Acta Alimentaria, Vol. 28 (3), pp. 235–249 (1999)

N-3 FATTY ACID ENRICHMENT AND OXIDATIVE STABILITY OF BROILER CHICKEN

(A REVIEW)

H. A. MANILLA and F. HUSVÉTH

Department of Animal Physiology, Pannon University, Georgikon Faculty of Agricultural Sciences, H–8361 Keszthely, Deák F. u. 16. Hungary

(Received: 7 October 1998; accepted: 20 March 1999)

Increasing awareness of the health benefits of n-3 fatty acids has led to studies related to the manipulation of the fatty acid composition of animal products. These fatty acids, especially eicosapentaenoic acid (EPA; C20:5n-3) and docosahexaenoic acid (DHA; C22:6n-3), are abundant in foods of marine origin. Fish consumption is, however, limited by seasonal availability, affordability and consumers' preference. Recent studies on the provision of n-3 fatty acid rich foods have therefore centred on the enrichment of products such as poultry meat through feeding fish oil diets. However, decreased quality (storage and flavour) has been associated with products from poultry fed such diets. Other dietary sources of n-3 fatty acids such as fish meal and plant seed oils result in minor improvement of the quality and low levels of EPA and DHA in the enriched product. Supplementation of high levels of vitamin E or other synthetic antibiotics in diets may increase oxidative stability and hence the storage quality of n-3 fatty acid enriched broiler meat. However, their reported influence on off-flavour is conflicting. Other methods of reducing off-flavour in enriched meat involving the use of processed n-3 PUFA sources although may reduce off-flavour, result in reduced deposition of EPA and DPA. Marine algae (MA) is an attractive source of n-3 fatty acids because it is a primary rich source of DHA and contains naturally occurring carotinoids, which are useful for their antioxidant activity. Investigations into the use of MA and identification of cheaper sources of n-3 PUFA for the enrichment of broiler chicken are needed. In addition, the search for viable methods of reducing off-flavour in n-3 enriched broiler meat should continue. The production of high quality and affordable broiler meat is essential for realising the full benefits associated with the consumption of n-3 fatty acid enriched products.

Keywords: n-3 fatty acids; broiler chicken; oxidative stability; marine algae; vitamin E

1. Introduction

In recent years there has been an increase in morbidity and mortality from cancer, atherosclerosis, coronary heart diseases (CHD) and other related diseases the world

0139-3006/99/$ 5.00

over. Research has established a positive relationship between dietary fat intake and fatty acid composition of foods, and incidence of these diseases in humans (BURR et al., 1989; HRBOTCKY & WEBER, 1993). Current studies, involving the production of high quality animal products, have therefore been directed towards enriching animal products with health beneficial fatty acids of the n-3 family. A number of these studies have, however, focused on the enrichment of broiler chickens with these fatty acids through dietary sources. The tendency of broiler chicken meat so enriched to high rate of lipid peroxidation, has also prompted investigations into the influence of dietary n-3 fatty acid sources on the oxidative stability of the resultant product and on ways of reducing the rate of lipid peroxidation.

This review presents the physiological and health benefits of essential fatty acids in human diet. Current studies on dietary manipulation of the fatty acid composition of broiler chickens with emphasis on the n-3 polyunsaturated fatty acids (PUFA) are reviewed. The various methods of improving the oxidative stability of n-3 fatty acid enriched products are also discussed.

2. Essential fatty acids (n-3 and n-6 PUFA) in human health

Investigations on the diet–health relationship among various populations, North Americans (SINCLAIR, 1953), Greenland Eskimos (BANG & DYERBERG, 1972) and Nigerians (HOLMAN et al., 1996), have established that consumption of fish reduces the risks of CHD in humans.

The effect of fish consumption on the incidence of CHD is suggested to be related primarily to the long chain n-3 PUFA (eicosapentaenoic acid, EPA; and docosahexaenoic acid, DHA) found in fish oils.

Apart from their effects on CHD, n-3 PUFA (especially EPA and DHA) have been shown to posses anti-promotional effects on some types of cancer, rheumatoid arthritis, and multiple sclerosis (BRITISH NUTRITION FOUNDATION, 1992) as well as inflammatory bowel diseases (IBD; MESTER et al., 1999). Evidence from animal studies suggests that retinal function and learning ability are affected by nutritional deficiency of DHA during development (NEURINGER et al., 1988; BOURRE et al., 1989).

3. Relationship between n-3 and n-6 fatty acids

HOLMAN and co-workers (1996) reported an imbalance between n-3 and n-6 fatty acid in the food and plasma of many populations and a negative correlation between the plasma content of these two families of fatty acids in humans. Earlier, HOLMAN and MOHRHAUER (1963) observed that an increase in linolenic acid (C18:3n-3) intake

suppresses the metabolic products of linoleic (C18:2n-6) acid and enhances those of linolenic acid. Also it has been suggested that PUFA of the n-3 family exert an inhibiting effect on the metabolism of arachidonic acid (C20:4n-6; DYERBERG & BANG, 1978; HEROLD & KINSELLA, 1986), and the conversion of dietary linoleic acids to arachidonic acid (LANDS et al., 1973). Reduction in the concentration of arachidonic acid and its metabolites is suggested as one of the reasons why n-3 fatty acids reduce the risk of CHD (LEAF & WEBER, 1988). Also, a high intake of n-6 PUFA has been shown to increase the risk of gallstone in humans (STURDEVANT et al., 1973), reduce high density lipoprotein concentration (MATTSON & GRUNDY, 1985) and suppress the immune system (SANDERS, 1988; RASMUSSEN et al., 1994).

These findings have led to the suggestion that it may be desirable to give attention not only to the n-3 PUFA level but also to the n-6 to n-3 fatty acid ratio in human foods (LANDS, 1989; BRITISH NUTRITION FOUNDATION, 1992). YEHUDA and CARASSO (1993) in studies with rats found the optimum functional ratio between n-6 and n-3 fatty acids to be 4:1. BRITISH NUTRITION FOUNDATION (1992) recommended the consumption of n-6 and n-3 fatty acids to be in the ratio of 6:1.

