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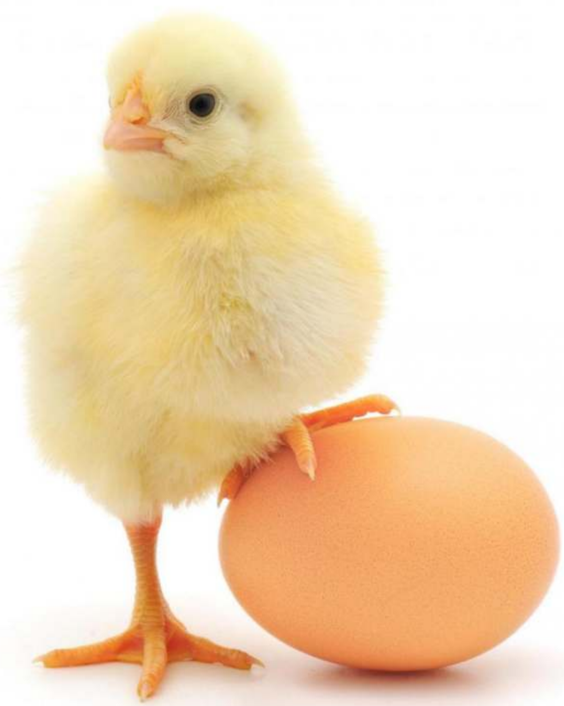

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ANSInet
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
Mob: +92 300 3008585, Fax: +92 41 8815544
E-mail: editorijps@gmail.com

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Relationships Between the Intake of n-3 Polyunsaturated Fatty Acids by Hens and the Fatty Acid Composition of Their Eggs

F.J. Bavelaar and A.C. Beynen
Department of Nutrition, Faculty of Veterinary Medicine, University of Utrecht,
3508 TD Utrecht, The Netherlands
E-mail: a.c.beynen@vet.uu.nl

Abstract: The objective of this literature survey was to establish the relationships between fatty acid intake of hens and the fatty acid composition of their eggs. The content of eicosapentaenoic acid (EPA) of egg yolk was not clearly influenced by α-linolenic acid intake, but there was a linear relationship with EPA intake albeit that the efficiency of incorporation was very low. Maximum egg yolk contents of docosahexaenoic acid (DHA) of about 1.5% of total fatty acids were attained at a dietary α-linolenic acid concentration higher than 7% of total fatty acids. Dietary DHA was found to be efficiently incorporated into egg yolk. There were linear relationships between dietary α-linolenic acid and linoleic acid and their contents in egg total lipids. The relationships presented, including the regression equations, may assist in the diet-mediated steering of the fatty acid composition of eggs.

Key words: n-3 polyunsaturated fatty acids, EPA, DHA, diet, egg yolk, chickens

Introduction

Replacement of dietary saturated fatty acids by polyunsaturated fatty acids lowers serum cholesterol concentrations and thereby reduces the risk of coronary heart disease (Consensus Conference, 1985; Grundy *et al.*, 1982). The cholesterol-lowering effect of polyunsaturated fatty acids is significant only at substantial intakes. In contrast, the n-3 polyunsaturated fatty acids, α-linolenic, eicosapentaenoic (EPA) and docosahexaenoic (DHA) acid, may reduce coronary heart disease and overall mortality at low intakes (Harris and Isley, 2001; Oomen *et al.*, 2000; Simopoulos, 1991; Von Schacky, 2000). The fatty acid composition of eggs can be modified through the hen's diet (Hargis and Van Elswijk, 1993; Kuksis, 1992). The content of linoleic acid, the major n-6 polyunsaturated fatty acid, can be raised. However, because linoleic acid is abundant in the western human diet, the enrichment of eggs with this fatty acid has no practical relevance. EPA and DHA are present only in fish products. Eggs enriched with EPA and DHA could be a source of these n-3 polyunsaturated fatty acids for people not consuming fish products. The recommended daily intake of total n-3 polyunsaturated fatty acids has been set at 0.5 % of the dietary energy, which is equivalent to 1.1 – 1.5 g per day per adult (Ministry of Supply and Services of Canada, 1990). Ferrier *et al.* (1995) calculated that one egg from a hen fed a diet containing 10% flaxseed would deliver about 30% of the daily need of total n-3 polyunsaturated fatty acids. Such an egg provides about 264 mg α-linolenic acid, 10 mg EPA and 82 mg DHA. The latter two fatty acids probably are the most potent n-3 polyunsaturated fatty acids in relation to human health.

