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ENRICHMENT OF EGGS AND POULTRY MEAT WITH BIOLOGICALLY ACTIVE SUBSTANCES BY FEED MODIFICATIONS AND EFFECTS ON THE FINAL QUALITY OF THE PRODUCT

Michael A. Grashorn

Dept. of Farm Animal Ethology and Poultry Science, University of Hohenheim, Stuttgart, Germany

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In developed countries nutrition of people is assured. Therefore, consumers are not longer interested only in the nutritive value of their food but in the content of natural substances exhibiting special health effects. This has led to the development of functional foods. Already in the late 1980ies first attempts have been made by enriching chicken eggs with omega-3 fatty acids which have proven beneficial effects on the cardiovascular system. Meanwhile, enrichment procedures have been extended to other components and as well to poultry meat.

Enriching both eggs and poultry meat with health promoting substances is quite easily achieved. In general, enrichment of eggs is more pronounced than enrichment of poultry meat due to the higher fat content of eggs. When enriching eggs and poultry meat with health promoting substances it has to be considered that a negative impact on quality features may occur. This is mainly proven for n-3 fatty acids due to increased liability to oxidation and for CLA due to the increase in toughness of poultry meat. But, the functional food approach is an interesting issue for egg and poultry meat production as functional eggs and functional poultry meat may contribute significantly to the intake of health promoting substances in humans.

INTRODUCTION

In developed countries nutrition of people is assured. Therefore, consumers are not longer interested only in the nutritive value of their food but in the content of natural substances exhibiting special health effects, although especially the chicken egg provides high contents of 'healthy' substances (*e.g.* n3 fatty acids, antioxidants, immunglobulins *etc*.) [Narahari, 2003; Nau *et al.*, 2002; Ternes & Drotleff, 2001]. In the past many attempts have been made to enrich poultry products with these kinds of substances resulting in the development of functional eggs [Pritchard, 2003] and chicken meat. But, the enrichment of products may have a negative effect on product quality [Surai *et al.*, 2002].

The present paper will give an overview on enriching chicken eggs and poultry meat with special types of fatty acids and antioxidants and the effects of enrichment on product quality.

ENRICHED CHICKEN EGGS

Omega-3 fatty acids

It is well known that dietary fatty acid profiles are directly reflected in the lipids of egg yolks. Therefore, many attempts have been made to enrich eggs with n-3 fatty acids which have proven positive effects on the cardio vascular system, and reduced inflammation processes as well as cancer in humans. This research started already in the 1980ies with David Farrell as the main activist [f.e. Farrell, 1995]. Results of research indicated that linseed, linseed oil, rapeseed, fish oil or algae are suitable dietary sources for this purpose [f.e. Farrell, 1993; Murakami *et al.*, 2003; Rizzi *et al.*, 2003, Salobir *et al.*, 2003; Scheideler & Froning, 1996; Yannakopoulos *et al.*, 2004]. The contents of linolenic (LNA) and docosahexaenoic (DHA) acids may be increased in egg yolk by the factor 5 to 30, depending on the dietary sources and their contents in the diet. The most enriched chicken eggs are at the time the 'Designer Eggs' which contain a 30 times higher content of DHA than the standard egg [Narahari, 2003]. Other examples are the 'Omega Egg' in Germany [Hartfiel *et al.*, 1997], the 'Columbus Egg' in the United Kingdom (Table 1) and the 'Bio-omega-3 egg' in Greece (Table 2). In all cases one egg will fully cover the RDI of n-3 fatty acids for humans. Besides, the eggs provide as well considerable amounts of vitamin E and Se. But, en-

TABLE 1. Selected nutrients of the 'Columbus Egg' in England and covering of human RDI [De Meester *et al.*, 2000].

	Columbus Egg	Covering of recommended daily intake (%)
Omega-3 fatty acids	>600 mg	150
Vitamin E	10 mg	100
Selenium	35 μg	50
Iodine	50 μg	25
β-Carotin	150 IE	5
Polyphenols	Traces	-

*Author's address for correspondence: Michael A. Grashorn, Dept. of Farm Animal Ethology and Poultry Science, Institute 470c, University of Hohenheim, 70593 Stuttgart, Germany; e-mail: grashorn@uni-hohenheim.de

TABLE 2. Nutritive content of conventional and Bio-Omega-3 eggs [Yannakopoulos *et al.*, 2004].