4. Broiler chicken as a source of n-3 fatty acids in human diet

Broiler chicken can provide an excellent alternative source of PUFA of the n-3 family for humans (CHANMUGAM et al., 1992; HARGIS & VAN ELSWYK, 1993). Poultry meat is naturally low in fat content and rich in PUFA (IGENE & PEARSON, 1979). HULAN and co-workers (1988) calculated the amount of n-3 fatty acids that can be made available to a consumer of fat modified broiler chicken meat and reported that 100 g of such chicken meat would contain approximately 142 mg of EPA+DPA+DHA. This provides slightly higher amount of these fatty acids than the same amount of cod flesh (138 mg). In a follow-up study, HULAN and co-workers (1989) reported that feeding a 12% red fish meal diet to broiler chickens would provide approximately 197 mg of EPA+DPA+DHA per 100 g meat.

5. Dietary manipulation of lipid composition of poultry meat

Early studies involving the production of high quality poultry products were focused on the manipulation of total fat content for leaner meat and low cholesterol content of eggs (CARTWRIGHT, 1991). Relatively few studies were directed towards the manipulation of the fatty acid composition of poultry meat. Table 1 shows the n-3 fatty acid composition of breast muscles from broilers fed a standard no added fat diet and 4% cod liver or linseed oil diets. These data clearly demonstrate the remarkable

changes that occur in the n-3 fatty acid composition of broiler muscle as a result of the influence of diet.

OLOMU and BARACOS (1991) fed flax oil (highly polyunsaturated) to broilers with the aim of evaluating its effects on the incorporation of n-3 fatty acids into the skeletal muscle tissue. They reported an increased accumulation of n-3 fatty acids (linolenic acid and its long chain products, EPA, DPA and DHA) in skeletal muscle lipids with significant decrease in n-6 fatty acids levels. Their observation is in agreement with that of an earlier study by PHETTEPLACE and WATKINS (1989) who also reported a general increase in the tissue contents of linolenic acid and its long chain derivatives with the feeding of flax oil to chickens. CHANMUGAM and co-workers (1992) fed diets supplemented with corn, linseed, or menhaden oil to broilers. Birds supplemented with linseed oil (rich in linolenic acid) had significantly higher levels of n-3 fatty acids and higher n-3 to n-6 fatty acid ratio than those supplemented with the same level of menhaden oil primarily due to an accumulation of linolenic acid. Levels of EPA were increased in all the groups fed menhaden oil and higher levels of linseed oil when compared with the controls fed the same levels of corn oil. In a similar study, YAU and co-workers (1991) fed broiler diets containing safflower (highly polyunsaturated), olive (highly monounsaturated) and coconut (highly saturated) oils and reported that the ratios of specific fatty acids and the fatty acid profile of the breast meat were similar to those of the dietary oils. In an earlier study, MARION and WOODROOF (1963) investigating the effects of dietary corn oil (highly polyunsaturated) and tallow (highly saturated), on the fatty acid composition of breast, thigh, and skin tissues of broiler chickens, reported that each of the tissues analysed exhibited a fatty acid composition similar to those of the diet.

Table 1

N-3 fatty acid composition of the breast muscle of chickens fed a standard no added fat diet, cod liver and linseed oil diets (MANILLA, 1998)

	Standard no added fat diet	4% cod liver oil diet	4% linseed oil diet
	% total fatty acids		
C18 : 3n-3	0.6	1.7	10.0
C20 : 5n-3	1.0	4.2	2.7
C22 : 5n-3	1.8	4.0	3.1
C22 : 6n-3	3.4	9.9	2.6
Total n-3	6.8	19.8	18.3

The results of these studies indicated that feeding diets having the fatty acid composition desired of the resulting tissue might customise fatty acid profile of broiler tissues. In general, high n-3 PUFA diets increase tissue n-3 fatty acid concentration and depress those of n-6 and monounsaturated fatty acids. Dietary fish oils result in high deposition of EPA and DHA.

The influence of dietary fatty acid composition on various tissues of broiler chicken has also been widely studied (MARION & WOODROOF, 1963; MILLER and ROBISCH, 1969; LIN et al., 1989a; HUANG et al., 1990; YAU et al., 1991; PINCHASOV & NIR, 1992; HRDINKA et al., 1996) with reports of significant differences in fatty acid profile between muscle and adipose tissues of chicks fed diets of similar fatty acid composition.

Most of the above studies, reported higher deposition of EPA and DHA in the breast when compared with the adipose tissues. Similar results of increased levels of EPA and DHA deposition in the broiler muscle tissue, when compared with adipose (EDWARDS & MAY, 1965; MILLER et al., 1967a,b), with differences in deposition level between the breast and the thigh muscles (MARION & WOODROOF, 1963), with the feeding of various dietary oils have been made in earlier reports.

The observation of preferential deposition of n-3 fatty acids within muscle fat depots may be of interest due to the fact that these are the consumers' choice carcass portions.

6. Sources of n-3 fatty acids for broiler diets

6.1. Fish oil and fish meal

Most studies on the n-3 fatty acid enrichment of poultry meat through dietary sources have focused on the use of marine sources of n-3 fatty acids especially fish oil and fish meal (CARRICK & HAUGE, 1926; MARION & WOODROOF, 1963; EDWARDS & MAY, 1965; MILLER et al., 1967a,b; MILLER & ROBISCH, 1969; HULAN et al., 1988; ACKMAN et al., 1988; HULAN et al., 1989). Studies cited above reported substantial enhancement of EPA, DHA, and other n-3 fatty acids in the tissues of chickens with the supplementation of various fish oil or fish meal in the diets. HULAN and co-workers (1988) fed chickens with a diet containing 5% fish meal and reported a substantial increase in EPA, DHA and other n-3 PUFA in the total carcass and edible meat lipids. Earlier, MILLER and ROBISCH (1969), in a broiler feeding trial with menhaden, herring and safflower oils, reported the highest level of deposition of EPA and DHA for diet supplemented with menhaden oil followed by herring oil (8% less than menhaden in total 20-carbon n-3 fatty acids).

