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# Dietary α-Linolenic Acid and Laying Hen Strain: Fatty Acids of Liver, Adipose Tissue, White Meat, Dark Meat, and Egg Yolk

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The effect of dietary 18:3$n-3$ on fatty acids and total lipids of liver, adipose tissue (subdermal fat), egg yolk, and dark and white meat was studied in six strains (White Leghorn, Brown Leghorn, Light Sussex, New Hampshire, Barred Rock, and Rhode Island Red) of laying hens. Dietary 18:3$n-3$ resulted in an increase ($P < 0.001$) in $n-3$ fatty acid content of all tissues. Among the tissues, the adipose tissue incorporated the highest level of 18:3$n-3$. The increase in tissue $n-3$ fatty acids resulted in a concomitant reduction ($P < 0.05$) in 18:1 and 20:4$n-6$. Among strains, light Sussex incorporated the lowest ($P < 0.05$) concentration of 18:3$n-3$ in the hepatic tissue. A significant strain effect ($P < 0.05$) was observed in the total lipids of egg yolk, adipose tissue, and dark and white meat. The high 18:3$n-3$ diet resulted in a reduction ($P < 0.05$) in the total lipid content of the liver tissue in all strains.

**Keywords:** *n−3 fatty acids; hen strains; liver; adipose tissue; egg; meat*

## INTRODUCTION

Polyunsaturated fatty acids (PUFA) such as 18:3$n-3$ and 18:2$n-6$ are essential and are not synthesized; however, they can be incorporated into egg or tissue lipids through dietary fat. Incorporation of 18:3$n-3$ in the laying hen's diet has been reported to modify the $n-3$ and $n-6$ fatty acid composition of egg yolk (Caston and Leeson, 1990; Cherian and Sim, 1991, 1993) and carcass fat (Hulan *et al.*, 1989; Ajuyah *et al.*, 1991, 1992). Thus, the biochemical pathway of fatty acid biosynthesis or tissue deposition may be influenced by the nature of dietary fatty acids.

In chickens, liver is the primary site of *de novo* fatty acid synthesis (Leveille *et al.*, 1985). The major route of fat absorption is by mixed micelle formations. The chylomicrons are absorbed directly into the portal blood by chickens for transport to the liver for further synthesis and subsequent tissue deposition, allowing direct exposure of the liver to dietary fat. Thus, the fatty acid composition of tissue lipids is determined by both hepatic lipogenesis and the fatty acid composition of exogenous dietary fat as sources of fatty acid deposition in the hen. The supplementation of dietary fat influences both of these parameters such that they may act in the same or in opposite directions depending on the composition of the dietary fat source.

Factors other than diet, such as age and strain of the bird, may affect lipid metabolism in the laying hen (Sell *et al.*, 1968; Stadelman and Pratt, 1989). Edwards *et al.* (1964) reported that the iodine number of egg lipids varied significantly among various strains of hens. As iodine number is an indication of the unsaturation of the fatty acids and as yolk lipids are synthesized in the liver, it is reasonable to expect that hen strains may influence patterns of lipogenesis. In this context, the present study examines the effect of feeding diets high or low in α-linolenic acid (HLNA or LLNA, respectively) on the lipid and fatty acid composition of the liver (site of lipogenesis) and adipose tissue (subdermal fat) (as a storage depot of lipids) or on products such as eggs, white meat (breast muscle), and dark meat (leg muscle) of six different strains of laying hens.

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**Table 1. Nutrient Composition of Laying Hen Diets**

| ingredients and analyses | laying hen diet[a] HLNA | LLNA |
|---|---|---|
| wheat (%) | 60.0 | 65.9 |
| soybean meal (%) | 10.0 | 16.7 |
| flax (%) | 17.0 | 0.0 |
| animal fat (%) | 0.0 | 4.5 |
| limestone (%) | 8.3 | 8.3 |
| calcium phosphate (%) | 2.2 | 2.1 |
| salt (%) | 0.3 | 0.3 |
| DL-methionine (%) | 0.9 | 1.0 |
| layer premix[b] (%) | 2.0 | 2.0 |
| calcd analyses | | |
| CP (%) | 16.0 | 16.0 |
| ME (kcal/kg) | 2753 | 2800 |
| ether extracts (%) | 6.3 | 5.5 |
| calcium (%) | 3.6 | 3.6 |
| available P (%) | 0.6 | 0.6 |

[a] The HLNA and LLNA diet contained ground flax seeds high in 18:3$n-3$ or animal tallow low in 18:3$n-3$, respectively. [b] Supplied per kilogram of the diet the following: vitamin A, 8000 IU; cholecalciferol, 1200 ICU; vitamin E, 5 IU; riboflavin, 4 mg; calcium pantothenate, 6 mg; niacin, 15 mg; vitamin $B_{12}$, 10 $\mu$g; choline chloride, 100 mg; biotin, 100 $\mu$g; selenium, 0.1 mg; DL-methionine, 500 mg; manganese sulfate, 0.4 g; zinc oxide, 0.1 g.

