DHA. The C_{18} (linolenic acid) form of fatty acids can be utilised by some species to a limited extent. Full dependence on this fatty acid to provide the n-3 source is generally of limited effectiveness. The long chain n-3 fatty acids EPA and DHA play a particularly important role. They improve immune status and lessen inflammatory conditions. This leads to higher productivity and reduced losses. If, as seems likely, increasing consumer pressure forces animal producers to reduce routine use of drugs, balancing n-6 : n-3 PUFAs in the diet will become even more critical.

3. FISH OIL AND MEAL - THEIR USE TO IMPROVE FERTILITY

Work with dairy cows (see section 3.3 below) has shown evidence that the LC n-3 PUFAs from fish oil can affect fertility through the prostaglandins and progesterone production. This mechanism may also account for fertility effects of fish lipids for other species.

3.1. Poultry

With cockerels receiving either salmon oil (5%) or corn oil (5%) in their diet, the former gave significantly higher fertility rates (96%) than the latter (91.6%) (36).

Work with fish meal has shown improved hatchability of eggs produced by hens fed fish meal (37).

3.2 Pigs

Several pig trials show higher numbers born to sows fed fish meal (38,39,40). In a trial feeding 4% menhaden oil versus starch to gilts and sows, significantly higher foetal survival ($P<0.06$) was obtained with menhaden oil - 93.7% v 78.8% (39). In another trial with gilts and sows, although the differences were not significant, the average foetal survival with fish oil was 75.2%

compared to 70.6% in those not receiving it. Working with a newly introduced herd of gilts at the North of Scotland College (SAC) more piglets were born to gilts which received 5% fish meal in the diet (11.61 v 11.06) though this difference did not quite reach significance (P=0.14) (40). In the second parity, the sows produced similar numbers of piglets born (11.36 v 11.35).

3.3 Cows

Large scale dairy cow trials in both Israel (41) and Ireland (42) have shown better fertility as a result of fish meal feeding; marked increases in conception rate were seen. Work at the University of Florida has investigated including fish meal as a source of fish lipids in the dairy cow's diet. Levels of progesterone were increased thereby enhancing antiluteolytic mechanisms and embryo survival (43,44). This result indicated that it was the fish lipids acting through their contribution of LC n-3 PUFAs on the prostaglandins and progesterone production that improved fertility. A recently completed trial at the Irish centre (Hillsborough) showed that by supplementing silage fed cows with fish meal, conception rate increased from 58% to 82%.

3.4 Effects of Fish Meal and Oil on Fertility - Conclusion

Both fish oil and fish meal have been shown to improve fertility. In cows the fish lipids appear to increase levels of progesterone to improve embryo survival. Similar mechanisms may account for improved fertility in pigs. Some involvement of fish protein where fish meal is fed, in addition to the lipid effect, is possible.

4. FISH MEAL AND FISH OIL TO MANIPULATE FAT COMPOSITION IN ANIMAL PRODUCTS

Generally, the composition of fat in animals reflects dietary fat. Intensification of animal production with less dependence on grass/vegetables and more use of cereals has led to more saturated fat. In extensive rearing - free range poultry, (layers and meat birds) and grazed cattle the n-3 PUFA α-linolenic acid (ALA) present in grass, vegetables, insects, etc., is consumed and trace amounts converted to longer chain n-3 - EPA and DHA. However, increasing supplementation of diets for intensively produced animals with lipids from oilseeds has occurred. These have contained predominately n-6 PUFAs. Consequently animal fat has become higher in these fatty acids and lower in n-3 PUFAs. With generally very high n-6:n-3 ratios in diets of intensively reared animals, chain elongation of any small amounts of linolenic acid present would be unlikely (see Section 1.2). As the human consumer also makes little use of linolenic acid for the same reasons, direct feeding of EPA and DHA in the form of fish oil to animals is far more effective way of introducing these fatty acids through meat, etc., to the human diet.

4.1 Manipulating Fat Composition in Eggs - Healthier Eggs from Fish Oil Fed Birds

In the laying bird, giving sufficient dietary n-3 in the form of α-linolenic acid where n-6 is not too excessive, e.g. using linseed oil, some DHA is produced. Conversion efficiency is low; thus low levels are found in the egg. Relatively high DHA levels in the egg can be achieved feeding either fish oil, fish meal or algal products (45,46,47), without adversely affecting flavour.