DYERBERG and BANG (1978), and HEROLD and KINSELLA (1986) suggested that the beneficial effect of seafood consumption in reducing the risk of CHD is due to their high content of n-3 PUFA (especially EPA and DHA). Fish oil is rich in EPA and DHA which are considered the group of fatty acids contributing to the anti ischeamic disease effect of PUFA enriched products (NETTLETON, 1991). These findings may have led to the idea that it may be desirable to increase the n-3 fatty acids of chickens with marine sources.

The feeding of fish oil have been reported to strongly influence flavour and storage quality of carcass. In an early study, CARRICK & HAUGE (1926) reported significant off-flavour in meat samples from chickens fed 4% dietary cod liver oil. EDWARDS and MAY (1965) using untrained panellists, reported that meat samples from broilers fed menhaden oil alone were poorer in flavour (using mean flavour scores) than those fed menhaden in combination with plant seed oils. Unacceptable odours have also been observed by other authors in carcasses of chickens fed fish oil at levels of 4% (DANSKY, 1962), 2.5% (HOLDAS & MAY, 1966), 2% (CARRICK & HAUGE, 1926; EDWARDS & MAY, 1965) and 1.8% (HARDIN et al., 1964). In studies with turkey, feeding of fish oil at levels of 2- or 5% (ASMUNDSON et al., 1938; KLOSE et al., 1953) also produced off-flavour.

Decreased product quality associated with feeding fish oil prompted investigations to examine the effects of dietary fish meal as an alternative to fish oil on the flavour of broiler chicken meat. The feeding of various levels of fish meal of over 14% has been associated with unacceptable flavours (DEAN et al., 1971; HULAN et al., 1989; RATNAYAKE et al., 1989). In an earlier study, ASMUNDSON and co-workers (1938) replaced 2–10% (commonly used levels) fish oil with fish meal in broiler diet and reported decreased off-flavour in meat when compared with fish oil. RATNAYAKE and co-workers (1989) found no off flavour with meat samples from broiler chickens fed 4% or 8% dietary red fish meal. However, they noted that meat samples from chicks fed 12% red fish meal were less preferred in flavour than those birds fed lower dietary fish meal levels.

Although a large number of the studies reviewed tended to suggest that fish meal decreases off-flavour in n-3 fatty acid modified poultry meat, the resultant flavours were identified as “less preferred” by panellists using flavour scores.

6.2. Oils of plant origin

Because of the association of off-flavour of poultry meat products with dietary fish oils, several investigations were conducted to investigate the effects of plant sources of n-3 fatty acids in diet on the fatty acid composition and quality of broiler chicken meat. PHETTEPLACE and WATKINS (1989) compared the effects of 5% dietary linseed oil (rich in linolenic acid) with 5% menhaden oil when fed to broilers and reported that

while both oils resulted in significant increases in total tissue n-3 fatty acids, muscle deposition of the sum total of EPA and DHA was significantly less (2.9 and 2.2 weight % in breast and thigh muscles, respectively) in linseed oil fed chicks than in those fed menhaden oil (20 and 17 weight % in breast and thigh muscles, respectively). Linseed oil resulted predominantly in linolenic acid deposition in muscle tissue. Recent studies on the effect of dietary linseed oil on off-flavour of broiler meat appear to be lacking. Early work by KLOSE and co-workers (1951, 1953) studied the effects of dietary linseed on off-flavour of turkey meat and reported moderate fish flavour with birds fed 2% or 5% dietary linseed when compared with corn oil or beef tallow. OLOMU and BARACOS (1991) using various combinations of animal tallow and flaxseed oil (FSO) reported that linolenic acid was the primary constituent of muscle lipids of broilers fed 4.5% dietary flax seed oil, increasing from less than 1% (in muscle tissues of birds fed 6% animal tallow) to 8.9% of muscle lipids in response to dietary flax seed oil. Deposition of EPA and DHA in muscle tissue was significantly low. Flaxseed oil contains about 50% linolenic acid, making it the richest plant source of n-3 fatty acids.

The evaluation of the effect of other n-3 PUFA rich plant oils such as rapeseed oil (HAWRYSH et al., 1980), canola oil (SALMON et al., 1981), safflower oil (MILLER & ROBISCH, 1969) have also been conducted with report of lower tissue deposition of EPA and DHA and improved flavour when compared with fish oil. Plant sources of n-3 fatty acids (oils) are rich in linolenic acid (LANDS, 1986) and contain low concentrations of EPA and DHA (NETTLETON, 1991). Therefore, the reduction in occurrence of off-flavour reported in the above studies with dietary plant oils may be related to the high linolenic acid, and low EPA and DHA content of the products. Results from these studies also reveal that the ability of broiler chickens to synthesise long chain n-3 PUFA from linolenic acid (C18:3n-3) is apparently limited. Despite the improvement in flavour of meat enriched with n-3 fatty acids through the feeding oils of plant origin, the resulting n-3 fatty acid of the meat product must be considered.

6.3. Marine microalgae (MA)

A recent development in the search for optimum source of n-3 fatty acids for poultry feed has been the use of fermented natural marine microalgae (MA) with a high DHA content (BARCLAY et al., 1994). MA is a rich source of DHA which has been shown to inhibit diseases which inhibition is associated with EPA consumption (GAUDETTE & HOLUB, 1991). Studies have demonstrated that DHA can be converted in the animal tissue to EPA (FISCHER et al., 1987; GRONN et al., 1991; ROSENTHAL et al., 1991). REITAN and co-workers (1993) examined the effects of dietary MA on the performance of fish and reported an increased tissue deposition of DHA. In a recent study HERBER and VAN ELSWYK (1996) investigated the influence of MA as a poultry feed supplement in the enrichment of shell egg with n-3 fatty acids. They observed that

levels of total n-3 fatty acids in yolk were significantly increased with a reduction in yolk n-6 fatty acids. Yolk DHA deposition was efficient with the highest yolk DHA level attained in eggs from hens fed 4.8% MA as compared to a typical corn-soybean control, 1.5% menhaden oil and 2.4% of MA.