**Table 2. Fatty Acid Composition (Percent) of Experimental Diets**

| fatty acid | laying hen diet[a] HLNA | LLNA |
|---|---|---|
| 16:0 | 8.2 | 21.5 |
| 18:0 | 3.2 | 9.5 |
| ΣSFA[b] | 11.5 | 31.0 |
| 16:1 | 0.2 | 3.1 |
| 18:1 | 23.6 | 41.2 |
| ΣMUFA[b] | 23.8 | 51.1 |
| 18:2$n-6$ | 24.0 | 11.1 |
| 20:4$n-6$ | 0.0 | 1.3 |
| Σ$n-6$ | 27.2 | 12.4 |
| 18:3$n-3$ | 40.7 | 6.3 |
| ΣPUFA[b] | 67.9 | 18.7 |

[a] HLNA and LLNA diet contained ground flax seeds high in 18:3$n-3$ or animal tallow low in 18:3$n-3$, respectively. SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid.

Increasing concern over the relationship between animal fats high in saturated fatty acids and coronary heart disease has prompted health experts to recommend a reduction in the consumption of animal products. Poultry products constitute a major proportion of animal product in the Western diet. Due to the cholesterol lowering and protective effects of $n-3$ PUFA against coronary heart disease [for reviews see Fernades and Venkatraman (1993) and Simopoulos (1991)], incorporating PUFA and increasing the polyunsaturated to saturated fatty acid (PUFA:SFA) ratio of egg yolk or tissue lipids would make poultry products more acceptable to health-conscious consumers.

## MATERIALS AND METHODS

**Sample Collection.** Ten eggs and tissue samples [liver, white meat, dark meat, and adipose tissue (subdermal fat) ($n$ = 5)] were obtained from six different strains [White Leghorn (WL), Brown Leghorn (BL), Light Sussex (LS), New Hampshire (NH), Barred Rock (BR), and Rhode Island Red (RIR)] of laying hens kept as breeding stock at the University of Alberta farm. The birds ($n$ = 5 per diet and strain) were fed wheat and soybean meal based diets with or without added ground flax seed rich in α-linolenic acid. The nutrient composition and fatty acid composition of the diet are shown in Tables 1 and 2.

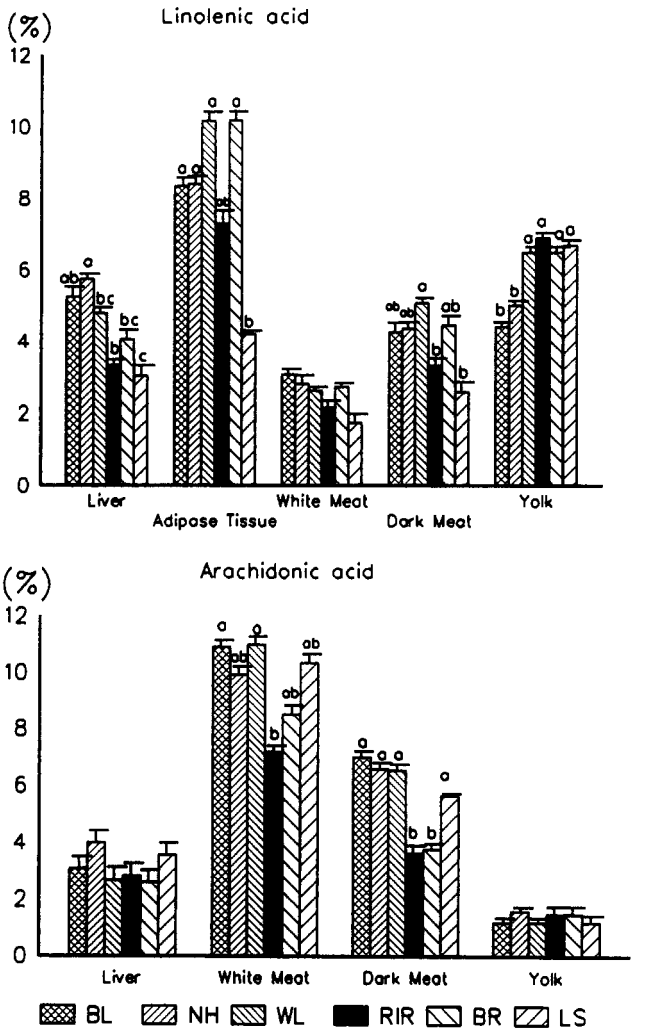


**Figure 1.** Incorporation patterns of α-linolenic acid (18:3$n-3$) in the liver, adipose tissue, white meat, dark meat, and yolk and of arachidonic acid (20:4$n-6$) in liver, white meat, dark meat, and yolk of different strains of laying hens fed diets high in $n-3$ polyunsaturated fatty acids. $n$ = 5. Data presented as mean ± SD. a–c indicate values are significantly different ($P$ < 0.05). BL, Brown Leghorn; NH, New Hampshire; WL, White Leghorn; RIR, Rhode Island Red; BR, Barred Rock; LS, Light Sussex.