A survey at the Clemson University, South Carolina compared DHA and EPA levels in eggs (corrected to 60g weight) from hens fed menhaden oil (3%) or flax seed (linseed) (46). The EPA levels were 43 and 12 mg and DHA levels 220 and 83 mg per egg respectively - that is, around three times higher as a result of fish oil feeding. Dr. David Farrell at the University of New England has shown how fish oil feeding can result in eggs providing over 1g of n-3 fatty acids in their yolk (47,48). He went on to feed these to human volunteers showing significant reductions in their plasma n-6:n-3 ratios (48). These papers and others have been covered recently in a comprehensive review of the subject by Leskanich and Noble, 1997 (49).

4.2 Poultry Meat

In meat animals dietary long chain n-3 PUFAs tend to deposit in the phospholipids in the meat rather than in the adipose tissue. In consequence, LC n-3 PUFAs are deposited in lean meat. Furthermore, the level deposited tends to increase as dietary intake increases (49).

Whilst increasing fish oil in the diet increases EPA and DHA in meat what is the limit? Eventually off-flavours will occur. By ensuring adequate stability of the diet with antioxidant and fortifying vitamin E levels, e.g. 100iu in broiler diets - relatively high levels can be fed. Up to 2% has been shown to have no effect on the sensory qualities of broiler meat, provided these criteria were met and the fish oil was withdrawn in the last week - according to work at Cambridge University (50) and Bristol University (51). The latter group used a professional taste panel (see Table 3). (Meat was tested after six months freezer storage at both centres.)

The Cambridge work showed that acceptable broiler meat was produced containing 94 and 135 mg long chain n-3 PUFAs (C_{20} and above) in breast and thigh meat respectively per 100g portion of meat - a typical meal in the UK (Table 4). This would make a significant contribution to the extra 1g daily typically required in Western diets (see Table 1)

4.3 Pig Meat

Morgan *et al* fed diets to pigs with 0.95% or without fish oil (control) (52). All diets also contained 2.5% fish meal. Ham muscles from fish oil fed pigs at slaughter had 0.8% EPA and 0.8% DHA in their fat, whereas those from the control treatment had no EPA and 0.5% DHA. A diet which included 0.75% α-linolenic acid had no EPA and only 0.3% DHA in the muscle. This shows that as with poultry, chain elongation of α-linolenic acid to EPA and DHA was limited. Neither the appearance of the meat nor its taste were affected by any of the diets.

4.4 Milk Fat, Beef and Lamb

In dairy cows, fish oil feeding above 100g per day appears to depress the level of milk fat, whilst milk protein remains the same or increases (53). This may be an advantage in certain quota situations where a lower fat content allows more milk to be sold. Nevertheless, it is recommended that for dairy cows and cattle, limits on fish oil feeding should be set at 200g and 50g per head per day respectively.

Fish oil feeding can affect rumen function. High intakes (over 100g daily in dairy cows for example) may change microbial activity. Some hydrogenation of the LC PUFAs occurs. The end products can be absorbed subsequently from the intestine. When they reach the mammary gland, it is believed they reduce fat synthesis (54). Although unsaturated fatty acids generally depress microbial activity in the rumen, work with fish oil seems to indicate this may not be the case - improved digestion of fibre, for example, has been observed (55).

Some of the long chain n-3 fatty acids in fish oil escape hydrogenation in the rumen (56). Traces get into milk (57). Small amounts can go into beef (58,59). In grass fed beef, traces of EPA and DHA are found in the meat; this

TABLE 3

BRISTOL UNIVERSITY

INFLUENCE OF DIET ON THE EATING QUALITY OF COLD ROAST CHICKEN BREAST

Values are the means derived from analysis of variance using diet and assessor as factors and panel as a 'block' for 6 replications.

Attribute[1]	Control	10% fish meal	2% fish oil	Variance Ratio	SED	Signf
Texture	7.13^{b}	6.70^{a}	6.98^{b}	9.10	0.103	***
Juiciness	4.48	4.33	4.32	0.47	0.190	ns
Flavour	4.18	3.68	4.02	2.47	0.229	ns
Abnormal flavour	2.68	2.97	2.72	0.88	0.233	ns
Overall liking	4.77	4.52	4.87	1.43	0.214	ns

[1]All above score 0 to 5 where the higher score is preferable, except for abnormal flavour intensity
sed = standard error of differences of means
signf = significance value, where *=p>0.05, **p>0.01, ***p>0.001
Means with the same superscript do not differ significantly.

