Long-Term Effects of Feeding Flaxseed-Based Diets. 1. Egg Production Parameters, Components, and Eggshell Quality in Two Strains of Laying Hens[1]

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ABSTRACT We used a split-plot design of five diets: control (corn-soy) with 3.8% Ca, 10% flaxseed with 3.8% Ca, 10% flaxseed with 4.5% Ca, 10% flaxseed with 3.8% Ca and 22,000 IU vitamin D_3/kg, and 10% flaxseed with 4.5% Ca and 22,000 IU vitamin D_3/kg, and two strains of birds, DeKalb Delta (DD) and Hy-Line W-36 (HL), to evaluate long-term effects of flaxseed supplementation on egg production parameters. Each of the five treatments was randomly assigned and replicated six times with five hens per replicate pen from 21 to 57 wk of age. Phase I was from 21 to 39 wk, Phase II was from 40 to 48 wk, and Phase III was from 49 to 57 wk. Feed consumption was significantly ($P < 0.04$) greater for the hens fed 10% flaxseed diets (100.9 g) when compared to the corn-soy controls (99.3 g). Overall average egg production ($P < 0.05$) was 87.8, 87.1, 86.0, 87.1, 84.8, for diets 1, 2, 3, 4, and 5, respectively. Average hen weights during the study were significantly lower for the flaxseed-fed hens (1.559 kg) compared to the controls (1.616 kg). Egg weight was significantly affected by diet during Phase III with heavier eggs from flaxseed fed hens (62.6 g) compared to controls (61.44 g), but overall egg weight was not significantly affected. Average egg mass was not significantly affected by dietary treatments, but DD hens had a decrease in egg mass with Ca supplementation (Diet 2 vs. Diet 3), whereas HL egg mass increased with Ca supplementation. Percentage albumen had a significant strain effect and strain by diet interactions. Overall, significantly less albumen ($P < 0.001$) was produced by HL (59.4%) compared to DD (61.3%). Supplemental Ca increased albumen percentage in DD (interaction effect $P < 0.03$) and decreased albumen percentage in the HL strain. Flaxseed supplementation significantly increased albumen percentage ($P < 0.02$) when compared to the corn-soy control, 60.5 and 59.9%, respectively. An interaction effect ($P < 0.01$) was noted for percentage wet yolk, in which increasing Ca decreased wet yolk percentage in DD but increased yolk percentage in HL. Wet yolk percentage was also significantly ($P < 0.001$) less in DD (25.0%) when compared to HL (26.9%). Addition of flaxseed decreased yolk percent when compared to controls ($P < 0.03$) during Phase II. Ca supplementation significantly ($P < 0.03$) increased yolk solids in both strains. Grams of yolk solids per egg were affected by flaxseed supplementation ($P < 0.06$). Flaxseed eggs contained 7.18 g per egg yolk solids compared to 7.3 g in corn-soy control group. Wet shell percentage was significantly lower in the flaxseed diets (12.4%) when compared to the controls (12.6%). Addition of flaxseed to the diet of laying hens did not have any adverse effects on egg production parameters, but flaxseed supplementation can significantly alter weight of yolk solids and yolk and albumen percentages.

(*Key words*: flaxseed, egg production, layer, albumen, yolk solid)

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INTRODUCTION

Interest in n-3 fatty acid [α-linolenic acid; eicosapentaenoic acid (EPA), 20:5,n-3; docosahexaenoic acid (DHA), 22:6,n-3] intakes and overall healthy eating habits have gained momentum in light of recent research relating increased consumption of n-3 fatty acids to lowered incidence of human disease. Diseases such as coronary heart disease (Kinsella et al., 1990), lupus nephritis (Clark and Parbtani, 1996), and high blood pressure (Pauletto et al., 1996) may be prevented or reduced by increased n-3 fatty acid intake. Omega-3 fatty acids are also important for the development of brains and retinas in newborns (Jorgensen et al., 1996; Uauy et al. 1996).