Many experiments have been conducted to investigate the effect of diet on the fatty acid composition of eggs, but no mathematical relations have been established. This study focussed on the relationship between dietary fatty acids and the contents of EPA and DHA in eggs. The amount of the two fatty acids can be increased in egg yolk through two ways. First, the dietary intake of α-linolenic acid can be increased. α-Linolenic acid is converted into EPA and DHA in the body of the hen (Cherian and Sim, 1991) and the newly synthesized n-3 polyunsaturated fatty acids are then excreted in the egg. The contents of EPA and DHA can also be increased by increasing the intake of these fatty acids by feeding fish products. To complete the issue, we also looked at the relationship between dietary intakes and egg yolk contents of linoleic and α-linolenic acid. The relations between dietary and egg yolk fatty acids were established on the basis of literature data.

Materials and Methods

Data collection: The literature used was collected with the help of Medline (keywords: egg(s) and fatty acid composition) and through references given by the literature found. The data used (Table 1) were restricted to chickens and the fatty acid composition of total lipids in egg yolk. The ME content of the diets was calculated using the ingredient composition of the diets. The ME of the ingredients was calculated with the following formula (Centraal Veevoederbureau, Lelystad, The Netherlands). ME ingredient = [((GE-CP * DC-CP – 5.2) * CP) + (GE-CF * DC-CF * CF) + (GE-CHO * DC-CHO * CHO)]/1000, where ME= metabolizable energy (MJ/kg), GE= gross energy (kJ/g), DC= digestibility coefficient (%/100), CP= crude protein (g/kg), CF= crude fat (g/kg) and CHO= carbohydrates (g/kg). The GE contents of CP, CF and

Table 1: Characteristics of the literature data used

Author	No. of dietary treatments	No. of animals per treatment	Duration of treatment (weeks)	Age at beginning treatment (weeks)
Ahn *et al*., 1995	2	25	10	72
Ahn *et al*., 1999	3	8	2	79
Anderson *et al*., 1989	5	Unknown	unknown	unknown
Atteh *et al*., 1987	5	8	8	35
Beynen, 2004	4	25	5	41
Caston and Leeson, 1990	4	10	4	32
Chen *et al*., 1965	1	6	6	unknown
Cherian and Sim, 1991	4	10	2	unknown
Cherian *et al*., 1996	4	60	4	64
Evans *et al*., 1961	3	12	2	unknown
Fisher and Leveille, 1957	6	5	5	unknown
Grimes *et al*., 1996	4	16	8	26 / 58
Grobas *et al*., 2001	9	5	15	28
Guenter *et al*., 1971	5	9	12	26
Halle, 1996	9	21	50	19
Hammershoj, 1995	4	96	13	29
Hargis *et al*., 1991	2	120	18	36
Huang *et al*., 1990	2	12	4	26
Jiang *et al*., 1991	4	132	3	64
Machlin *et al*., 1962	2	unknown	12	In second year of production
Meluzzi *et al*., 2000	2	96	4	39
Nash *et al*., 1995	4	12	unknown	unknown
Navarro *et al*., 1972	4	10	>2	In beginning of production
Ohtake and Hoshino, 1976	unknown	unknown	unknown	unknown
Scheideler and Froning, 1996	8	12	7	43
Scheideler *et al*., 1998	2	24	8	50
Sell *et al*., 1968	3	unknown	unknown	unknown
Sim *et al*., 1973	17	24	24	24
Sim and Bragg, 1978	2	16	unknown	30
Wheeler *et al*., 1959	12	unknown	Differed per treatment, 3, 5 or 6	unknown