TABLE 4

N-3 FATTY ACIDS (MG) PROVIDED BY 100G OF BREAST AND THIGH MUSCLES FROM BROILERS FED DIFFERENT LEVELS OF FISH OIL

	BREAST MUSCLE			THIGH MUSCLE		
Fish oil in diet (g/kg)	0	10	20	0	10	20
20 : 5 n-3	4^{c}	18^{b}	25^{a}	2^{c}	24^{b}	40^{a}
22 : 5 n-3	9^{b}	19^{a}	21^{a}	12^{c}	24^{b}	29^{a}
22 : 6 n-3	9^{b}	39^{a}	48^{a}	12^{c}	45^{b}	62^{a}
Total n-3	23^{b}	76^{a}	94^{a}	30^{c}	95^{b}	135^{a}

^{a,b,c} Within muscle type values on the same line with different letters differ at P<0.05

is absent in animals fed poor forage and/or high concentrate diets. Fish meal and/or fish oil can be used to restore and boost EPA and DHA in beef and lamb (60,61) which can be a significant part of daily intake by human meat consumers.

4.5 Manipulation of Fat Composition - Conclusion

Fish oil and/or fish meal can be used to introduce and/or boost EPA and DHA levels in meat and eggs. The level of these fatty acids in the diet will determine levels in the meat. Care must be taken to stabilise the diet with antioxidant, and to supplement it with vitamin E. This will ensure that working within the limits given above, meat and eggs will be a valuable source of these nutritionally important fatty acids and at the same time eating quality will be maintained.

Fish lipids are more effective generally than vegetable lipids as a source of EPA and DHA in the product. Vegetable lipids tend to deposit C_{18} n-3 (linolenic acid ALA) which has limited use in to-day's human diet in the West where n-6 PUFAs predominate. Algal lipids are effective concentrated sources of EPA and DHA but are expensive to produce. Fish oil with its low price and high energy value comes into most diets on a least cost basis.

5. APPENDIX

The Function of Polyunsaturated Fatty Acids (PUFAs)

The PUFAs can be divided into two main groups omega-6 (Appendix Figure 1) and omega-3 (n-3) which have different physiological functions and effects. Humans and animals cannot synthesise PUFAs from basic carbon sources - they require a dietary source. The main n-6 PUFAs are linoleic acid and its metabolites γ-linolenic acid (GLA) occurring particularly in vegetable oils and arachidonic acid (AA) occurring mainly in animal tissue (Appendix Table 1). The main n-3 PUFAs are (linolenic (ALA)) and its metabolites eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The former occurs in vegetable oils, and in vegetables. EPA and DHA are found in fish - particularly oily fish. They have a longer chain length in their molecular structure - 20 and 22 carbon atoms compared with 18 in GLA and ALA. They are sometimes referred to as n-3 LC PUFAs. They are produced by phytoplankton and zooplankton on which fish feed, and algae.

The two essential fatty acids, linoleic acid (n-6) and α-linolenic acid (n-3) are transformed into longer-chain PUFAs and their derivatives by enzymes (desaturases and elongases). These same enzymes metabolise both n-6 and n-3 fatty acids. If the dietary intake of one is too great, metabolism of the other family can be impaired. This can lead to an imbalance in the production of prostaglandins, leukotrienes and thromboxanes (1,3,4). These hormone-like compounds are involved in important physiological processes including the central nervous system, regulation of blood pressure and clotting time, inflammatory reactions and the immune system's defence mechanisms.

APPENDIX FIGURES

The following figures show the effects of 2% dietary fish oil on broilers challenged with simluated disease (20) as follows:-

Appendix Figures: Effect of 2% Fish Oil

2a	-	Weight gain increased
2b	-	Body temperature rise lower
2c	-	Interleukin 1 index lower
2d	-	Hemopexin level lower
2e	-	Metallothionein lower
2f	-	Anti IBV titres

5.1

APPENDIX TABLE 1

FATTY ACID COMPOSITION OF LIPIDS IN OILS, FATS AND PROTEIN MEALS, ETC.[1]