Fish products are high in n-3 fatty acids such as DHA and EPA, but because fish may not be readily available

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Abbreviation Key: DD = DeKalb Delta; DHA = docosahexaenoic acid; EPA = eicosapentaenoic acid; HL = Hy-Line W-36.

everywhere (geographical area), other sources for n-3 fatty acids are needed. Recent studies have used chickens to incorporate n-3 fatty acids into poultry eggs or meat (Ajuyah et al., 1991; Jiang et al., 1991). Scheideler and Froning (1996) reported significant increases in linolenic, DPA, and DHA contents in the yolk when feeding hens a 10% flaxseed diet compared to a corn/soybean meal control. The addition of flaxseed or other n-3 fatty acid-rich feedstuffs has been reported to decrease yolk percent and yolk weight that may also have an impact on total cholesterol in the egg (Scheideler and Froning, 1996). Whitehead et al. (1993) reported a decrease in yolk weight with the addition of fish oil to the diet of laying hens. Caston et al. (1994) and Scheideler and Froning (1996) reported that yolk weight and percentage yolk of whole egg were decreased with 10 or 20% flaxseed supplementation. Others have associated the decrease in yolk weight with a decrease in egg weight, which is not desirable. Changing the components of whole eggs can change the nutritional value significantly.

Flaxseed and other high-oil feedstuffs have been reported to decrease production rates and reduce shell quality when supplemented into layer diets. Aymond and Van Elswyk (1995) reported in a short-term trial (5 wk) a decrease in egg production in hens consuming a diet containing 15% flaxseed by as early as 2 wk. Scheideler et al. (1995) reported a decrease in egg production rates with the addition of 10% flaxseed to the diet, which could be the result of anti-nutritional factors contained within full-fat flaxseed.

Anti-nutritional factors, such as linatine (trypsin inhibitor; Klosterman et al., 1967) found in mucilage, can decrease the productivity of the animal by decreasing the amount of endogenous enzymes released from the pancreas, thus decreasing digestion of feed particles. Nonstarch polysaccharide (mucilage) is also found in flaxseed and increases intestinal viscosity in monogastric animals, causing a decrease in nutrient availability. Linseed mucilage, which composes about 8% of the seed, comprises a mixture of polysaccharides such as rhamanose, fucose, arabinozylans, zylose, galactose, galacturonic acid, and glucose (Erskine and Jones, 1957). Arabinozylans have been shown to increase intestinal viscosity, which decreases nutrient availability by increasing passage rate, reducing rates of diffusion of endogenous enzymes and nutritional substrates, or both (Classen and Bedford, 1991). Components such as cyanogenic glycosides (linustatin, neolinustatin, and linamarin; Oomah et al., 1992) produce prussic acid and thiocyanate ions that can be very detrimental to the animal. The toxicity stems from the fact that when the seed is crushed in water, hydrogen cyanide (HCN) is released from cyanogenic glycosides by the action of the enzyme β-glycosidase that is present in the seed itself or from gut microflora (Chadha et al., 1994). Cyanogenic compounds can be removed from flaxseed by boiling in water, drying, and wet autoclaving or by acid treatment, followed by autoclaving (Mazza and Oomah, 1995). Flaxseed also contains a substantial amount of phytochemicals (phytoestrogens (entrolactone) and lignans) that act as steroid hormones and compete with estrogen, thus decreasing its level in the blood and potentially interfering with Ca absorption in the laying hen.

With this in mind, the first objective of this study was to evaluate the effect of feeding flaxseed on long-term hen production parameters such as egg production and shell quality and to determine whether supplemental Ca or cholecalciferol can alleviate potential shell quality problems. Our second objective was to evaluate the effect of strain of hen and flaxseed-based diets for layers on egg components and yield.

MATERIALS AND METHODS

Animals and Housing

One hundred fifty 21-wk-old DeKalb® Delta (DD) hens and Hy-Line® W-36 (HL) hens were randomly divided into five dietary treatments. Each treatment was replicated (pen) six times. The hens were housed five per cage (480 cm^2 floor space per hen) in a four-tier manure belt cage system.[3] Feed and water were provided ad libitum. The experiment was conducted in the summer and winter months in a tunnel-ventilated, evaporative-cooled building. Sensors monitored the inside temperatures and adjusted ventilation fans or convection heaters to control temperature. Hens were maintained on a 16 h:8 h light:darkness photoperiod following light stimulation. Feeding and egg collection were conducted daily during the morning hours. Feed weigh backs were three times weekly (Monday, Wednesday, and Friday) to monitor feed consumption and reduce feed wastage.