	Unit/egg	Conventional egg	Bio-Omega-3 egg
Lipids	g	4.74	4.15
PUFA	g	0.9	1.19
Omega-3	mg	40	350
Cholesterol	mg	220	175
Iodine	µg	9	34
Selenium	µg	5	22
Vitamin E	mg	0.7	3.5

TABLE 3. Contents of carotinoids in fresh eggs (dietary contents: apo-8-ester 3 mg/kg; canthaxanthin 4 mg/kg; native xanthophylls 2.5 mg/kg; yolk colour according to the DSM colour fan 13; own investigations).

Pigment	Source	µg/Egg
Lutein	natural	37
Zeaxanthin	natural	6
Apo-8-Ester	artficial	205
Canthaxanthin	artificial	206
Total pigments	-	454

riching eggs with n-3 polyunsaturated fatty acids (PUFA) will result in a higher liability of eggs to oxidation and to off-flavours [Surai *et al.*, 2002; Tserveni-Gousi *et al.*, 2004]. Off--flavours may further occur by the use of fish oil as a dietary source due to included fish typical components. Therefore, for the production of n-3 enriched eggs only high quality fish oil should be used and distinct amounts of antioxidants (f.e. α-tocopherol) should be supplemented, as well [Galobart *et al.*, 1999; Krämer *et al.*, 1997]. Up to now no clear negative effect of n-3 enrichment on other quality criteria of eggs, including functional properties could be observed.

Conjugated linoleic acid

Conjugated linoleic acid (CLA) may reduce the risk of cancer, atherosclerosis and plasma cholesterol level and may strengthen the immune system [Aletor *et al.*, 2003; Aydin *et al.*, 2001]. Normally, CLA uptake in humans is by milk or milk products [Fritsche & Steinhart, 1998]. But, CLA may also be enriched in eggs by feeding diets containing special oil formulations supplemented with CLA [Du *et al.*, 2001].

Antioxidants

The most famous antioxidant used in animal nutrition is α-tocopherol (α-TA), which is easily deposited in the egg yolk [Galobart *et al.*, 1999, 2001; Hartfiel *et al.*, 1997; Surai *et al.*, 1995]. But, other existing substances in yolks may also prohibit oxidation, as selenium or carotenoids [Rizzi *et al.*, 2003; Salobir *et al.*, 2003; Tucker *et al.*, 2003; Yaroshenko *et al.*, 2004]. Antioxidants are deposited in yolks according to dietary levels. Enriching egg yolks with α-TA or carotenoids (Table 3) can be done in a wide range and does not affect egg quality, except that with increasing levels of carotenoids intensity of yolk colour increases. Supplementing carotenoids to diets it has to be considered that yellow and red pigments should be added in ratios given by the manufacturer to avoid off-colours [Galobart *et al.*, 2001]. The artificial carotenoids (apo-8-ester, canthaxanthin) usually supplemented to the layer's diet cover more than 90% of total carotenoids in the egg. Enriching eggs with Se is more complicated as high levels of Se in the food are toxic for humans. Nevertheless, it is easy to enrich eggs with 35 µg Se which amounts to 50 % of the recommended daily intake (RDI) for humans [Yaroshenko *et al.*, 2004]. No negative impacts of antioxidants on any egg quality criteria are known.

Cystatine and lysozyme

Composition and level of proteins in albumen cannot be changed easily as proteins are not directly transferred from the food to the egg as formation of proteins is determined by the RNA code and takes place in the *magnum*. Albumen includes many proteins with antimicrobial or even antiviral activity, as the albumen is the barrier of the developing embryo to microorganisms in the surrounding environment. The most interesting proteins in the albumen are cystatine and lysozyme (Table 4), but also immunglobuline yolk (IgY) [Lagarde, 2000; Sim *et al.*, 2000; Trziszka *et al.*, 2002]. Contents and activities of these proteins may be increased by stimulating the immune system of the hen. This may be done by vaccination with sheep red blood cells (SRBC) or other challenging agents [Sim *et al.*, 2000]. Furthermore, it is well known that also differences between genotypes of hens exist for contents and activities of cytstatine and lysozyme, allowing for selection programs for increased levels of these proteins. No information is available on probable effects on egg quality, but it has to be considered that egg white proteins may cause allergies in humans [Mine, 2003].