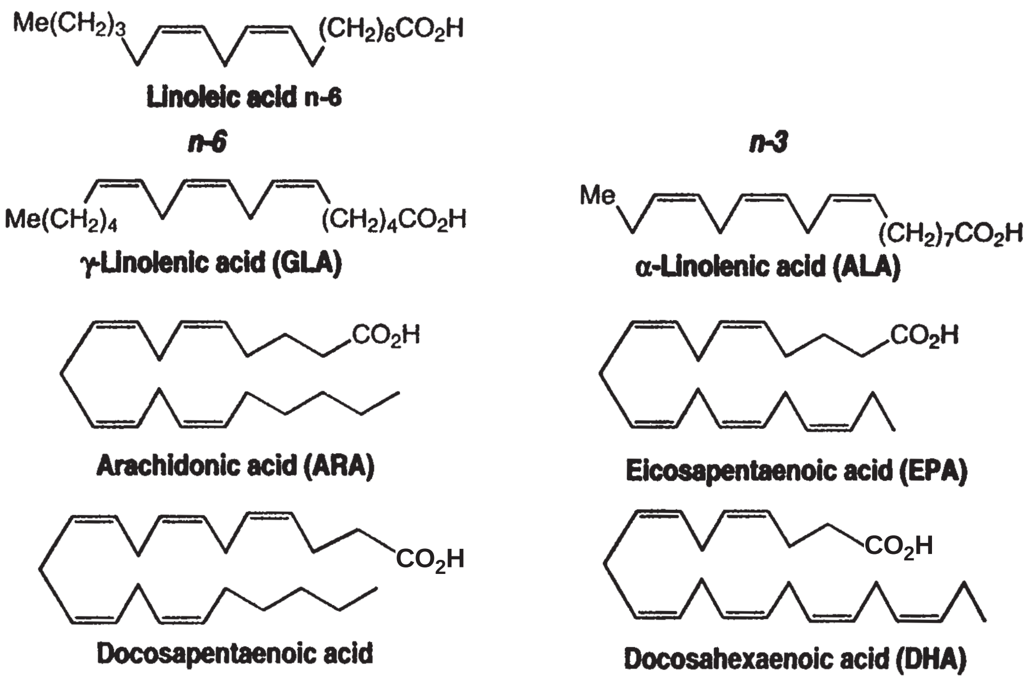
(As g per 100g fatty acids)

LIPIDS IN OILS/ FATS	ω6 Total	ω3 C18	ω3 Total	ω3 C20+	ω6:ω3
Menhaden	3.9	0.9	23.9	23	0.16
Herring	3.3	0.6	16.8	16.2	0.20
Animal (Pig)	11	0.6	0.6	0	18.30
Soyabean	54.4	7.1	7.1	0	7.67
Maize[4]	50.4	0.9	0.9	0	56
Linseed	14.5	56	56	0	0.26
Rapeseed	29.5	10	10	0	2.95
Cotton seed	27.5	-	0	0	>100
Sunflower	65	0.1	0.1	0	>100
LIPIDS IN MEALS, ETC.					
Anchovy meal[2]	4.1	0.4	34.3	33.9	0.12
Herring meal[2]	2.4	1.1	27.1	26	0.09
White fish meal[2]	3.4	0.5	35.5	35	0.10
Fresh grass[3]	8.4	74.8	74.8	0	0.11
Wheat germ[4]	54.8	6.9	6.9	0	7.9

[1](60)
[2]As % lipid: from IAFMM Technical Bulletins Nos. 4, 22
[3](61)
[4](62)