**Lipid Analysis.** Total lipids were extracted from feed samples, egg yolk, liver, adipose tissue, and white and dark meat with chloroform/methanol (2:1 v/v) according to the method of Folch *et al.* (1957). Percentage lipid content was determined gravimetrically. The total lipids were converted to fatty acid methyl esters using a mixture of boron trifluoride, hexane, and methanol (35:20:45 v/v/v) (Metcalfe *et al.*, 1961). The fatty acid methyl esters were separated and quantified by an automated gas chromatograph equipped with autosampler and flame ionization detectors (Model 3400, Varian Associates, Inc., Sunnyvale, CA), using a 30 m × 0.25 mm i.d. fused silica capillary column (Supelco Canada, Ltd., Oakville, ON) as described previously (Cherian and Sim, 1992). A Shimadzu EZChrom (Shimadzu Scientific Instruments, Inc., Columbia, MD) laboratory data integration system was used to integrate peak areas.

**Statistics.** Two-way ANOVA was used to analyze the effects of strain and diet on egg and tissue fatty acids. Mean values among strains were further analyzed by SNK (Student–Newman–Keuls) multiple range test at $P$ < 0.05 (Steel and Torrie, 1980).

## RESULTS

Generally, the fatty acid composition of the diets reflected the dietary fat source (Table 2). The inclusion

**Table 3. Fatty Acid Composition (Percent) of Liver Tissue from Different Strains of Laying Hens Fed Diets High (HLNA) or Low (LLNA) in $n-3$ Polyunsaturated Fatty Acids**

| | | hen strain[c] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| fatty acid | diet[a] | WL | BL | LS | NH | BR | RIR | SEM[d] |
| 16:0 | HLNA | 21.3ab | 21.4ab | 23.3a | 19.9b | 23.3a | 22.7a | 0.51 |
| | LLNA | 21.8bc | 23.3ab | 24.3a | 21.2c | 22.6abc | 22.1bc | 0.46 |
| 18:0 | HLNA | 15.2 | 14.2 | 12.2 | 15.6 | 15.1 | 12.3 | 0.97 |
| | LLNA | 11.5b | 12.4b | 11.4b | 15.9a | 11.7b | 13.5ab | 0.50 |
| 18:1 | HLNA | 38.1 | 36.1 | 40.9 | 34.1 | 37.0 | 40.8 | 2.18 |
| | LLNA | 48.9a | 43.6b | 44.8ab | 40.5b | 44.7ab | 40.3b | 1.23 |
| 18:2$n-6$ | HLNA | 9.8 | 11.2 | 8.6 | 12.2 | 9.7 | 9.5 | 0.88 |
| | LLNA | 8.2c | 10.1ab | 8.9bc | 11.4a | 10.1ab | 11.7a | 0.43 |
| 20:4$n-6$ | HLNA | 2.7 | 3.1 | 2.1 | 4.9 | 2.6 | 2.8 | 0.07 |
| | LLNA | 3.2b | 3.9b | 3.4b | 6.7a | 4.0b | 5.7a | 0.39 |
| 18:3$n-3$ | HLNA | 4.8bc | 5.3b | 2.6c | 5.8b | 4.1 | 6.8a | 0.52 |
| | LLNA | 0.4ab | 0.6a | 0.5ab | 0.6a | 0.5ab | 2.9b | 0.05 |
| 22:6$n-3$ | HLNA | 2.5 | 3.2 | 3.4 | 3.3 | 2.3 | 2.7 | 0.46 |
| | LLNA | 1.1c | 1.3bc | 1.4bc | 2.4a | 1.7b | 2.0ab | 0.12 |
| ΣSFA[b] | HLNA | 37.1 | 36.2 | 36.4 | 36.0 | 38.9 | 35.5 | 1.21 |
| | LLNA | 34.0b | 36.4a | 36.5a | 37.6a | 34.5b | 36.2a | 0.55 |
| ΣMUFA[b] | HLNA | 40.9 | 39.1 | 36.8 | 36.6 | 43.7 | 44.4 | 2.18 |
| | LLNA | 52.0a | 46.9b | 48.1ab | 38.9c | 47.2b | 42.4c | 1.28 |
| Σ$n-6$ | HLNA | 13.8 | 15.2 | 13.1 | 17.3 | 13.2 | 13.2 | 1.36 |
| | LLNA | 12.4c | 14.8bc | 13.3c | 20.1a | 15.3bc | 19.2a | 0.91 |
| Σ$n-3$ | HLNA | 8.2ab | 9.5ab | 7.5ab | 10.1a | 7.7ab | 6.8b | 0.75 |
| | LLNA | 1.6d | 1.9cd | 1.9cd | 3.2a | 2.5b | 2.9ab | 0.18 |
| ΣPUFA[b] | HLNA | 22.0 | 24.7 | 21.8 | 27.4 | 20.9 | 20.1 | 1.76 |
| | LLNA | 13.9c | 16.7c | 15.3c | 23.4a | 17.7b | 22.1ab | 1.06 |
| P:S[b] | HLNA | 0.6b | 0.7a | 0.5b | 0.8a | 0.5b | 0.6b | 0.03 |
| | LLNA | 0.4b | 0.5ab | 0.4b | 0.6a | 0.5ab | 0.6a | 0.02 |
| Σlipids | HLNA | 6.2 | 5.9 | 7.5 | 5.3 | 7.2 | 6.5 | 0.38 |
| | LLNA | 8.9 | 7.0 | 7.8 | 7.3 | 7.8 | 8.2 | 0.38 |