MA is an attractive source of n-3 fatty acids. It is a primary source in the natural fish diet. It is also a source of natural carotinoids (canthaxanthin and beta-carotene) which are useful for their antioxidant activity (BENDICH, 1989; BURTON, 1989). The presence of these will enhance oxidative stability of broiler tissue while providing humans with the fatty acids associated with health benefits. Apart from these benefits, microalgae can be effectively preserved (GRIMA et al., 1994) and cultured to give a high biomass and PUFA content (COCCHI et al., 1994).

These studies suggest that there are numerous viable n-3 fatty acid sources for poultry ration. However, it must be realised that the fatty acid composition of the final product varies depending on the dietary source. The optimum dietary source of n-3 fatty acids will be one that supplies both similar fatty acids as fish oil and offers oxidatively stable fat.

7. Oxidative stability and n-3 PUFA enriched broiler meat quality

To fully realise the benefits associated with consumption of n-3 fatty acid enriched poultry meat and products, they must meet consumer's requirement in taste and storage quality. The decrease in product quality (flavour and storage) of n-3 PUFA enriched poultry meat product has been associated with the oxidation of highly unsaturated fatty acids in the tissues (SALMON & O'NEIL, 1973). KLOSE and co-workers (1953) investigated the oxidative stability of meat from turkey fed linseed and fish oil (highly unsaturated) and reported positive correlation between oxidation activity (peroxide and aldehyde production) in carcass and dietary PUFA levels. Unsaturated fats easily undergo oxidation as a result of their double bonds, to produce oxidation products (peroxides and aldehydes) which are responsible for the off-flavour in oxidised tissues (ALLEN & FOEGEDING, 1981; MACDONALD et al., 1982; PERSON et al., 1983) and reduction in storage quality (GRAY & CRACKEL, 1991).

Studies have also shown that the triacylglycerol fraction of the n-3 PUFA modified meat containing significant levels of long chain fatty acids such as EPA and DHA are positively correlated with tissue off-flavour (WESSELS et al., 1973).

8. Improving the oxidative stability of n-3 fatty acid enriched broiler chicken meat

8.1. Use of antioxidants

Attempts have been made at reducing lipid peroxidation of meat through the use of antioxidants. LIN and co-workers (1989b) reported that an antioxidant stabilisation of dietary oil improved the shelf life of n-3 fatty acid enriched meat products. Similarly, EDWARDS and MAY (1965) reported improved flavour scores for meat samples from birds fed menhaden oil together with antioxidant in the diet. Antioxidants such as santoquin (EDWARDS & MAY, 1965) and ethoxyquin (ATKINSON et al., 1972; LIN et al., 1989b; MONHAN et al., 1990) have been studied with varying results on their effects on meat flavour and n-3 PUFA deposition in the muscle of broiler chickens.

8.2. Dietary vitamin E supplementation

Recent investigations on the improvement of the oxidative status of poultry meat have been directed towards the supplementation of diets with high level of vitamin E. Studies have shown that dietary supplementation of both free α-tocopherol or its acetate ester in the diets of broilers and turkey increases tocopherol content of tissues, delays lipid oxidation and extends the shelf life of meat (MECCHI et al., 1956; MARUSICH et al., 1975; UEBERSAX et al., 1978; COMBS & RENGENSTEIN, 1980; BARTOV & BORNSTEIN, 1981; BARTOV et al., 1983). LIN and co-workers (1989a,b), investigating the effects of dietary supplementation of α-tocopherol on oxidative stability of broiler meat reported that meat from broilers given 100 IU kg^{-1} α-tocopherol in feed was more stable than meat from those fed unsupplemented diets. In addition, the oxidative stability of the thigh and the breast muscle were significantly improved during storage. When oxidised oils were used in the diet 200 IU kg^{-1} α-tocopherol supplementation in feed improved the oxidative stability of broiler meat when compared with unsupplemented diet (LIN et al., 1989b). SHELDON (1984) fed turkeys 275 IU α-tocopherol acetate/kg feed for three weeks before slaughter and reported 3 times higher tissue concentration of α-tocopherol than those from the control chicks fed 1.63 IU kg^{-1}. Furthermore, tissues from the supplemented diets were more stable in cold store. AJUYAH and co-workers (1993), evaluating the stability of n-3 enriched broiler meat after supplementing full-flax seed based broiler diet with vitamin E, reported a significant reduction in meat susceptibility to oxidation.

Several other recent studies have also reported improvement in the oxidative stability of chicken meat (SHEEHY et al., 1993; KLAUS et al., 1995) and pork meat (LESKANICH et al., 1997; FLACHOWSKY et al., 1997) with dietary supplementation of α-tocopherol. CHERIAN and co-workers (1996) studied the effect of dietary oils with added tocopherols on the fatty acid composition of liver, adipose tissue, thigh and breast meat

in broiler chickens and reported a significant increase ($P<0.05$) in the content of EPA and DHA in adipose tissue and breast meat from birds fed menhaden oil with added tocopherol diet when compared with that without tocopherol. AJUYAH and co-workers (1993) reported an elevation of the n-3 PUFA in the broiler muscle with dietary antioxidant supplementation.