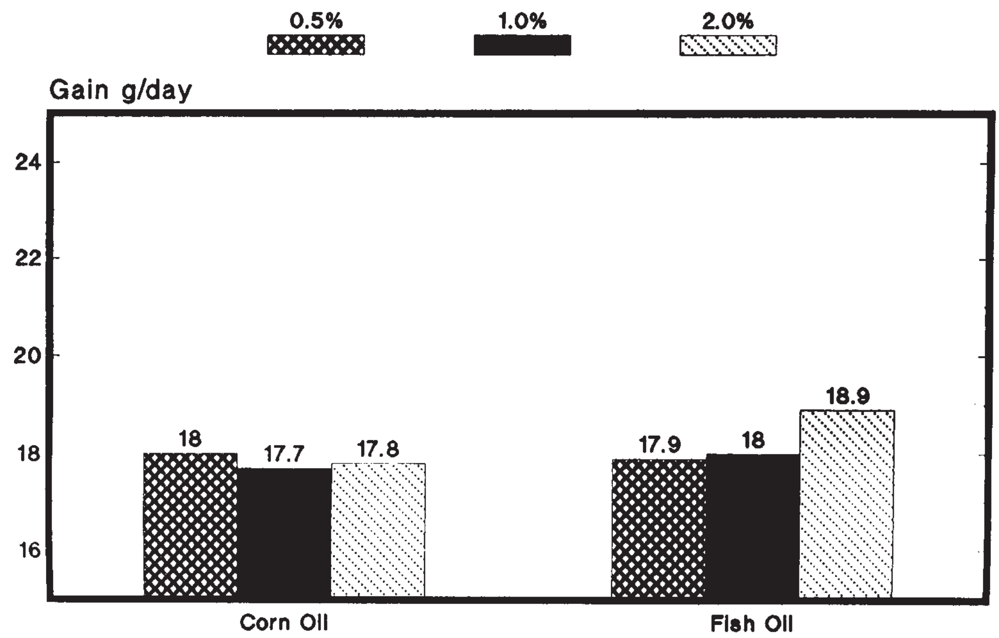
Appendix Figure 1

Main Omega-3 and omega-6 fatty acids



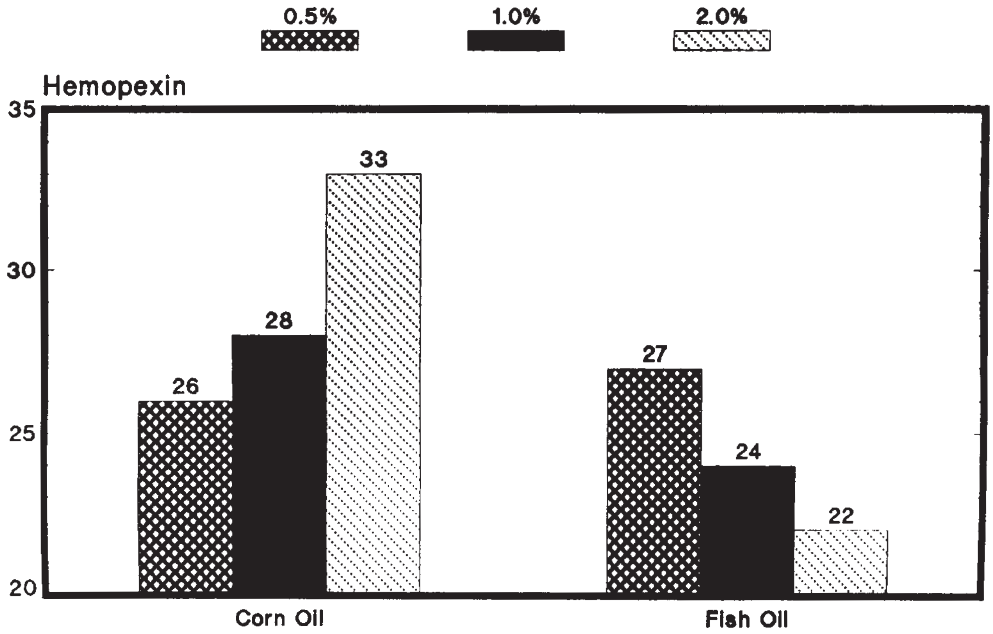
Appendix Figure 2a

WEIGHT GAIN OF BROILERS - LPS CHALLENGE



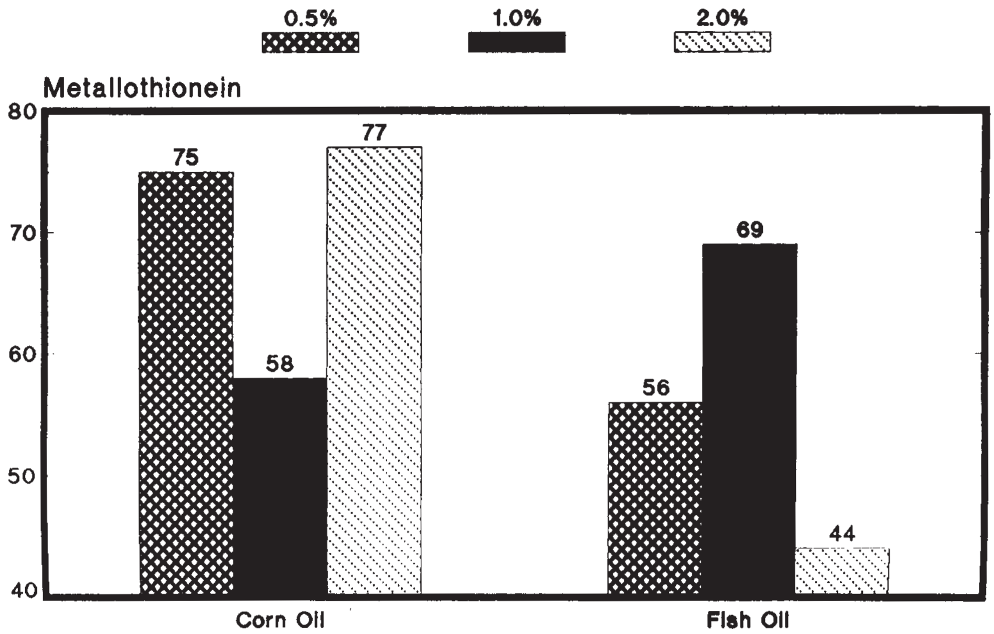
Appendix Figure 2d