[a] The HLNA and LLNA diet contained ground flax seeds high in 18:3$n-3$ or animal tallow low in 18:3$n-3$, respectively. [b] SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; P:S, polyunsaturated/saturated fatty acid. [c] WL, White Leghorn; BL, Brown Leghorn; LS, Light Sussex; NH, New Hampshire; BR, Barred Rock; RIR, Rhode Island Red. Different letters within row are significantly different ($P < 0.05$). [d] SEM, standard error of mean.

of flax seeds increased the 18:3$n-3$ and 18:2$n-6$ fatty acid content to a total PUFA level of 64.7%. Total saturated fatty acids (16:0, 18:0) were also higher (31%) in the LLNA diet due to the inclusion of animal tallow. This resulted in a lower PUFA:SFA ratio in the LLNA diet when compared with the HLNA diet.

**Fatty Acid Composition of Liver Tissue.** Liver PUFA was significantly altered in all of the strains fed HLNA diet (Table 3). This increase in liver PUFA reflected a significant decrease in MUFA, particularly for oleic acid ($P < 0.001$). However, no change was observed in the saturated fatty acids (16:0, 18:0). When $n-3$ PUFA was included in the diet, a significant incorporation of 18:3$n-3$ and 22:6$n-3$ was observed in the hepatic lipids. Among strains, LS incorporated the lowest concentration of 18:3$n-3$ (Table 3). An increase in liver $n-3$ fatty acids resulted in a concomitant decrease in liver 20:4$n-6$ content ($P < 0.05$) in all strains. However, no difference was observed in the 18:2$n-6$ fatty acid concentration in the liver tissue. The PUFA content was significantly greater in the liver tissue of birds receiving HLNA diet when compared with that of those in the LLNA diet. The total lipid content of liver tissue was not affected by the strain of birds; however, diet resulted in a significantly lower level of lipids in birds receiving HLNA diets ($P < 0.05$) (Table 3).

**Fatty Acid Composition of Adipose Tissue.** The increased dietary intake of PUFA was reflected in the PUFA composition of adipose tissue (Table 4). Among strains, LS had the least incorporation of PUFA. No difference was observed in the 16:0 and 18:0 levels in the adipose tissue of birds fed HLNA or LLNA diets. The percentage of oleic acid was significantly ($P < 0.001$) lower in the adipose tissue of birds receiving HLNA diet. The six-fold increase in 18:3$n-3$ from the HLNA diet had a significant effect on the 18:3$n-3$ fatty acid content in adipose tissue in all strains of birds. However, this did not result in any change in longer chain $n-3$ fatty acids. The longer chain metabolites of 18:3$n-3$ such as 20:5 and 22:6$n-3$ fatty acids were not detected in the adipose tissue of any of the birds. The total PUFA content was increased ($P < 0.05$) in all strains receiving HLNA diet. No difference was observed in the total lipid content of abdominal fat pads in birds receiving HLNA or LLNA diet; however, a significant strain difference was observed. The total lipid content of adipose tissue of BR was significantly higher than that of the other breeds ($P < 0.05$) (Table 4).

**Fatty Acid Composition of Yolk Lipids.** The fatty acid composition of yolk total lipids reflected that of the laying hen diets (Table 5). Irrespective of the strain and diet, no change was observed in the saturated fatty acid content of yolk. The incorporation of $n-3$ PUFA in the hens' diet resulted in a significant reduction of oleic acid in the yolk. The HLNA diet resulted in a significant ($P < 0.05$) increase of 18:3$n-3$ and other longer chain $n-3$ fatty acids such as 22:6$n-3$ with a concomitant reduc-