8.3. Other methods

The off-flavour observed with n-3 fatty acid modified meat has also been attributed to the quality of the dietary sources, especially of fish meal and oils. STANSBY (1990) indicated that the off-flavour associated with meat samples from dietary fish oil and fish meal is due to volatile compounds and a range of other substances from peroxidation during processing and storage. It does appear that extensive processing with the resulting increased surface area of fish and oils make these sources susceptible to oxidative deterioration, which enhances the formation of volatile compounds. FRY and co-workers (1965) recommended the use of high grade fish oil and fish meal as dietary sources of n-3 fatty acids for poultry enrichment. In an early study, CRUIKSHANK (1939) reported no off-flavour and fishy-flavour with feeding high and low-grade fish meal, respectively.

To reduce the high levels of oxidation compounds (by-products) in dietary n-3 sources they were subjected to water, acid and ethanol extraction (WESSELS et al., 1973) before feeding. Improved flavour scores were observed for the three-extraction methods. However, a significant reduction (85%) of the n-3 fatty acid deposition was observed for ethanol extraction, which gave the highest flavour scores. The results suggest that the extraction methods modify the fatty acid composition of these sources, which may result in reduced deposition of n-3 fatty acids especially EPA and DHA in the product.

Heat stabilisation of dietary oil (ATKINSON et al., 1972) has also been studied with report of no significant improvement of off-flavour.

The effects of starving chicks (DEAN et al., 1971) and withdrawal of fish oil form diet (CARRICK & HAUGE, 1926; ASMUNDSON et al., 1938; MILLER & ROBISCH, 1969) before slaughter on the off-flavour of meat have also been studied with reports of reduced off-flavour. However, these methods may reduce weight gain and levels of deposited n-3 fatty acids, respectively.

9. Conclusion

Broiler chicken may effectively be enriched with n-3 PUFA through dietary means. However, the high rate of lipid peroxidation of such enriched product, which affects flavour and storage quality, may still be a limiting factor to its full acceptance by consumers. High (supernutritional) levels of vitamin E and other antioxidants in diet may improve the oxidative stability and hence storage quality of enriched products. Investigations on ways of reducing off-flavour have not produced a viable method. Investigations into the use of marine algae (MA) and identification of other cheap sources of n-3 PUFA for broiler ration are needed. In addition the search for viable methods of reducing off-flavour should continue. Quality and affordability will play an increasing role in the acceptability and marketing of n-3 enriched broiler meat products.

References

ACKMAN, R. G., LAMOTHE, M. F., HULAN, H. W. & PROUDFOOT, F. G. (1988): The broiler chicken - its current and potential role as a source of long chain n-3 fatty acids in our diets. *N-3 News*, *3*, 1–3.

AJUYAH, A. O., AHIN, D. U., HARDIN, R. T. & SIM, J. S. (1993): Dietary antioxidants and storage affect chemical characteristics of omega-3 fatty acid enriched broiler chicken meat. *J. Fd Sci.*, *58*, 43–46.

ALLEN, C. E. & FOEGEDING, E. (1981): Some lipid characteristics and interactions in muscle foods – a review. *Fd Technol.*, *35*, (5), 253–257.

ASMUNDSON, V. S., JUKES, T. H., TYLER, H. M. & MAXWELL, M. L. (1938): The effects of certain fish meals and fish oils in the ration on flavour of the turkey. *Poultry Sci.*, *17*, 147–151.

ATKINSON, A., SWART, L. G., VAN DER MERWE, R. P. & WESSELS, J. P. H. (1972): Flavour studies with different levels and times of fish meal feeding and some flavour imparting additives in broiler diets. *Agroanimalia*, *4*, 53–62.

BANG, H. O. & DYERBERG, J. (1972): Plasma lipids and lipoprotein in Greenlandic west coast Eskimos. *Acta med. Scand.*, *192*, 85–88.

BARCLAY, W. R., MEAGER, K. M. & ABRIL, J. R. (1994): Heterotrophic production of long chain omega-3 fatty acids utilizing algae-like microorganisms. *J. appl. Phycol.*, *6*, 123–129.

BARTOV, I. & BORNSTEIN, S. (1981) Stability of abdominal fat and meat of broilers: Combined effect of dietary vitamin E and synthetic antioxidants. *Poultry Sci.*, *60*, 1840–1845.

BARTOV, I., BASKER, D. & ANGEL, S. (1983): Effect of dietary vitamin E on the stability and sensory quality of turkey meat. *Poultry Sci.*, *62*, 1224–1230.

BENDICH, A. (1989): Symposium conclusions: Biological actions of carotinoids. *J. Nutr.*, *119*, 135–136.

BOURRE, J. M., DUMONT, O., PICIOTTI, M., PASCAL, C. & DURAND, G. (1989): Polyunsaturated fatty acids of the n-3 series and the nervous system development. -in: GALLI, C. & SIMOPOULOS, A. P. (Eds) *Dietary ω3 and ω6 fatty acids–biological effects and nutritional essentiality*. Plenum Press, New York, pp. 159–175.

BRITISH NUTRITION FOUNDATION (BNF) (1992): *Unsaturated fatty acids: Nutritional and physiological significance*. The Report of British Nutrition Foundation's Task Force. Chapman and Hall, London, pp. 211.

BURR, M. L., FEHILY, A. M., GILBERT, J. F., ROGERS, S., HOLLIDAY, R. M., SWEETNAM, P. M., ELWOOD, P. C. & DEADMAN, N. M. (1989): Effects of changes in fat, fish and fibre intakes on death and reinfarction trial (DART). *Lancet*, *II*, 757–761.

BURTON, G. W. (1989): Antioxidant action of carotinoids. *J. Nutr.*, *119*, 109–111.

CARRICK, C. W. & HAUGE, S. M. (1926): The effects of cod liver oil upon flavour in poultry meat. *Poultry Sci.*, *5*, 213–215.

CARTWRIGHT, A. L. (1991): Adipose cellularity in *Gallus domesticus*: Investigations to control body composition in the growing chicken. *J. Nutr.*, *121*, 1486–1497.

