A high n-3 fatty acid egg vs. a high n-6 fatty acid diet: the significance of health-oriented agriculture

N. Shapira[1], P. Weill[2], R. Loewenbach[3]

[1]Tel Aviv University, Stanley Steyer School of Health Professions – Ramat Aviv 69978, Israel; [2]Valorex – Combourtillé, France; [3]Alonim, Israel

nivnet@inter.net.il

INTRODUCTION

High dietary and adipose n-6 polyunsaturated fatty acids (PUFA) and n-6:n-3 fatty acid (FA) ratio have been suggested to underlie the 'Israeli Paradox' – higher chronic disease rates than in other Mediterranean countries, comparable to high-risk Western countries such as the United States and northern Europe – despite 'good' diet – adequate in total energy, fat, and saturated fat (SFA), and high in PUFA:SFA (P:S) ratio, vegetables, and fruits (Yam et al., 1996; Dubnov and Berry, 2003; Kark et al., 2003; ICDC, 2003).

In contrast, higher levels of n-3 PUFA, with a low n-6:n-3 FA ratio, exert protective effects (Seo et al., 2005; Nettleton, 2004; Weisman et al., 2004; Simopoulos, 2002), and n-3 long-chain PUFA (LCPUFA), i.e. eicosapentaenoic acid (EPA, 20:5 n-3) and docosahexaenoic acid (DHA, 22:6 n-3), warrant special attention for these roles.

However, conversion from LCPUFA-precursor alpha-linolenic acid (ALA, 18:3 n-3) to DHA can be quite low in humans – between 0.05-4.0% (Burdge & Calder, 2005) − depending on individual metabolism and dietary habits, the high amounts of n-6 FA, as in the typical Israeli diet, may competitively inhibit this process (James et al., 2000).

High Israeli consumption of n-6 FA results primarily from dietary intake, i.e. high consumption of vegetable oils,– 65% of total fat, most of them high in n-6 FA, soybean oil contribute 60% (FAO,1996) − but also indirectly from the high n-6:n-3 FA ratio in the food chain, i.e. poultry (14:1), and dairy (12.5:1), as well as farmed fish (6:1 carp, 6.5:1 tilapia) (Shapira 2006, unpublished data), as a result of high n-6 FA feed.

The Israeli regular egg is particularly high in n-6 FA (19.6 FA%), low in n-3 FA (1.2 FA%), with a high n-6:n-3 FA ratio (16.3:1). Laying hen feed formulation is affected by market cost and the practice of using high amounts of n-6 FA to guarantee large egg size per Israeli consumer preference – grades 1 (>70 g) and 2 (65-70 g) – which are the major commercially marketable eggs in Israel (Lahav, 2001). As egg FA profile is known to be highly dependent upon feed and n-3 FA content can be increased significantly (Bourre 2005; Yannakopoulos et al., 2005; Nitsan et al., 1999; Jiang & Sims, 1993), the question raised addresses the possibility of 'field fortification' via simple addition of a single, whole n-3 FA source to an otherwise high n-6 FA hen feed to produce eggs that may contribute significantly to the Israeli diet and be readily accepted by the consumer.

MATERIALS AND METHODS

3500 laying hens were divided randomly into two groups, and fed for five weeks with either a standard corn-based feed (control) or the same feed fortified with 5% extruded linseed (ELS) mix in accordance with the methods of Weill et al. (2002).

Feed compositions were calculated according to average content of components.

Laying hen performance was evaluated by routine monitoring of feed intake (g/day), egg production (% egg-laying), and size of sample eggs (g).

FA analyses of feeds and eggs were performed by fat extraction (Directive European 98/64/CE process B), preparation of esters methylation (NF EN ISO 5509), and gas chromatographic separation and quantification (NF EN ISO 5508 June 1995/NF EN ISO June 2000).

Nutritional contribution of one fortified egg was calculated by adding fat and FA values to current average intakes among Israelis, assessed during a recent national nutrition survey

(ICDC, 2003) and compared to Dietary Reference Intakes (DRI) for ALA (0.6-1.2 %kcalories [kcal]) and LCPUFA (0.06-0.12 %kcal) (IOM, 2002).
Cost analysis was conducted by calculation of exchanging 5% ELS mix supplement with alternative sources of oils and other components.
Sensory analysis was conducted by blind comparison of fortified vs. control eggs by 10 volunteers, with regard to taste, color, and smell.
Statistical analyses between groups were performed using two-tailed paired t-test.