**Table 4. Fatty Acid Composition (Percent) of Adipose Tissue from Different Strains of Laying Hens Fed Diets High (HLNA) or Low (LLNA) in $n-3$ Polyunsaturated Fatty Acid**

| | | hen strain[c] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| fatty acid | diet[a] | WL | BL | LS | NH | BR | RIR | SEM[d] |
| 16:0 | HLNA | 18.8b | 18.0b | 21.0a | 18.1b | 16.2c | 21.0a | 0.51 |
| | LLNA | 19.3bc | 18.0c | 22.0a | 20.4ab | 19.9bc | 21.4ab | 0.54 |
| 18:0 | HLNA | 5.6 | 4.2 | 5.0 | 4.7 | 4.5 | 5.6 | 0.33 |
| | LLNA | 6.5ab | 4.2c | 5.4bc | 6.3ab | 5.3bc | 7.7a | 0.41 |
| 18:1 | HLNA | 46.6b | 45.7b | 51.4a | 46.7b | 45.1b | 43.4c | 0.91 |
| | LLNA | 53.3a | 52.0ab | 51.7ab | 51.9ab | 51.4ab | 49.4b | 0.72 |
| 18:2$n-6$ | HLNA | 15.5 | 15.8 | 12.5 | 16.7 | 17.4 | 17.0 | 1.37 |
| | LLNA | 14.4ab | 15.1ab | 13.5b | 14.7ab | 15.7a | 15.3a | 0.48 |
| 18:3$n-3$ | HLNA | 10.2a | 8.3a | 4.2b | 8.4a | 10.2a | 7.5ab | 1.06 |
| | LLNA | 1.1b | 3.9a | 0.9b | 1.1b | 1.1b | 1.2b | 0.52 |
| ΣSFA[b] | HLNA | 25.2b | 23.1b | 27.0a | 23.7b | 21.7c | 27.8a | 0.55 |
| | LLNA | 26.9bc | 24.1c | 28.4b | 27.5b | 26.2bc | 30.1a | 0.55 |
| ΣMUFA[b] | HLNA | 49.1b | 52.3b | 56.7a | 50.9b | 49.4b | 47.9b | 0.98 |
| | LLNA | 57.7a | 57.2a | 53.3b | 56.4a | 53.8b | 55.6ab | 0.94 |
| ΣPUFA[b] | HLNA | 25.7ab | 24.3b | 16.7c | 25.1ab | 27.6a | 24.5b | 0.95 |
| | LLNA | 15.5bc | 19.4a | 14.4c | 15.8bc | 17.1b | 16.5b | 0.54 |
| Σlipids | HLNA | 74.2b | 68.6c | 68.6c | 67.6c | 65.9c | 81.3a | 1.12 |
| | LLNA | 70.8bc | 65.6c | 66.2c | 73.6b | 69.4c | 80.4a | 1.12 |

[a] The HLNA and LLNA diet contained ground flax seeds high in 18:3$n-3$ or animal tallow low in 18:3$n-3$. respectively. [b] SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; P:S, polyunsaturated/saturated fatty acid. [c] WL, White Leghorn; BL, Brown Leghorn; LS, Light Sussex; NH, New Hampshire; BR, Barred Rock; RIR, Rhode Island Red. Different letters within a row are significantly different ($P < 0.05$). [d] SEM, standard error of mean.

tion in arachidonic acid. The magnitude of changes among different strains for $n-3$ fatty acid incorporation, however, was different. The enhancement of 18:3$n-3$ in the yolk lipids in the order of magnitude was RIR > LS > WL, BR > NH > BL. The enhancement of 22:6$n-3$ was similar to that of 18:3$n-3$ with the lowest level of 22:6$n-3$ in BL, indicating that the ability of laying hens to incorporate $n-3$ fatty acids in the yolk is strain dependent. Addition of HLNA diet resulted in a significant ($P < 0.05$) increase in total PUFA and a reduction ($P < 0.05$) in P:S ratio in all of the different strains (Table 5). No difference was observed in the egg total lipid content of birds receiving HLNA or LLNA diet; however, a significant strain difference was observed. Eggs from LS and BR birds contained significantly lower lipids than eggs from WL eggs ($P < 0.05$). The eggs from the Leghorn breeds (WL, BL) had white shells, and the rest (BR, NH, RIR, LS) had brown shells.

**Fatty Acid Composition of White and Dark Meat Lipids.** The fatty acid compositions of white and dark meat lipids are shown in Table 6 and Figure 1. The high $n-3$ PUFA diet resulted in a significant ($P < 0.05$) increase in PUFA in the white and dark meat. Among different strains, the magnitude of incorporation of PUFAs was as follows: WL > BL > NH > LS > BR > RIR for dark and white meat. Regardless of the strain, hens fed HLNA diet deposited significantly ($P < 0.001$) higher levels of 18:3$n-3$ in both white and dark meat. Among strains, the incorporation of 18:3$n-3$ was highest for WL and least for LS in the dark meat ($P < 0.05$) (Figure 1). The incorporation of 20:4$n-6$ differed significantly among strains (Figure 1). Among different strains, RIR incorporated the lowest levels of 20:4$n-6$ and 20:5$n-3$. Feeding of HLNA diet also resulted in a significant increase in PUFA ($P < 0.05$) in all of the strains except RIR. A significant strain effect was observed in the total lipid content of dark and white meat (Table 6). However, the effect of diet on the total lipid content of dark and white meat was minimal.