POULTRY MEAT

Omega-3 fatty acids

As in eggs omega-3 fatty acids may easily be incorporated into tissues of meat-type poultry [Coetze & Hoffman, 2002; Cortinas *et al.*, 2004; Lopez-Ferrer *et al.*, 1999;]. The same dietary sources are used for this purpose with the exception that fish products are avoided due to occurring off-flavours (Table 5). Exchanging the content of fish oil in the diet by linseed oil or rapeseed oil in the last two weeks of fattening will not result in these quality aberrations. Another point of interest may be that increasing the n-3 fatty acid content in tissues may result in lower fatness of carcasses [Crespo & Esteve-Garcia, 2001]. Using diets rich in n-3 fatty acids increases contents of n-3 PUFA in breast and thigh meat by 10 to 12 times, providing 60 to 200% of the n-3 RDI for humans, respectively. But, n-3 enriched poultry meat is highly susceptible to oxidation making the additional supplementation of antioxidants as α-TA necessary [Cortinas *et al.*, 2003].

Conjugated linoleic acid

The content of CLA may be increased by 40 times in breast and thigh meat, by feeding CLA enriched diets to

TABLE 4. Egg white proteins with anti-microbial activity [after Ternes *et al.*, 1994].

Protein	% of protein	Properties
Lysozyme	3.5	Complexes with Ovomucin, anti-microbial
Ovomacroglobulin	0.5	Immunogenetic
Ovoinhibitor	0.1	Inhibitor of proteinase
Cystatine	0.05	Acts against Papain and Ficin, anti-microbial

TABLE 5. Sensoric assessment* chicken breast and thigh meat after feeding of diets including fish oil (FO), linseed oil (LO) and rapeseed oil (RO) [Lopez-Ferrer *et al.*, 1999].

		Breast	Thigh		Breast	Thigh
FO**	LO			RO		
5 w	0 w	1.72	2.38	0 w	2.71	2.57
4 w	1 w	3.50	3.83	1 w	3.50	3.95
3 w	2 w	3.71	4.66	2 w	3.90	4.06
0 w	5 w	4.09	4.75	5 w	4.35	4.38

* range: 1 = negative, 5 = positive
** 5 weeks FO and 0 weeks LO/RO, 4 weeks FO and 1 week LO/RO, 3 weeks FO and 2 weeks LO/RO, 0 weeks FO and 5 weeks LO/RO

TABLE 6. Content of saturated, mono-unsaturated, poly-unsaturated (without CLA) and conjugated fatty acids (CLA) in breast and thigh meat depending on the dietary content of CLA (mg/ 100 g tissue) [Sirri *et al.*, 2003].

Fatty acid	0 % CLA	2 % CLA	4 % CLA
Breast muscle			
SAT	277	244	284
MUFA	241	144	177
PUFA (without CLA)	332	278	291
CLA	1.5	32.1	69.5
n-3	27.6	28.6	24.2
Thigh muscle			
SAT	593	596	625
MUFA	670	425	463
PUFA (without CLA)	830	679	675
CLA	4.7	95.5	177
n-3	64.7	50.8	51.0

SAT = saturated fatty acids, MUFA = mono-unsaturated fatty acids, PUFA = poly-unsaturated fatty acids, n-3 = Omega-3 fatty acids

broilers [Aletor *et al.*, 2003; Aydin *et al.*, 2001; Sirri *et al.*, 2003; Du & Ahn, 2002]. Despite this high increase in the CLA content in breast and thigh meat the RDI for CLA in humans may only be covered by roughly 10% (Table 6). Furthermore, CLA enriched poultry meat shows deviations in meat quality. CLA enriched meat is more tough, dark and less red and yellow. This is also confirmed by sensoric tests. Colour and flavour of CLA enriched meat were in favour of the test panel, whereas, texture and juiciness were assessed negatively (Table 7). The toughness of the meat may be explained by the higher proportion of saturated fatty acids in CLA enriched muscle tissues [Du & Ahn, 2002].