RESULTS

N-3 PUFA supplement: ELS fat contains a very high n-3 FA component (53%) – close to that of spring grass lipids ethereal extract (65%), a major component of traditional chicken feed – and much more n-3 FA than most feed oils, i.e. maize (0%), sunflower (1%), soy (8%), and rapeseed (9%).
Feed formulations: Control and fortified feeds were basically very similar: maize (46 and 47.5%, respectively), soy (11 and 15%), sunflower (10 and 10%), and sorghum (6 and 6%) – save for oil sources – canola (4 and 0%) or ELS (0 and 5%). Because the feed grains contained primarily n-6 FA, ELS (16% ALA) was the major source of n-3 FA in the fortified feed (800 mg/100 g). Total energy (kcal) and macronutrient (protein, fat, and carbohydrate) contents of the two feeds were nearly equivalent. N-3 FA fortification increased total n-3 18:3 FA content 5-fold (3.0 to 15.0% FA in control vs. fortified), increased total PUFA by 44% (32 to 46 %), and reduced the n-6:n-3 FA ratio 15-fold (31:1 to 2:1). A small reduction was observed in SFA (28.5 to 22.0%) and MUFA (40.0% to 32.0%).
Laying hen performance: No significant effect on laying hens was observed with five-week n-3 FA fortification, as compared to control, with regard to feed intake (average 117.6 g/day), egg production (97.5%), and egg size (≥65.0 g).

Table 1. FA profile of Israeli standard, control and n-3 FA-fortified eggs (5% ELS).

% FA	Total SFA	Total MUFA	Total PUFA	LA (18:2 n-6)	AA (20:4 n-6)	ALA (18:3 n-3)	DHA (22:6 n-3)	Total n-3 PUFA	Total n-6 PUFA	n-6:n-3 PUFA ratio	n-6:n-3 LCPUFA ratio
Control	**34.7**	**44.3**	**22.1**	**16.5**	**1.9**	**0.4**	**0.7**	**1.2**	**19.6**	**16.3**	**2.7**
n-3 FA Fortified	**32.6 ±0.4[a]**	**42.3 ±0.6[b]**	**25.2 ±0.7**	**18.3 ±0.5[b]**	**1.5 ±0.1[b]**	**2.6 ±0.2[a]**	**1.7 ±0.2[a]**	**4.5 ±0.3[a]**	**20.5 ±0.5[c]**	**4.5 ±0.3[a]**	**0.9**

[a] $p<0.0005$, [b] $p<0.005$, [c] $p<0.05$. [d] $p<0.5$

Egg composition: Total PUFA increased by 14%, and SFA and MUFA decreased slightly (by 6.7 and 5%, respectively) with n-3 FA fortification. ALA increased 638% (from 28.8 mg/egg in control to 184.3 in fortified), DHA 237% (50.4 to 119.5 mg) and total n-3 FA 376% (79.2 to 303.8 mg). Total n-6 FA increased by 4.5%, linoleic acid (LA, 18:2 n-6 PUFA) was slightly increased (by 11%), whereas AA was significantly decreased (by 28.4%), as was the AA:ALA ratio (by 50%). Decreases were also observed in FA ratios, LA:ALA by 578%, total n-6:n-3 by 384%, and long-chain PUFA (LCPUFA) n-6:n-3 ratio (AA:DHA) by 304% (Table 1). The principal increase in n-3 FA and resultant reduced n-6:n-3 FA ratio were seen already after the first week of feed n-3 FA supplementation, with a small and gradual increase thereafter
Egg contribution to Israeli n-3 FA consumption: Based on current n-3 FA consumption (ICDC, 2004), one fortified egg could yield a 12.7-19.0% increase for men (Jews-Arabs) and 17.9-25.3% for women, and reduce dietary n-6:n-3 FA ratio by 12.5%. It contains 6.1-18.7% of the DRI for ALA and 39.6-121.0% for DHA, vs. 1.0-2.9 and 16.7-51.0%, respectively, in control eggs (IOM, 2002). Sensory analysis and size of the fortified egg did not differ

significantly from the control, and feed cost analysis showed an average increase of 4-7%, ranging according to market prices.