## DISCUSSION

In avians, the liver plays a central role in the regulation of lipid metabolism. Because the lymphatic system is rudimentary, the liver is the first tissue to be exposed to dietary lipids. This unique feature of lipid metabolism in the avians is reflected in the fatty acid composition of liver and tissue lipids. In general, dietary $n-3$ PUFA produced marked increases in 18:3$n-3$ and 22:6$n-3$ with concomitant decreases in 20:4$n-6$ and 18:1 in all of the strains and the tissues examined. Although the differences among strains were relatively small as reported previously (Sell *et al.*, 1968), the incorporation of $n-3$ PUFA varied among strains, suggesting a strain effect on fatty acid metabolism in avians.

The pattern of fatty acid incorporation in the liver tissue resembled the fatty acid incorporation of egg yolk, which is not surprising because yolk lipids are synthesized in the liver and transported via blood for subsequent deposition (Redshaw and Follet, 1972). The control of liver in incorporating lipids to egg yolk (Naber and Biggert, 1989) is further reflected in the saturated fatty acid content in the liver and yolk lipids. The relatively greater concentration of saturated fatty acids in the LLNA diet did not result in any significant change in the yolk or tissue saturated fatty acid content. These results are in agreement with our previous results (Cherian and Sim, 1991) and those of others (Hargis *et al.*, 1991) suggesting that the ability of laying hens to alter the saturated fatty acid composition of egg yolk or tissue seems to be limited. The presence of saturated fatty acids in the tissues depends on their presence in the diet, their oxidation rate, and their synthesis in the liver (Nir *et al.*, 1988). Observations from the present study suggest a dietary threshold for the incorporation of saturated fatty acids, and the higher dietary intake of PUFA does not discriminate against the synthesis,

**Table 5. Fatty Acid Composition (Percent) of Egg Yolk from Different Strains of Laying Hens Fed Diets High (HLNA) or Low (LLNA) in $n-3$ Polyunsaturated Fatty Acid**

| | | hen strain[c] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| fatty acid | diet[a] | WL | BL | LS | NH | BR | RIR | SEM |
| 16:0 | HLNA | 20.3 | 22.6 | 21.0 | 22.2 | 20.8 | 19.8 | 0.32 |
| | LLNA | 22.1 | 23.1 | 23.3 | 21.9 | 22.4 | 23.0 | 0.25 |
| 18:0 | HLNA | 9.9 | 9.9 | 9.2 | 8.8 | 9.5 | 9.6 | 0.21 |
| | LLNA | 8.9 | 9.4 | 8.1 | 8.3 | 8.3 | 7.8 | 0.19 |
| 18:1 | HLNA | 44.9 | 46.2 | 43.3 | 44.1 | 43.5 | 44.5 | 0.36 |
| | LLNA | 51.6b | 53.7a | 51.6b | 53.0a | 51.4b | 50.5b | 0.15 |
| 18:2$n-6$ | HLNA | 10.8ab | 9.6b | 8.4b | 11.4ab | 12.3a | 12.7a | 0.21 |
| | LLNA | 9.1b | 9.4b | 10.4ab | 10.2ab | 11.2a | 11.2a | 0.09 |
| 20:4$n-6$ | HLNA | 1.2b | 1.2b | 1.2b | 1.6a | 1.5a | 1.5a | 0.05 |
| | HLNA | 2.0ab | 1.9ab | 2.1a | 2.2a | 2.1a | 1.7b | 0.04 |
| 18:3$n-3$ | HLNA | 6.5a | 4.4b | 6.7a | 5.0b | 6.5a | 6.9a | 0.24 |
| | LLNA | 0.5b | 0.1c | 0.6ab | 0.3b | 0.7a | 0.7a | 0.05 |
| 22:6$n-3$ | HLNA | 2.1ab | 1.9b | 2.2a | 2.2a | 2.0ab | 1.9b | 0.09 |
| | LLNA | 0.9b | 0.9b | 1.2a | 1.2a | 1.1a | 0.9b | 0.06 |
| ΣSFA[b] | HLNA | 30.9 | 32.9 | 30.8 | 31.6 | 30.5 | 30.9 | 0.89 |
| | LLNA | 31.1 | 32.5 | 31.4 | 30.2 | 31.6 | 31.8 | 0.82 |
| ΣMUFA[b] | HLNA | 47.5 | 49.2 | 46.2 | 47.5 | 45.9 | 46.4 | 0.38 |
| | LLNA | 56.3a | 56.0a | 54.4ab | 55.9a | 52.9b | 53.6ab | 0.26 |
| Σ$n-6$ | HLNA | 12.4 | 11.2 | 13.8 | 13.3 | 14.2 | 14.3 | 0.71 |
| | LLNA | 11.2 | 10.6 | 11.6 | 12.4 | 13.3 | 12.9 | 0.53 |
| Σ$n-3$ | HLNA | 9.2 | 6.7 | 10.2 | 7.7 | 9.3 | 9.4 | 0.25 |
| | LLNA | 1.4 | 1.2 | 1.8 | 1.5 | 1.7 | 1.7 | 0.06 |
| ΣPUFA[b] | HLNA | 21.6 | 21.9 | 24.0 | 21.0 | 23.5 | 23.7 | 0.52 |
| | LLNA | 12.6b | 11.5b | 13.4b | 13.9b | 15.0a | 14.6a | 0.23 |
| P:S[b] | HLNA | 0.7a | 0.5b | 0.8a | 0.7a | 0.8a | 0.8a | 0.02 |
| | LLNA | 0.4 | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 | 0.03 |
| Σlipids (g/egg) | HLNA | 6.7a | 6.1ab | 5.5b | 6.7a | 5.9b | 6.1ab | 0.19 |
| | LLNA | 6.7a | 5.9b | 5.9b | 5.9b | 5.9b | 6.2ab | 0.19 |