CHO were taken to be 23.8, 39 and 17 kJ/g respectively. The amount of linoleic, α-linolenic, eicosapentaenoic and docosahexaenoic acid in the diet or the egg yolk is expressed as weight percentage of total fatty acids (TFA). The amount of linoleic and α-linolenic acid in the diet is also given as energy percentage of total dietary ME (TME). For the fatty acids the ME content of crude fat was assumed. The data used for the calculations were taken from the Dutch, 1999 CVB feedstuff tables (Centraal Veevoederbureau, Lelystad, The Netherlands) and the USDA nutrient database (www. nal. usda. gov/ fnic/foodcomp). When the relative percentage of dietary fatty acids was not given in the CVB and USDA nutrient database, it was assumed that the dietary fat contained 95% of its weight in the form of fatty acids. In several articles, the amounts of dietary linoleic, α-linolenic, eicosapentaenoic and docosahexaenoic acid had not been given and therefore they were calculated on the basis of the fatty acid composition of the ingredients (CVB, USDA). In the articles of Hargis *et al.* (1991), Huang *et al.* (1990) and Meluzzi *et al.* (2000) the fatty acids of the egg yolk were expressed as mg per g egg. These values were converted into fatty acids expressed as weight percentage of TFA. For this conversion, an egg yolk lipid content of 34% was used (Stadelman and Pratt, 1989), and it was assumed that the egg yolk lipid contained 95 % of its weight in the form of fatty acids.

Statistical analyses: The linear regression equations were calculated with the following statistical model. Y = a + b * X, where Y = egg yolk total lipid fatty acid (weight % TFA) and X = dietary fatty acid (weight % TFA or % TME). The calculations have been made with the statistical computer program SPSS (SPSS Inc., Chicago, USA). Group mean values for egg yolk fatty acids were used and no corrections were made for the number of eggs or animals represented by each value.

Results and Discussion

First, the relation between the diet without fish products

Table 2: The regression formulas for the relation between dietary and egg yolk fatty acids for diets with added fish products

Y	X	Number		R^2	Intercept±SE/P value	Slope ± SE/P value
		Data	Experi-ments			
Egg yolk C20:5 (%TFA)	Dietary C20:5 (%TFA)	18	9	0.63	-0.01 ± 0.11/P=0.949	0.10±0.02 / P<0.000
Egg yolk C22:6 (%TFA)	Dietary total n-3 (%TFA)	18	9	0.44	1.25 ± 0.57/P=0.043	0.17± 0.05 / P = 0.003

Table 3: The regression formulas for the relation between dietary and egg yolk fatty acids

Y	X	Number		R^2	Intercept±SE/P value	Slope ± SE / P value
		Data points	Experi-ments			
Egg yolk C18:2 (% TFA)	Dietary C18:2 (% TFA)	131	29	0.51	5.31 ± 1.00 / P < 0.000	0.28 ± 0.02 / P < 0.000
Egg yolk C18:2 (% TFA)	Dietary C18:2 (% TME)	100	22	0.70	9.11 ± 0.57 / P < 0.000	0.75 ± 0.05 / P < 0.000
Egg yolk C18:3 (% TFA)	Dietary C18:3 (% TFA)	100	23	0.81	0.23 ± 0.21 / P = 0.280	0.21 ± 0.01 / P < 0.000
Egg yolk C18:3 (% TFA)	Dietary C18:3 (% TME)	66	16	0.75	1.31 ± 0.28 / P < 0.000	0.50 ± 0.04 / P < 0.000

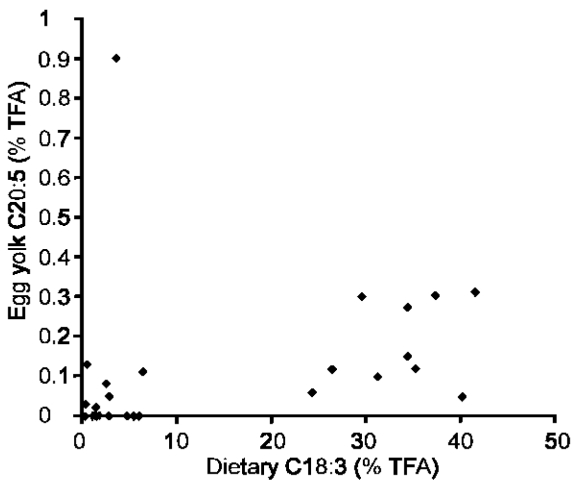

Fig. 1: The relationship between dietary α-linolenic acid content and egg yolk EPA content when a diet without fish products is fed to the hens. Dietary and egg yolk fatty acids are expressed as weight percentage of total fatty acids (% TFA)