DISCUSSION

The objectives of the study were to evaluate feasibility of field supplementation of high n-6 PUFA laying hen feed with a whole n-3 FA source (5% ELS) to produce an egg which could significantly contribute to the nutritional status of Israelis – known to have high n-6 FA intake – and be readily accepted by the Israeli consumer with regard to size, cost, and taste.

The effectiveness of the method as demonstrated by significant increases in total egg n-3 FA by 377%, and a 332% reduction in n-6:n-3 FA ratio after only one week of fortification and the high degree (%) of n-3 FA transformation of feed ALA to egg total n-3 FA, ALA, and DHA (32, 19.5, and 12.5%, respectively, of 800 mg ALA/100 g feed) is of particular relevance to general health in conditions of relative dietary n-3 FA scarcity, as in Israel (Eilat-Adar et al., 2004; Endevelt and Shahar, 2004). Such effective n-3 FA transformation – despite the extremely high initial n-6:n-3 FA ratio – confirms the egg being an exceptionally effective medium for n-3 FA (ALA) elongation and desaturation to n-3 LCPUFA (DHA), enabling successful competition with the enzymatic transformation of n-6 FA (LA) to n-6 LCPUFA (AA), and preferentially concentrating n-3 FA in egg yolk lipids, as compared to hen body tissues (Nitsan et al., 1999).

Fortified egg appears to be a unique source of n-3 FA, but without the drawback of environmental contaminants (Foran et al., 2005). The nutritional significance of egg n-3 FA transformation efficiency was recently documented (Bourre, 2005), is well-known in the field of 'designer' egg production (Hargis & Van Elswyk, 1993; Nitsan et al., 1999; Yannakopoulos et al., 2005; Cachaldora et al., 2006; Jiang & Sims, 1993), and could be critical to the Israeli diet – extremely high in n-6 FA and n-6:n-3 ratio – in light of the important health benefits of n-3 FA (Seo et al. 2005; Nettleton 2004; Weisman D et al., 2004; Simopoulos 2002).

The significant changes in egg composition and nutritional value, after only one week of whole linseed fortification, confirmed the effectiveness of the 'field' approach of minimal modification and low additional cost plus high acceptability with regard to maintenance of sensory and size market criteria.

This field supplementation approach is in accordance with the new paradigm of health-oriented agriculture, which is more consistent with nutritional needs – i.e. meeting the challenge of extremely high dietary n-6:n-3 FA ratio in Israel – and/or traditional methods of livestock feeding – i.e. n-3 FA-rich grass – and may increase nutritional contribution, be more widely attainable, and may even suggest new compositional standardization.

ACKNOWLEDGEMENTS

The author thanks Osnat Sharon, M.Sc., R.D., for her assistance in this paper.

REFERENCES

1. Bourre JM. Where to find omega-3 fatty acids and how feeding animals with diet enriched in omega-3 fatty acids to increase nutritional value of derived products for human: what is actually useful? J Nutr Health Aging. 2005 Jul-Aug;9(4):232-42.
2. Burdge GC, Calder PC. Conversion of alpha-linolenic acid to longer-chain polyunsaturated fatty acids in human adults . Reprod Nutr Dev. 2005 Sep-Oct;45(5):581-97.
3. Cachaldora P, Garcia-Rebollar P, Alvarez C, De Blas JC, Mendez J. Effect of type and level of fish oil supplementation on yolk fat composition and n-3 fatty acids retention efficiency in laying hens. Br Poult Sci. 2006 Feb;47(1):43-9.
4. Dubnov G, Berry ME. Omega-6/omega-3 fatty acid ratio: the Israeli paradox. World Rev Nutr Diet. 2003;92:81-91.
5. Eilat-Adar S, Lipovetzky N, Goldbourt U, Henkin Y. Omega-3 fatty acids, fish, fish oil and cardiovascular disease – a review with implications to Israeli nutritional guidelines. Harefuah. 2004 Aug;143(8):585-91, 621-2.