CHANMUGAM, P., BOUDREAU, M., BOUTTE, T., PARK, R. S., HEBERT, J, BERRIO, L. & HWANG, D. H. (1992): Incorporation of different types of n-3 fatty acids into tissue lipids of poultry. *Poultry Sci.*, *71*, 516–521.

CHERIAN, G., WOLFE, F. W. & SIM, J. S. (1996): Dietary oils and added tocopherols: Effects on egg or tissue tocopherols, fatty acids, and oxidative stability. *Poultry Sci.*, *75*, 423–431.

COCCHI, M., NOBLE, R. C., FALLOWFIELD, H., SPEAKE, B. & TURCHETTO, E. (1994): The significance of n-3 fatty acid in foetal and neonatal development and some alternative sources. *Proc. Nutr. Soc.*, *53*, 224A.

COMBS, G. F., Jr. & RENGENSTEIN, J. M. (1980): Influence of selenium, vitamin E and ethoxyquin on lipid peroxidation in muscle tissue from fowl during low temperature storage. *Poultry Sci.*, *59*, 347–351.

CRUIKSHANK, E. M. (1939): The effects of cod liver oil and fish meal on the flavour of poultry products. *Proceedings of 7th World Poultry Congr.*, Vol. 7, 539–542.

DANSKY, L. M. (1962): The growth and promoting properties of menhaden fish oil as influenced by various fats. *Poultry Sci.*, *41*, 1352–1354.

DEAN, P., PROUDFOOT, G. G., LARMOUND, E. & AITKEN, J. R. (1971): The effects of feeding diets containing white fish meal on acceptability and flavour intensity of roasted broiler chickens. *Can. J. Anim. Sci.*, *51*, 15–20.

DYERBERG, J. & BANG, H. O. (1978): Dietary fats and thrombosis. *Lancet*, *1*, 152–156.

EDWARDS, H. M. Jr. & MAY, K. N. (1965): Studies with menhaden oil in practical-type broiler ration. *Poultry Sci.*, *44*, 685–688.

FISCHER, C., VISCHER, A. & PREAC-MURSIC, J. T. (1987): Dietary docosahexaenoic acid is reconverted in man to eicosapentaenoic acid, which can quickly be transformed to prostagladins I3. *Prostagladins*, *34*, 367–375.

FLACHOWSKY, G., SCHONE, F., SCHAARMANN, G., LUBBE, F. & BOHME, H. (1997): Influence of oilseeds in combination with vitamin-E supplementation in the diet on back fat quality of pigs. *Anim. Feed Sci. Technol.*, *64*, 91–100.

FRY, J. L., VAN WALLEGHEM, P., WALDROUP, P. W. & HARMIS, R. H. (1965): Fish meal studies: Effects of levels and sources of fishy flavour in broiler meat. *Poultry Sci.*, *44*, 1016–1019.

GAUDETTE, D. C. & HOLUB, B. J. (1991): Docosahexaenoic acid (DHA) and human platelet reactivity. *J. Nutr. Biochem.*, *2*, 116–121.

GRAY, J. I. & CRACKEL, R. L. (1991): Lipid oxidation in meat products. -in: COELHO, M. B. (Ed.) *Vitamin E in animal nutrition and management*. BASF, New Jersey, USA, pp. 147–153.

GRIMA, E. M., PEREZ, J. A. S., CAMACHO, F. G., FERMANDEZ, F. G. A., ALONSO, D. L. & DELCASTILLO, C. I. S. (1994): Preservation of the marine microalgae, *Isochrysis galbana* – Influence on the fatty acid profile. *Aquaculture*, *123*, 3–4.

GRONN, M., CHRISTENSEN, E., HAGVE, T. & CHRISTOPHERSON, B. O. (1991): Peroxisomal retroconversion of decosahexaenoic acid (22:6n-3) to eicosapentaenoic acid (20:5n-3) studied in isolated rat liver cells. *Biochem. biophys. Acta*, *1081*, 85–91.

HARDIN. J. O., MILLIGAN, J. L. & SIDWELL, V. D. (1964): The influence of solvent extracted fish meal and stabilised fish oil in broiler ration on performance and on the flavour of broiler meat. *Poultry Sci.*, *43*, 858–860.

HARGIS, P. S. & VAN ELSWYK, M. E. (1993): Manipulation of fatty acid composition of poultry meat and eggs for health conscious consumer. *World's Poultry Sci. J.*, *49*, 251–264.

HAWRYSH, Z. J., STEEDMAN-DOUGLAS, C. D., ROBBLEE, A. R., HARDIN, R. T. & SAM, R. M. (1980): Influence of low glucosinolate (cv. Tower) rapeseed meal on the eating quality of broiler chickens. 1. Subjective evaluation by a trained test panel and objective measurements. *Poultry Sci.*, *59*, 550–557.

HERBER, S. M. & VAN ELSWYK, M. E. (1996): Dietary marine algae promote efficient deposition of n-3 fatty acid for the production of enriched eggs. *Poultry Sci.*, *75*, 1501–1507.

HEROLD, P. M. & KINSELLA, J. E. (1986) Fish oil consumption and decreased risk of cardiovascular disease: A comparison of findings from animals and human feeding trials. *Am. J. clin. Nutr.*, *43*, 566–598.

HOLDAS, P. S. & MAY, K. N. (1966): Fish oil and fishy flavour of eggs and carcasses of hen. *Poultry Sci.*, *45*, 1405–1407.

HOLMAN, R. T. & MOHRHAUER, H. (1963): A hypothesis involving competition in the metabolism of polyunsaturated fatty acids. *Acta Chem.*, *17*, S84–S90.

HOLMAN, R. T., JOHNSON, S. B., BIBUS, D. M., OKEAHIALEM, T. C. & EGWIM, P. O. (1996): High omega 3 essential fatty acid status in Nigerians and low status in Minnesotans. *J. Biol.*, *1*, 2–3.