[a] The HLNA and LLNA diet contained ground flax seeds high in 18:3$n-3$ or animal tallow low in 18:3$n-3$, respectively. [b] SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; P:S, polyunsaturated/saturated fatty acid. [c] WL, White Leghorn; BL, Brown Leghorn; LS, Light Sussex; NH, New Hampshire; BR, Barred Rock; RIR, Rhode Island Red. Different letters within a row are significantly different ($P < 0.05$). [d] SEM, standard error of mean.

acylation, and turnover of saturated fatty acids among different strains of poultry.

Regardless of the strain, there was significantly less fat, by percentage, in the livers of laying hens fed $n-3$-PUFA-rich HLNA diet. The decreased concentrations of total liver fat observed in the present study could be due to decreased synthesis of fat in the $n-3$ PUFA-rich plant oil based diet when compared with saturated fatty acids from animal sources. Although a lipogenic inhibitory effect of $n-6$ PUFA has been reported (Naber and Biggert, 1989; Leveille *et al.*, 1985), the effect of $n-3$ PUFA from plant sources has not been documented. Hargis *et al.* (1991) reported increased hepatic lipid accumulation in laying hens fed diets containing $n-3$-PUFA-rich menhaden oil. However, as the total fat percentage was reduced in the HLNA-fed birds, it may be assumed that the hepatic lipid accumulation associated with fish oil feeding may be a phenomenon more peculiar to long-chain $n-3$ PUFA associated with fish oil.

The fatty acid composition of adipose tissue is determined by relative contributions of hepatic lipogenesis and dietary fat. This is reflected in the 18:3$n-3$ level of adipose tissue. Although oleic acid is usually predominant in the adipose tissue of many species including chickens (Hilditch and Williams, 1964), the increased dietary 18:3$n-3$ modified the composition such that 18:1 was replaced with 18:3$n-3$ in the adipose tissue. Because 18:3$n-3$ is desaurated and elongated to form the long-chain metabolite 22:6$n-3$, which is required for the normal functioning of the central nervous system (Bourre *et al.*, 1989; Wainwright, 1992), the increased deposition of 18:3$n-3$ in the depot fat (Figure 1) may be an adaptive mechanism in the avians to metabolically conserve this essential fatty acid for future need.

The decline in arachidonic acid in liver, egg yolk, adipose tissue, and muscle tissue suggests the inhibition of arachidonic acid metabolism from linolenic acid in all strains. Decreased arachidonic acid has been reported previously in chicken eggs (Cherian and Sim, 1991) and in meat (Ajuyah *et al.*, 1992) when laying hens were fed diets enriched with 18:3$n-3$. The decline in 20:4$n-6$ suggests an inhibition in the synthesis of 20:4$n-6$ when diets high in 18:3$n-3$ were fed. It has been known that the enzymatic pathway for the synthesis of 20:4$n-6$ from 18:2$n-6$ is shared by $n-3$ fatty acids (Brenner, 1971) and 18:3$n-3$ inhibits $\Delta-6$ desaturase and thereby reduces the conversion of 18:2$n-6$ to 20:4$n-6$ (Iritani and Narita, 1984). The difference in 20:4$n-6$ incorporation among strains (Figure 1) as observed from the present study suggests that the activity of rate-limiting enzyme ($\Delta-6$ desaturase enzyme) in the biosynthetic pathway of PUFA in poultry may be diet as well as strain dependent.

To summarize, in a biological system in which liver

**Table 6. Fatty Acid Composition (Percent) and Total Lipids of Dark and White Meat from Different Strains of Laying Hens Fed Diets High (HLNA) or Low (LLNA) in $n-3$ Polyunsaturated Fatty Acids**