HEMOPEXIN IN BROILERS - LPS CHALLENGE



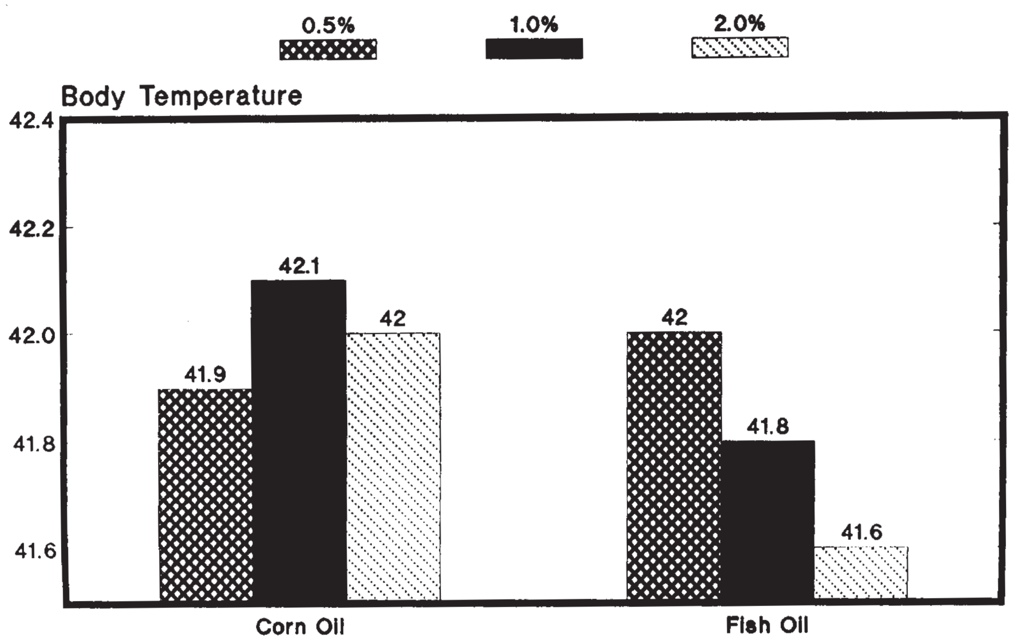
Appendix Figure 2e

METALLOTHIONEIN IN BROILERS - LPS CHALLENGE



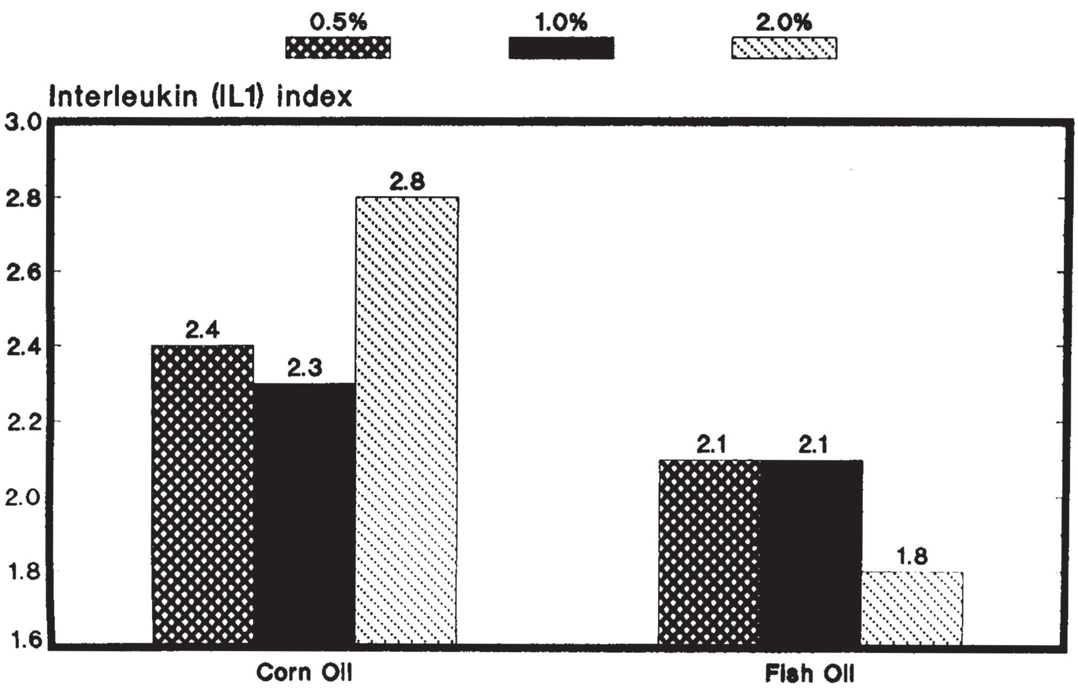
Appendix Figure 2b

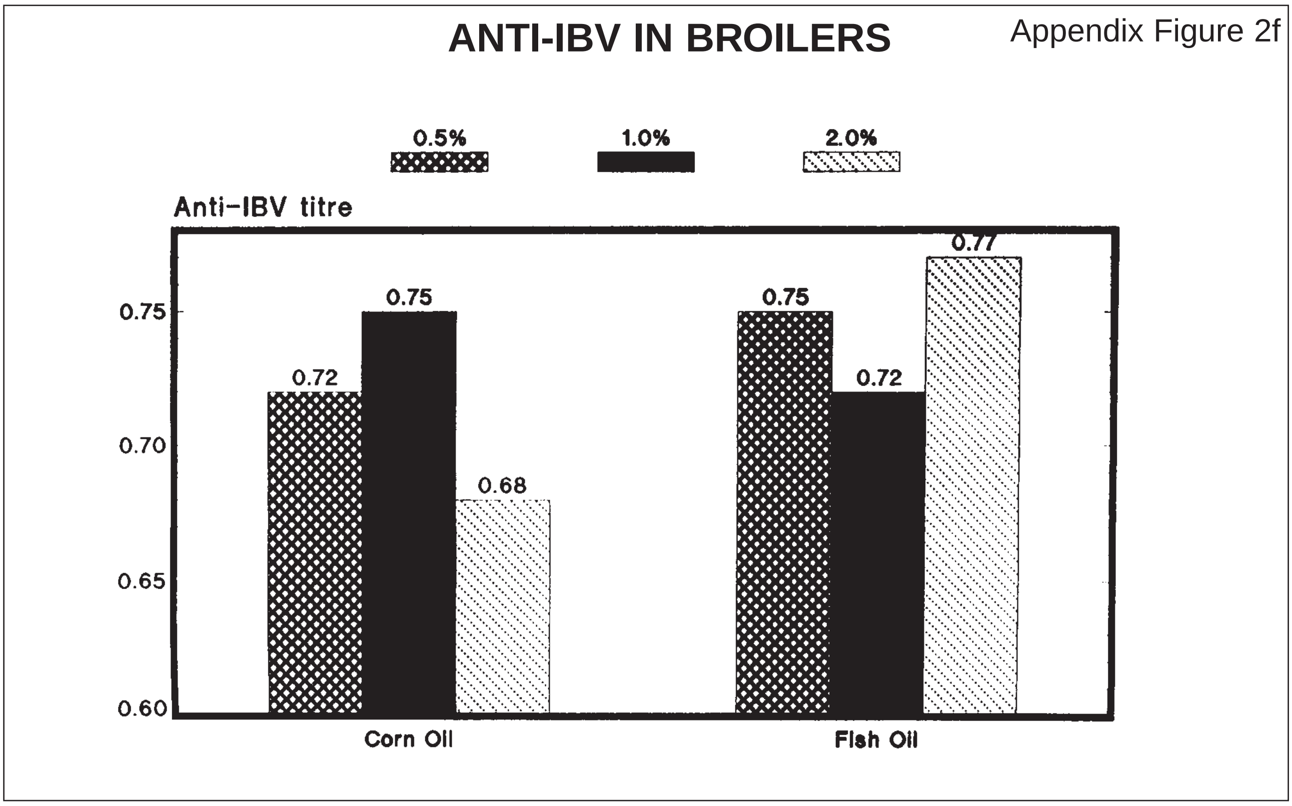