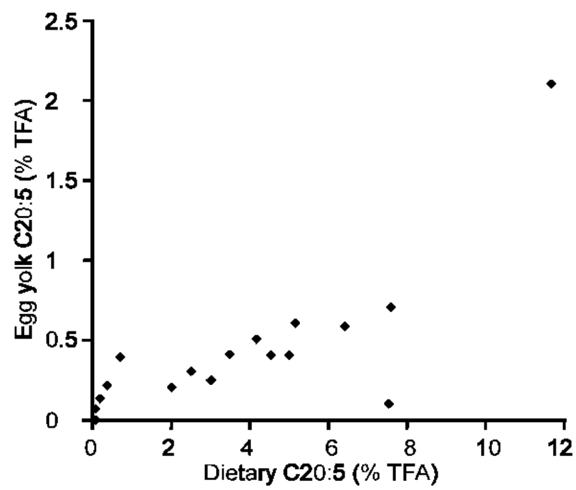

Fig. 2: The relationship between dietary and egg yolk EPA content, expressed as weight percentage of total fatty acids (% TFA)

and the amount of EPA in egg yolk was established. Fig. 1 shows that the available data are not suitable to calculate the linear regression equation between dietary α-linolenic acid and egg yolk EPA. The data consist of two clusters of points. An EPA level in egg yolk higher than 0.2% TFA was seen only at α-linolenic acid intakes higher than 35% TFA. This indicates that only a very small part of dietary α-linolenic acid is converted into EPA and excreted as such in the egg. When fish products are added to the diet, dietary EPA is the main source of EPA in the egg yolk. The linear correlation coefficient for dietary EPA and egg yolk EPA is 0.79 (Table 2). The regression formulas were also established, the slope for the relation between dietary and egg yolk EPA (Fig. 2) being 0.10.

For diets without fish products, there was a parabolic relation between dietary α-linolenic acid and egg yolk DHA (Fig. 3). A maximum DHA content of the egg, i.e. about 1.5% TFA, was attained at an α-linolenic acid intake of 7% TFA. When a diet containing fish products is fed, there was no clear relation between dietary DHA and egg yolk DHA (Fig. 4), but for the relation between total dietary n-3 polyunsaturated fatty acids and egg yolk DHA the linear correlation coefficient was 0.66 (Table 2). Thus, egg yolk DHA content can best be predicted by total dietary n-3 polyunsaturated fatty acids (Fig. 5). The slopes for the relation between total dietary n-3 polyunsaturated fatty acids and egg yolk DHA was 0.17 (Table 2).

It has been reported that range-fed Greek chickens produce eggs with EPA and DHA contents of 0.4 and 2.3% TFA, respectively (Simopoulos and Salem, 1989).

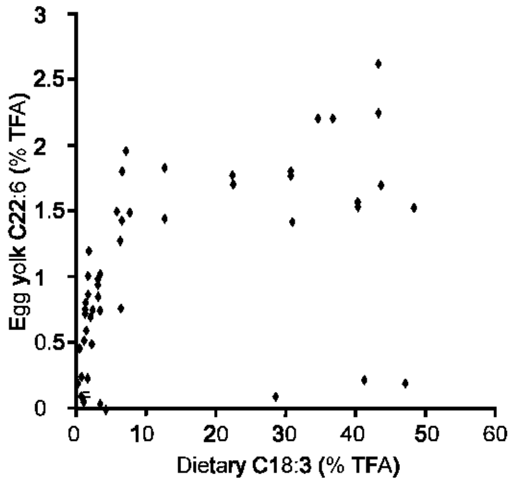

Fig. 3: The relationship between dietary α-linolenic acid content and egg yolk DHA content when a diet without fish products is fed to the hens. Dietary and egg yolk fatty acids are expressed as weight percentage of total fatty acids (% TFA)