HRBOTICKY, N. & WEBER, P. (1993): Dietary habits and cardiovascular risk. The role of cardiovascular disease. -in: NER SERNERI, G., GENSINI, F., ABBATE, R. & PRISCO, D. (Eds) *Atherosclerosis*. Scientific Press, Florence, pp. 131–152.

HRDINKA, C., ZOLLITSCH, W., KNAUS, W. & LETTNER, F. (1996): Effects of dietary fatty acid pattern on melting point and composition of adipose tissues and intramuscular fat of broiler carcasses. *Poultry Sci.*, *75*, 208–215.

HUANG, Z. B., LEIBOVITZ, H., LEE, C. M. & MILLAR, R. (1990): Effects of dietary fish oil on ω3 fatty acid level in chicken eggs and thigh flesh. *J. agric. Fd Chem.*, *38*, 743–747.

HULAN, H. W., ACKMAN, R. G., RATNAYAKE, W. M. N. & PROUDFOOT, F. G. (1988): Omega-3 fatty acid levels and performance of broiler chickens fed redfish meal or oil. *Can. J. Anim. Sci.*, *68*, 533–547.

HULAN, H. W., ACKMAN, R. G., RATNAYAKE, W. M. N. & PROUDFOOT, F. G. (1989): Omega-3 fatty acid levels and general performance of broiler chickens fed reddish meal or reddish oil. *Poultry Sci.*, *68*, 153–162.

IGENE, J. O. & PEARSON, A. M. (1979): The roles of phospholipids and triglycerides in warmed-systems. *J. Fd Sci.*, *44*, 1285–1290.

KLAUS, A. M., FUHMANN, H. & SALLMANN, H. P. (1995): Peroxidative and antioxidative metabolism of broiler chickens as influenced by dietary linoleic acid and vitamin E. *Arch. Geflügelkd.*, *59*, 135–144.

KLOSE, A. A., MECCHI, E. P., HANSON, H. L., STREETER, I. V. & LINE-WEAVER, H. (1951): The role of dietary fat in the quality of fresh and frozen storage turkeys. *J. Am. Oil Chem. Soc.*, *28*, 162–164.

KLOSE, A. A., HANSON, H. L., MECCHI, E. P., ANDERSON, J. H., STREETER, I. V. & LINE-WEAVER, H. (1953): Quality and stability of turkey as a function of dietary fat. *Poultry. Sci.*, *32*, 82–88.

LANDS, W. E. M. (1986): Overall supply of n-3 fatty acid. -in: SIMOPOULUS, A. P., KIFER, R. R., MARTIN, R. E. & BARLOW, S. M. (Eds) *Fish and human health*. Academic Press, New York, pp. 129–135.

LANDS, W. E. M. (1989): N-3 fatty acids as precursors for active metabolic substances: Dissonance between expected and observed events. *J. int. Med.*, *225*, 11–20.

LANDS, W. E. M., LETELLIER, P. E., ROME, L. H. & VANDERHOEK, J. Y. (1973): Inhibition of prostagladin biosynthesis. *Adv. Biosci.*, *9*, 15–28.

LEAF, A. & WEBER, P. C. (1988) Cardiovascular effects of n-3 fatty acids. *New Engl. J. Med.*, *312*, 1205–1209.

LESKANICH, C. O., MATTHEWS, K. R., WARKUP, C. C., NOBLE, R. C. & HAZZLEDINE, M. (1997): The effects of dietary oil containing (n-3) fatty acids on the fatty-acid, physicochemical, and organoleptic characteristics of pig meat and fat. *J. Anim. Sci.*, *75*, 673–683.

LIN, C. F., ASGHAR, A., GRAY, J. I., BUKCLEY, D. J., BOOREN, A. M., CRACKEL, R. L. & FLAGAL, C. J. (1989a): Effects of oxidised dietary oil and antioxidant supplementation on broiler growth and meat stability. *Br. Poultry Sci.*, *30*, 855.

LIN, C. F., GRAY, J. I., ASGHAR, A., BUCKLEY, D. J., BOOREN, A. M. & FLAGAL, C. J. (1989b): Effects of dietary oil and α-tocopherol supplementation on lipid composition and stability of broiler meat. *J. Fd Sci.*, *54*, 1457–1460.

MACDONALD, D., GRAY, J. I., UEXBERSAX, M. A. & MORTON, I. D. (1982): Statistical evaluation of three methods for measuring lipid oxidation in a model system. *Fd Chem.*, *8*, 21–25.

MANILLA, H. A. (1998): Nutritional manipulation of the fatty acid composition of broiler meat product using fats and oils. Ph.D. Thesis, Keszthely, pp. 54.

MARION, J. E. & WOODROOF, J. G. (1963): The fatty acid composition of breast, thigh and skin tissues of chicken broilers as influenced by dietary fats. *Poultry Sci.*, *48*, 1202–1207.

MARUSICH, W. L., DERITTER, E., OGRINZ, E. F., KEATING, J, MITROVIC, M. & BUNNEL, R. H. (1975): Effect of supplemental vitamin E in control of rancidity in poultry meat. *Poultry Sci.*, *54*, 831–844.

MATTSON, F. H. & GRUNDY, S. M. (1985): Comparisons of the effects of dietary saturated, monounsaturated and polyunsaturated fatty acids in plasma lipids and lipoproteins in man. *J. Lipid Res.*, *26*, 194–202.

MECCHI, E. P., POOL, M. F., NONAKA, M., KLOSE, A. A., MARSDEN, S. J. & LLILLE, R. J. (1956): Further studies on tocopherol content and stability of carcass fat of chickens and turkeys. *Poultry Sci.*, *35*, 1246–1251.

MESTER, A., MAKÓ, E., NAGYLUCSKAY, S., KARLINGER, K., MARTON, E. & GYÖRKE, T. (1999): High resolution computed tomography detection of alimentary factors related arthropathies in inflammatory bowel disease (IBD). *Acta Alimentaria*, *28*, 171–181.