Diets

A phase feeding program was used during the experiment: Phase I (21 to 39 wk of age), Phase II (40 to 48 wk of age), and Phase III (49 to 57 wk of age). Diets were formulated based on expected feed consumption and age of hens. Recommendations for dietary nutrients were based on DD[4] and HL[5] breeder guides. Diets were formulated to be isocaloric and isonitrogenous. The following five dietary treatments were used: 1) corn/soybean meal-based control with 3.8% Ca and 2,574 IU cholecalciferol/kg of diet (requirement), 2) 10% flaxseed with 3.8% Ca and required cholecalciferol, 3) 10% flaxseed with 4.5% Ca and 2,574 IU cholecalciferol/kg, 4) 10% flaxseed with 3.8% Ca and additional 22,000 IU cholecalciferol/kg[6] of diet, and 5) 10% flaxseed with 4.5% Ca and additional 22,000 IU cholecalciferol/kg of diet. Three basal diets were formulated (Diets 1 to 3) from which Diets 4 and 5

[3]Farmer Automatic of America, Statesboro, GA 30458.

[4]DeKalb Delta Pullet and Layer Management Guide, 1994. Third ed. DeKalb, IL 60115.

[5]Hy-Line W-36 Commercial Management Guide, 1991. Fourth ed. Des Moines, IA 50266.

[6]Roche®, Ames, IA 50010-9999.

TABLE 1. Basal diets – Phase I, II, and III

	Phase I			Phase II			Phase III		
Ingredients	Diet 1	Diet 2[1]	Diet 3	Diet 1	Diet 2	Diet 3	Diet 1	Diet 2	Diet 3
	% of diet								
Corn	53.51	50.85	46.87	54.79	56.00	52.08	57.73	53.66	50.67
Soybean Meal	28.95	24.26	24.94	23.98	18.59	19.27	22.63	19.12	18.90
Flax	. . .	10.00	10.00	. . .	10.00	10.00	. . .	10.00	10.00
Limestone (50:50)	7.06	7.04	8.87	9.07	7.21	9.05	7.70	7.68	9.52
Oats	. . .	. . .	. . .	3.00	3.08	3.00	5.00	5.00	5.00
Tallow	6.00	3.40	4.85	5.04	1.00	2.48	3.35	1.00	2.34
Dical. Phosphate	2.16	2.13	2.13	1.91	1.87	1.88	1.52	1.48	1.49
Oyster Shell	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	0.50
NaCl	0.42	0.43	0.43	0.39	0.40	0.40	0.37	0.37	0.37
Lysine	. . .	. . .	. . .	0.11	0.14	0.13	. . .	. . .	. . .
Mineral Premix[2]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Vitamin Premix[3]	0.045	0.045	0.045	0.047	0.047	0.047	0.045	0.045	0.045
Methionine	0.26	0.25	0.25	0.08	0.07	0.08	0.07	0.06	0.07
Nutrients									
Protein, % (Calculated)	18.00	18.00	18.00	16.00	16.00	16.00	15.54	15.98	15.68
Protein, % (Analyzed)	18.54	17.65	. . .	16.21	15.86	. . .	16.02	16.22	. . .
ME, (kcal/kg)	2,875	2,875	2,875	2,825	2,825	2,825	2,810	2,810	2,810
Cal, % (Calculated)	3.80	3.80	4.50	3.80	3.80	4.50	3.90	3.90	4.60
Cal, % (Analyzed)	3.97	3.89	4.43	4.10	4.00	4.50	3.85	3.90	4.30
Available P, %	0.50	0.50	0.50	0.45	0.45	0.45	0.38	0.38	0.38
TSAA, %	0.79	0.80	0.80	0.76	0.74	0.74	0.63	0.64	0.63
Methionine, %	0.50	0.50	0.50	0.36	0.36	0.36	0.35	0.35	0.35
Lysine, %	0.99	0.98	0.99	0.95	0.95	0.95	0.85	0.86	0.85
Linoleic acid, %	1.55	2.87	2.84	1.56	2.90	2.88	1.58	2.88	2.87
Sodium, %	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.17

[1]Diets 4 and 5 were equivalent in nutrient composition to Diets 2 and 3, respectively, but with an additional 22,000 IU vitamin D_3/kg of diet.

[2]Provided per kilogram of diet: Mn, 88 mg; Cu, 6.6 mg; Fe, 40 mg; Zn, 88 mg; Se, 0.3 ppm; I, 3,300 ppm; Ca, 66.5 mg.