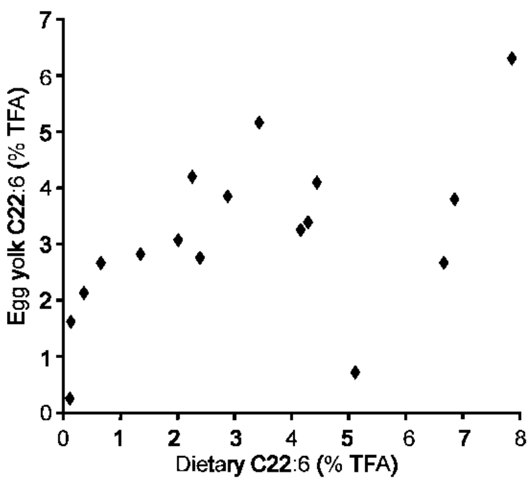

Fig. 4: The relationship between dietary and egg yolk DHA content expressed as weight percentage of total fatty acids (% TFA)

The present data indicate that the high egg content of EPA cannot be derived from dietary α-linolenic acid only, but must also originate from EPA in the diet.

The relationship between dietary and egg yolk linoleic acid content was established for 131 data points from 29 different experiments (Fig. 6). The linear correlation coefficient was 0.72 (Table 3). For 100 data points from 23 different studies, the relationship between dietary and egg yolk α-linolenic acid (Fig. 7) had a linear correlation coefficient of 0.90 (Table 3). The slopes of the regression lines for dietary linoleic and α-linolenic acid, expressed as weight percentage, and egg yolk linoleic and α-linolenic acid were 0.28 and 0.21, respectively

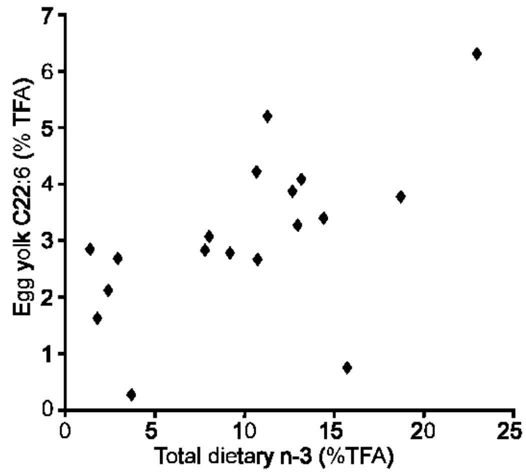

Fig. 5: The relationship between total dietary n-3 polyunsaturated fatty acids and egg yolk DHA content when a diet containing fish products is fed to the hens. Dietary and egg yolk fatty acids are expressed as weight percentage of total fatty acids (% TFA)

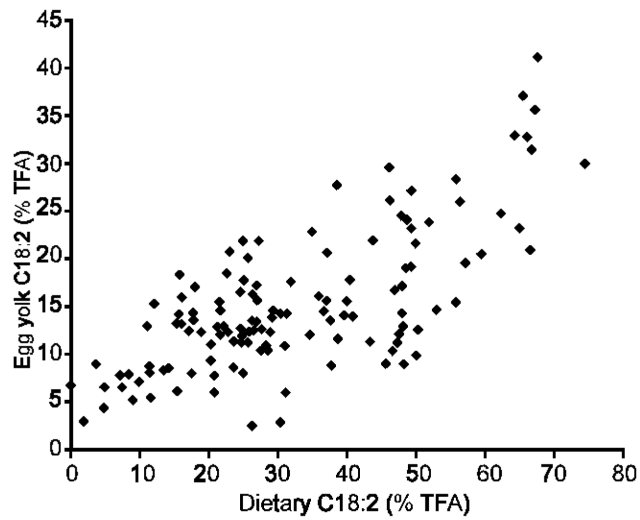

Fig. 6: The relationship between dietary and egg yolk content of linoleic acid expressed as weight percentage of total fatty acids (% TFA)

(Table 3). The slopes are much lower than those for linoleic and α-linolenic acid incorporation into adipose tissue in broilers (Bavelaar and Beynen, 2002). This indicates that dietary fatty acids are substantially diluted by de novo synthesized fatty acids when they are incorporated in egg yolk.