| | | hen strain[c] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| fatty acid | diet[a] | WL | BL | LS | NH | BR | RIR | SEM |
| | | | | Dark Meat | | | | |
| ΣSFA[b] | HLNA | 28.2 | 27.2 | 30.3 | 29.7 | 26.8 | 29.8 | 0.35 |
| | LLNA | 28.6a | 26.3b | 30.0a | 29.4a | 29.6a | 30.8a | 0.33 |
| ΣMUFA[b] | HLNA | 32.4 | 35.6 | 40.0 | 34.7 | 44.0 | 42.8 | 1.26 |
| | LLNA | 41.1 | 43.5 | 37.3 | 45.6 | 41.9 | 37.6 | 1.18 |
| $\Sigma n-6$ | HLNA | 29.5a | 27.9ab | 22.8ab | 26.5ab | 21.8ab | 21.1b | 0.78 |
| | LLNA | 26.7 | 27.3 | 28.4 | 22.0 | 24.9 | 26.4 | 0.73 |
| $\Sigma n-3$ | HLNA | 9.9 | 9.3 | 6.9 | 9.2 | 7.4 | 6.3 | 0.38 |
| | LLNA | 3.5 | 2.9 | 4.4 | 3.0 | 3.4 | 5.2 | 0.35 |
| ΣPUFA[b] | HLNA | 39.4a | 37.2a | 29.7ab | 35.6ab | 29.2ab | 27.4b | 1.06 |
| | LLNA | 30.3 | 30.2 | 32.7 | 25.0 | 28.5 | 31.6 | 0.73 |
| ΣP:S | HLNA | 1.4a | 1.4a | 0.9b | 1.2ab | 1.1ab | 0.9b | 0.03 |
| | LLNA | 1.1 | 1.1 | 1.1 | 0.8 | 0.9 | 1.0 | 0.03 |
| Σlipids | HLNA | 1.9b | 1.8b | 2.0b | 1.5b | 4.4a | 3.4 | 0.39 |
| | LLNA | 2.3b | 2.2b | 1.7b | 1.8b | 3.8a | 1.9b | 0.34 |
| | | | | White Meat | | | | |
| ΣSFA | HLNA | 30.8 | 31.0 | 30.8 | 32.9 | 31.2 | 35.3 | 0.46 |
| | LLNA | 33.6 | 34.2 | 36.2 | 33.1 | 32.3 | 32.1 | 0.49 |
| ΣMUFA[b] | HLNA | 29.5b | 32.3ab | 36.0a | 34.4a | 36.9a | 35.2a | 0.57 |
| | LLNA | 33.4 | 36.4 | 36.2 | 37.8 | 37.2 | 34.8 | 0.60 |
| $\Sigma n-6$ | HLNA | 30.0a | 27.7a | 23.6b | 24.1b | 24.4b | 23.0b | 0.51 |
| | LLNA | 29.3 | 26.4 | 22.5 | 25.1 | 26.4 | 26.9 | 0.54 |
| $\Sigma n-3$ | HLNA | 9.7a | 8.9ab | 9.6a | 8.6ab | 7.4ab | 6.5b | 0.26 |
| | LLNA | 3.7ab | 3.1b | 5.0ab | 3.8ab | 4.3ab | 4.3ab | 0.32 |
| ΣPUFA[b] | HLNA | 39.7a | 36.7ab | 33.2bc | 32.7bc | 31.8c | 29.5c | 0.58 |
| | LLNA | 33.0 | 29.4 | 27.6 | 29.0 | 30.6 | 33.1 | 0.61 |
| ΣP:S[b] | HLNA | 1.3a | 1.2ab | 1.1b | 1.0bc | 1.0bc | 0.9c | 0.03 |
| | LLNA | 1.0 | 0.9 | 0.8 | 0.9 | 1.0 | 0.9 | 0.03 |
| Σlipids | HLNA | 0.8b | 0.9ab | 0.9ab | 0.8b | 1.2a | 1.0ab | 0.09 |
| | LLNA | 0.8 | 0.9 | 0.9 | 1.1 | 1.0 | 1.1 | 0.08 |

[a] The HLNA and LLNA diet contained ground flax seeds high in 18:3$n-3$ or animal tallow low in 18:3$n-3$, respectively. [b] SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; P:S, polyunsaturated:saturated fatty acid. [c] WL, White Leghorn; BL, Brown Leghorn; LS. Light Sussex; NH, New Hampshire; BR, Barred Rock; RIR, Rhode Island Red. Different letters within a row are significantly different ($P < 0.05$). [d] SEM, standard error of mean.

plays a key role in fat metabolism, as in poultry, the present study examined the consequences of dietary PUFA in modulating fatty acid metabolism in various strain of hens. Ahn *et al.* (1995) reported that feeding diets with high $n-3$ polyunsaturation did not increase the oxidative stress or cause any off-flavor in $n-3$-PUFA-enriched eggs. Because some of these strains are still used for egg production in different parts of the world, these results may have implications in understanding physiological mechanisms underlying fatty acid metabolism and directing feeding programs accordingly. The changes in total PUFA and increased P:S ratio in the egg yolk and meat of hens fed a high-PUFA diet would make poultry products more acceptable to health-conscious consumers and may also have implications in optimum utilization and development of value-added further processed poultry products from hen meat of low market value. However, more work needs to be done on the organoleptic and oxidative stability consequences of $n-3$-PUFA-modified poultry products.

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