MILLER, D. & ROBISCH, P. (1969): Comparative effect of herring, menhaden and safflower oils on broiler tissue fatty acid composition and flavour. *Poultry Sci.*, *48*, 1246–2157.

MILLER, D., GRUGER, E. H. JR., LEONG, K. C. & KNOBL, G. M. Jr. (1967a): Effects of refined menhaden oil on the flavour and fatty acid composition of broiler flesh. *J. Fd Sci.*, *32*, 342–345.

MILLER, D., GRUGER, E. H. JR., LEONG, K. C. & KNOBL, G. M. Jr. (1967b): Dietary effect of menhaden oil ethyl esters on the fatty acid pattern of broiler muscle lipids. *Poultry Sci.*, *46*, 438–444.

MONHAN, F. J., BUCKLEY, D. J., GRAY, J. I., MORRISSEY, P. A., ASGHAR, A., HANRAHAN, T. J. & LYNCH, P. B. (1990): Effects of dietary vitamin E on the stability of raw and cooked pork. *Meat Sci.*, *27*, 99–108.

NETTLETON, J. A. (1991) N-3 fatty acid: composition of plants and seafood sources in human nutrition. *J. Am. Diet. Assoc.*, *91*, 331–337.

NEURINGER, M., ANDERSON, G. J. & CONNOR, W. E. (1988): The essentiality of n-3 fatty acids for the development and function of the retina and the brain. *Ann. Rev. Nutr.*, *8*, 517–541.

OLOMU, J. M. & BARACOS, V. E. (1991): Influence of dietary flaxseed oils on performance, muscle protein deposition and fatty acid composition of broiler. *Poultry Sci.*, *70*, 1403–1411.

PERSON, A. M., GRAY, J. I., WOLZAK, A. M. & HORENSTEIN, N. A. (1983): Safety implications of oxidised lipids in muscle foods. *Fd Technol.*, *37* (7), 121–124.

PHETTEPLACE, H. W. & WATKINS, B. A. (1989): Effects of various n-3 sources on fatty acid composition in chicken tissues. *J. Fd Comp. Anal.*, *2*, 104–117.

PINCHASOV, Y. & NIR, I. (1992): Effects of dietary polyunsaturated fatty acid concentration on performance, fat deposition, and carcass fatty acid composition in broiler chickens. *Poultry Sci.*, *71*, 1504–1512.

RASMUSSEN, L. B., KIENS, B., PEDERSEN, B. K. & RICHTER, E. A. (1994): Effects of diets and plasma fatty acid composition on immune status in elderly men. *Am. J. clin Nutr.*, *59*, 572–577.

RATNAYAKE, W. M. N., ACKMAN, R. G. & HULAN, H. W. (1989): Effects of red fish meal enriched diets on the taste and n-3 PUFA of 42 days old broiler chickens. *J. Sci. Fd Agric.*, *49*, 59–74.

REITAN, K. I., RAINUZZO, J. R., OIE, G. & OLSEN, Y. (1993): Nutritional effects of algae addition in first feeding of turbot *Scophthalamus maximus* larva. *Aquaculture*, *118*, 257–275.

ROSENTHAL, M. D., CARCIA, M. C., JONES, M. R. SPRECHER, H. (1991): Retroconversion and D4 desaturation of docosatetraenoate (22:4n-6) and docosapentaenoate (22:5n-3) by human cells in culture. *Biochem. biophys. Acta*, *1083*, 29–36.

SALMON, R. E. & O'NEIL, J. B. (1973): The effects of dietary fat and storage temperature on the storage stability of turkey meat. *Poultry Sci.*, *52*, 314–317.

SALMON, R. E., GARDINER, E. E., RLEIN, K. K. & LARMOND, E. (1981): Effects of canola (low glucosinate rapeseed) meal, protein and nutrient density on performance, carcass grade, and meat yield of canola meal on sensory quality of broilers. *Poultry. Sci.*, *60*, 2519–2528.

SANDERS, T. A. B. (1988): Essential and trans-fatty acids in nutrition. *Nutr. Res. Rev.*, *1*, 57–78.

SHEEHY, P. J. A., MORRISSEY, P. A. & FLYNN, A. (1993): Increased storage stability of chicken muscle by dietary α-tocopherol supplementation. *Irish J. agric. Fd Res.*, *32*, 67–73.

SHELDON, B. W. (1984): Effects of dietary tocopherol on the oxidative stability of turkey meat. *Poultry Sci.*, *63*, 673.

SINCLAIR, H. M. (1953) The diet of Canadian Indians and Eskimos. *Proc. Nutr. Soc.*, *12*, 69–82.

STANSBY, M. E. (1990): Deterioration. -in: STANSBY, M. E. (Ed.) *Fish oil in nutrition*. Van Nostrand Reinhold, New York, pp. 120–140.

STURDEVANT, R. A. L., PEARCE, M. L. & DAYTIN, S. (1973): Increased prevalence of cholelithiasis in men ingesting serum cholesterol-lowering diet. *New Engl. J. Med.*, *288*, 24–27.

UEBERSAX, M. A., DAWSON, L. E. & UEBERSAX, K. L. (1978): Storage stability (TBA) of meat obtained from turkeys receiving tocopherol supplementation. *Poultry Sci.*, *57*, 937–946.

WESSELS, J. P. H., ATKINSON, A., VAN DER MERWE, R. P. & DE JONGH, J. H. (1973): Flavour studies with fish meals and fish oil fractions in broiler diets. *J. Sci. Fd Agric.*, *24*, 451–461.

YAU, J. C., DENTON, J. H., BAILEY, C. A. & SAMS, A. R. (1991): Customising the fatty acid content of broiler tissue. *Poultry Sci.*, *70*, 167–172.

YEHUDA, S. & CARASSO, R. L. (1993): Modulation of learning, pain threshold and thermal regulation in the rat by preperations of free purified alpha-linolenic and linoleic acids. Determination of the optimal n3/n6 ratio. *Proc. natl. Acad. Sci.*, *90*, 10345–10349.