At low intakes of fat, dietary linoleic and α-linolenic acid will be relatively more diluted by de novo synthesized fatty acids than at high intakes (Beynen *et al*., 1980). To take this phenomenon of dilution into account, dietary linoleic and α-linolenic acid were also expressed as energy percentage of ME. For the relationship between

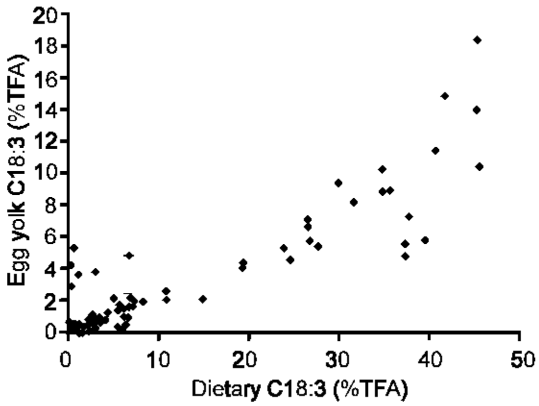

Fig. 7: The relationship between dietary and egg yolk content of α-linolenic acid expressed as weight percentage of total fatty acids (% TFA)

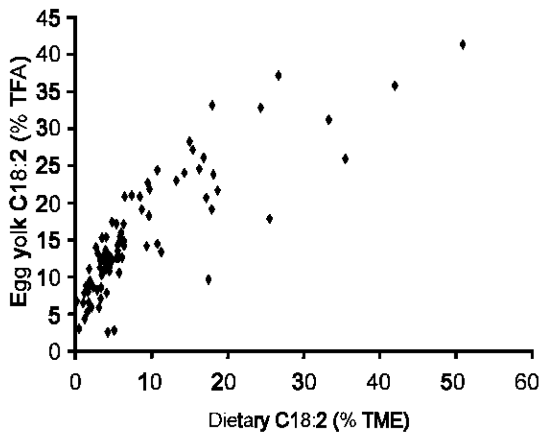

Fig. 8: The relationship between the energy percentage of dietary linoleic acid and its weight percentage in egg yolk

energy percentage of dietary linoleic and α-linolenic acid and weight percentage of egg yolk linoleic and α-linolenic acid (Fig. 8 and 9), linear correlation coefficients of 0.84 and 0.87, respectively, were calculated (Table 3). These correlations are not systematically stronger than those found for the weight percentage of dietary fatty acids. This suggests that incorporation of the dietary fatty acids was not markedly influenced by dilution.

It is possible that the true correlation coefficients between diet and egg yolk fatty acid content are stronger than those calculated. Data from different experiments were used, which leads to an increase in the variation and therefore a decrease in the correlation coefficient. For example, hens of different strains and different ages were used. Strain only has minor influence on the fatty acid composition of egg yolk (Ahn *et al.*, 1995; Grobas *et al.*, 2001; Scheideler *et al.*, 1998; Sell *et al.*, 1968), but

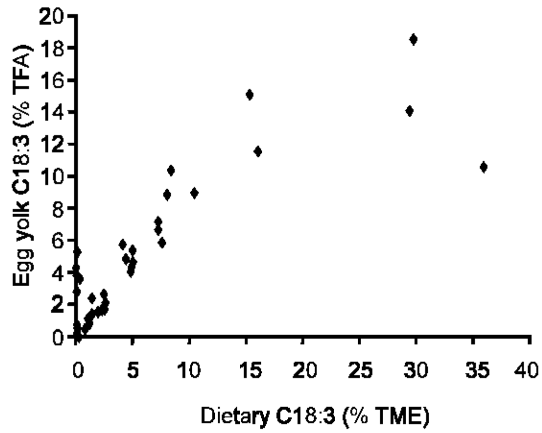

Fig. 9: The relationship between the energy percentage of dietary α-linolenic acid and its weight percentage in egg yolk

age has a significant effect (Nielsen, 1998; Scheideler *et al.*, 1998).

In conclusion, egg yolk EPA can be modified by feeding a diet containing EPA, whereas egg yolk DHA can be increased by either a diet rich in α-linolenic acid or a diet containing DHA. Since small amounts of DHA could be beneficial to human health (Harris and Isley, 2001), it is possible that enrichment of eggs with this fatty acid has practical relevance.

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