BODY TEMPERATURE OF BROILERS - LPS CHALLENGE

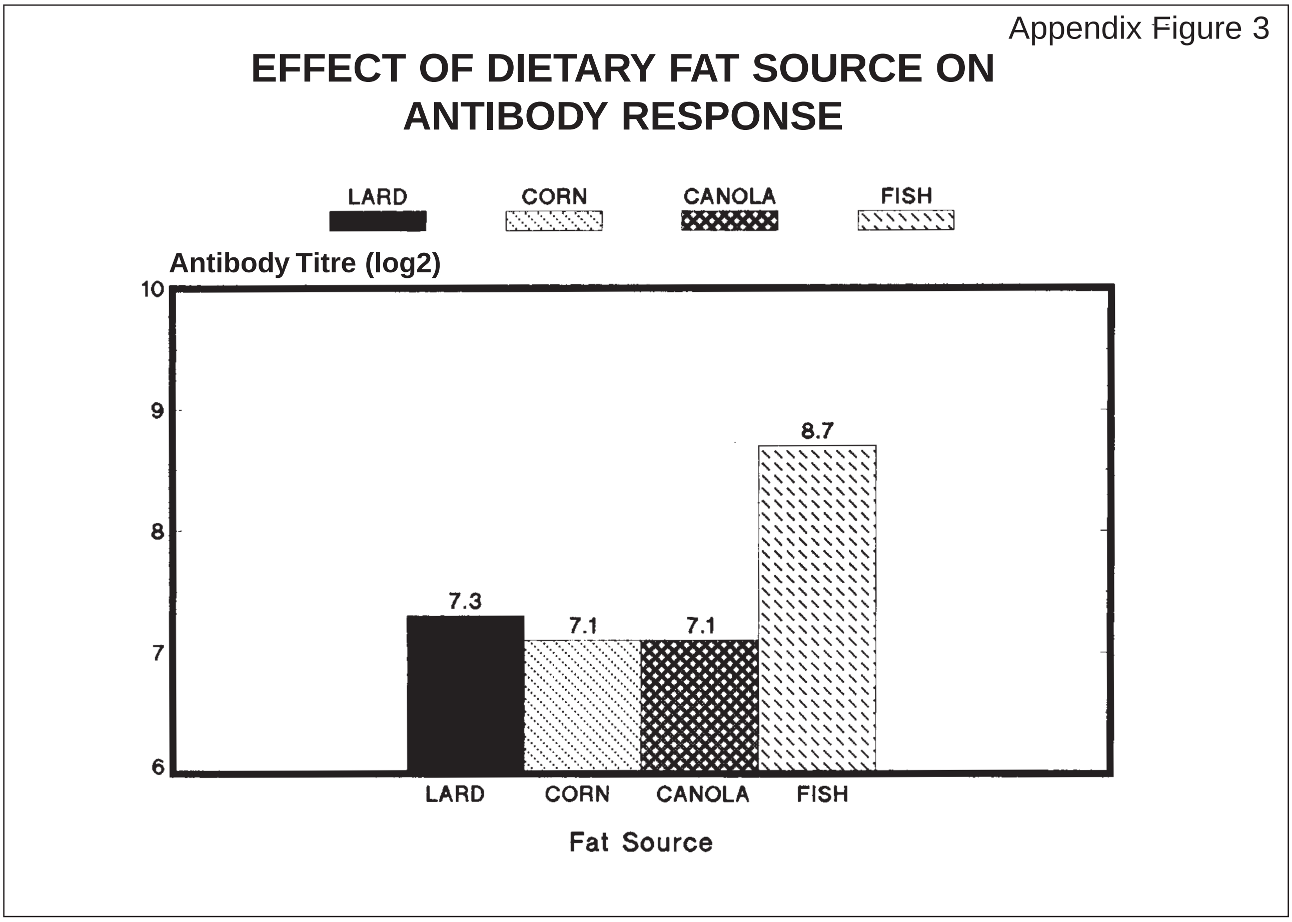


Appendix Figure 2c

INTERLEUKIN (IL1) IN BROILERS - LPS CHALLENGE




Appendix Figure 2f
ANTI-IBV IN BROILERS
0.5%
1.0%
2.0%
Anti-IBV titre
0.75
0.70
0.65
0.60
0.72
0.75
0.68
0.75
0.72
0.77
Corn Oil
Fish Oil


Appendix Figure 3
EFFECT OF DIETARY FAT SOURCE ON ANTIBODY RESPONSE
LARD
CORN
CANOLA
FISH
Antibody Titre (log2)
10
9
8
7
6
7.3
7.1
7.1
8.7
LARD
CORN
CANOLA
FISH
Fat Source

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