6. Endevelt R, Shahar DR. Omega-3: the vanishing nutrient beyond cardiovascular prevention and treatment . Isr Med Assoc J. 2004 Apr;6(4):2359.
7. Food and Agricultural Association of the United Nations (FAO). Food balance sheets. 1992-94 average. Israel. 1996: 218-20 Rome, Italy: Food and Agricultural Association of the United Nations (FAO).
8. Foran JA et al, Quantitative analysis of the benefits and risks of consuming farmed and wild salmon. J Nutr. 2005;135(11):2639-43.
9. Hargis PS, Van Elswyk ME. Manipulating the fatty acid composition of poultry meat and eggs for the health conscious consumer. World Poult Sci. 1993;70:874-83.
10. Institute of Medicine (IOM) Food and Nutrition Board. Dietary Reference Intakes, Washington D.C.: National Academy Press, 2002. Internet: http://www.iom.edu/CMS/3788.aspx (accessed 10 October 2006).
11. James MJ, Gibson RA, Cleland LG. Dietary polyunsaturated fatty acids and inflammatory mediator production. Am J Clin Nutr. 2000 Jan;71(1 Suppl):343S-8S.
12. Jiang Z, Sim JS. Consumption of n-3 polyunsaturated fatty acid-enriched eggs and changes in plasma lipids of human subjects. Nutrition. 1993 Nov-Dec;9(6):513-8.
13. Kark JD, Kaufmann NA, Binka F, Goldberger N, Berry EM. Adipose tissue n-6 fatty acids and acute myocardial infarction in a population consuming a diet high in polyunsaturated fatty acids. Am J Clin Nutr. 2003;77(4):796-802.
14. Lahav, D. Enforced restrictions during egg production. Knesset Center for Research and Science. 29 Oct 2001. Accessed 05/05/2007 from http://www.knesset.gov.il/MMM/data/docs/m00152.doc.
15. MABAT. First Israeli National Health and Nutrition Survey 1999–2001, Pub. 225. Part 1 − General Findings. Tel Hashomer, Israel:Israeli Center for Disease Control. 2003.
16. Nettleton JA on behalf of The Alaska Seafood Marketing Institute (ASMI). Increasing the consumption of long-chain ome-3 polyunsaturated fatty acids by Americans. Testimony to The Joint USDA/HHS 2005 Dietary Guidelines Advisory Committee. 28 Jan 2004.
17. Nitsan Z, Mokady S, Sukenik A. Enrichment of poultry products with omega3 fatty acids by dietary supplementation with the alga Nannochloropsis and mantur oil. J Agric Food Chem. 1999 Dec;47(12):5127-32.
18. Seo T, Blaner WS, Deckelbaum RJ. Omega-3 fatty acids: molecular approaches to optimal biological outcomes. Curr Opin Lipidol. 2005 Feb;16(1):11-8.
19. Simopoulos AP. The importance of the ratio of omega-6:omega-3 essential fatty acids. Biomed Pharmacother. 2002 Oct;56(8):365-79.Weisman D, Motro M, Schwammenthal E, Fisman EZ, Tenenbaum A, Tanne D, Adler Y. Efficacy of omega-3 fatty acid supplementation in primary and secondary prevention of coronary heart disease. Isr Med Assoc J. 2004 Apr;6(4):227-32.
20. Weill P, Schmitt B, Chesneau G, Daniel N, Safraou F, Legrand P. Effects of introducing linseed in livestock diet on blood fatty acid composition of consumers of animal products. Ann Nutr Metab. 2002;46(5):182-91.
21. Yam D, Eliraz A, Berry EM. Diet and disease – the Israeli paradox: possible dangers of a high omega 6 polyunsaturated fatty acid diet. Isr J Med Sci. 1996;32:1134-43.
22. Yannakopoulos A, Tserveni-Gousi A, Christaki E. Enhanced egg production in practice: the case of bio-omega-3 egg. Internatl J Poult Sci. 2005;4:531-5.

KEYWORDS: egg, hen feed, n-3 fatty acids, agriculture, Israel