Antioxidants

Poultry meat is easily enriched with α-TA or Se, but deposition of α-TA in tissues is decreasing with increasing amounts on PUFA in diets (Table 8), indicating the use of α-TA for prevention of oxidation [Cortinas *et al.*, 2003; Lopez-Ferrer *et al.*, 1999]. This has to be considered when calculating the necessary dietary supplementation level of α-TA for producing n-3 enriched poultry meat [Muggli, 1994]. In the contrary, Se is deposited in tissues in quite high levels [Yaroshenko *et al.*, 2004]. The normal content in tissues may be increased 3 to 4 times when feeding Se supplemented diets to birds. Se enriched muscle tissues, both thigh and breast, may cover up to 60% of the Se RDI for humans (Fig-

TABLE 7. Effect of conjugated linoleic acid (CLA) on texture, colour and sensoric features of chicken breast meat [Du & Ahn, 2002].

Fatty acid	0 % CLA	2 % CLA	3 % CLA
Texture (kp)	3.45[b]	3.62[ab]	3.81[a]
L*	80.7[a]	80.2[a]	79.1[b]
a*	8.44[a]	8.28[a]	7.80[b]
b*	22.1[a]	21.1[b]	19.2[c]
Sensory*			
Colour	5.94	6.00	6.11
Flovour	6.60	7.03	7.00
Tenderness	6.27	6.30	6.43
Juiciness	5.22	5.12	5.06

*range: 1 = negative, 15 = positive

TABLE 8. Effect of dietary unsaturation and α-tocopheryl acetate supplementation on α-tocopherol content in thigh meat (mg/ kg thigh; SEM=1.84; P-values<0.0001) [Cortinas *et al.*, 2003].

Dietary PUFA (mg/kg)	Global mean	α-tocopheryl acetate (mg(kg)			
		0	100	200	400
27	23.2[x]	0.33[g]	12.6[ef]	24.3[cd]	55.5[a]
38	18.5[y]	0.43[g]	12.9[ef]	19.1[de]	41.6[b]
48	14.6[z]	0.10[g]	10.3[ef]	17.6[de]	30.5[c]
59	12.9[z]	0.04[g]	6.05[fg]	15.0[ef]	10.6[c]
Global mean		0.22[z]	10.5[y]	19.0[x]	39.6[w]

ure 1). No negative impact on meat quality is observed and expected in α-TA or Se enriched poultry meat.

CONCLUSIONS

The functional food approach is an interesting issue for egg and poultry meat production. Enriching both eggs and poultry meat with health promoting substances is quite easily achieved. In general, enrichment of eggs is more pronounced than enrichment of poultry meat due to the higher fat content of eggs. When enriching eggs and poultry meat with health promoting substances it has to be considered that a negative impact on quality features may occur. This is mainly proven for n-3 fatty acids due to increased liability to oxidation and for CLA due to the increase in toughness of poultry meat.

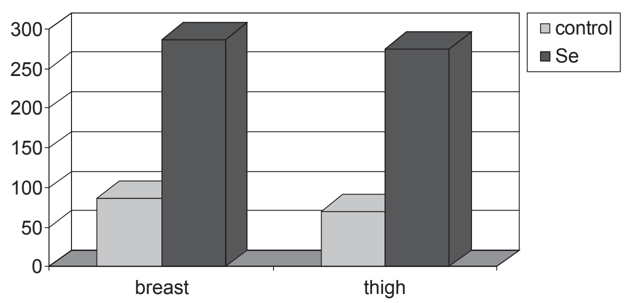

FIGURE 1. Se content of Se-enriched chicken meat (ng/g; Se supplementation 0.4-0.8 mg/kg diet; corresponds to 60 % of human RDI) [Yaroshenko *et al.*, 2004].

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