[3]Provided per kilogram of diet: vitamin A, 5,940 IU; cholecalciferol, 2,574 IU; vitamin E, 7.9 IU; riboflavin, 5.9 mg; pantothenic acid, 9.3 mg; niacin, 20 mg; folic acid, 0.25 mg; vitamin B_{12}, 0.012 mg; menadione, 1.19 mg.

were mixed by addition of cholecalciferol (Table 1). Two varieties of flaxseed (Omega and Neche) were used in the trial. Omega flaxseed (golden) was used from 21 to 46 wk of age, and Neche flaxseed (brown) was used to the end of the trial.

Production Data Collection

Feed was provided ad libitum in daily feedings to each pen of hens. Unconsumed feed was measured on Monday, Wednesday, and Friday, at which time the pans were weighed back. Average weekly hen consumption was then calculated by dividing total feed consumed during 7 d by number of hens per cage. Eggs were collected and counted daily, and average weekly egg production was calculated for each pen. Hens were weighed individually on a monthly basis, and average pen weights were calculated.

Eggs from 1 d of production each week were weighed and subsequently, biweekly, measured for specific gravity. Egg mass was calculated by multiplying egg production by egg weight to include another factor to determine actual egg yield. Biweekly, two eggs per pen were used to measure egg components by separating albumen, yolk, and shell. After weighing, yolks and shells were placed in aluminum pans and dried at 100 C for 24 h to determine dry yolk percentage, yolk solids, and percentage dry shell. Percentage albumen, wet yolk, dry yolk, grams of solids per egg, wet shell, and dry shell were calculated based on percentage of whole egg weight, and yolk solids percentage was calculated based on yolk percentage.

Statistics

A row by column blocking scheme was implemented to reduce a decreasing light (row) and temperature ventilation factor (column). Random effects comprised row and column. Main effects of diet and strain and interaction effect between diet and strain were tested. Time effect was analyzed by looking at the differences among phase averages (Phases I, II, and III). Analysis of variance was performed by Proc Mixed procedures (SAS Institute, 1994) for a split-plot design. The whole-plot and split-plot variables were strain and diet, respectively. The following model was used:

$$Y_{ijklm} = \mu + R_i + C_j + \rho_k + \alpha_l + \delta_{kl} + \beta_m + (\alpha\beta)_{lm} + \varepsilon_{ijklm}$$

where Y_{ijklm} = variable measured for the mth pen, μ = overall mean, R_i = effect as a result of the ith row; C_j = effect as a result of the jth column, ρ_k = effect as a result of the kth replicate, α_l = effect of the lth level of strain, δ_{kl} = whole-plot error component, β_m = effect of the mth level of diet, $(\alpha\beta)_{lm}$ = interaction effect of the lth strain and the mth diet, and ε_{ijklm} = split-plot error component.

Contrasts between treatment means were used to establish significance of the difference between controls and flaxseed-based diets and to determine whether supplementation with Ca, cholecalciferol, or Ca and cholecalciferol would change the effect of flaxseed supplementation on production parameters. Only significant values are reported in the tables provided.

The following contrasts were tested:

1. Control (Diet 1) vs. flaxseed (Diet 2)
2. Control (Diet 1) vs. average flaxseed diets (Diets 2, 3, 4, and 5)
3. Flaxseed (Diet 2) vs. flaxseed + Ca (Diet 3)
4. Flaxseed (Diet 2) vs. flaxseed + vitamin D (Diet 4)
5. Flaxseed (Diet 2) vs. flaxseed + Ca/vitamin D (Diet 5)
6. Ca main effect
7. Vitamin D main effect

RESULTS

Production Parameters

Overall feed consumption (Table 2) for the trial showed a significant effect ($P < 0.04$) of feeding flaxseed, with control hens (99.3 g/d) consuming less feed per day when compared to flaxseed-fed hens (100.8 g/d). Similar dietary effects were found during all three phases of feeding with the addition of a significant strain effect ($P < 0.04$) during Phase II when DD hens (106.6 g/d) consumed less feed than HL (108.0 g/hen per d). HL hens increased feed consumption more between Phases I and II compared to DD hens ($P < 0.04$; data not shown). Also hens fed flaxseed increased feed consumption more slowly between Phases I and II compared to control-fed hens ($P < 0.02$; data not shown). There were minimal differences in egg production (Table 2). Feeding flaxseed had no detrimental effects on egg production during any of the three phases of production. During Phase I there was a significant strain effect ($P < 0.04$), with DD hens having a lower rate of egg production than HL hens (86.7 and 89.3%, respectively). Comparison of egg production in Phases II and III, control hens significantly decreased in rate of production more rapidly than the average of the flaxseed-fed hens ($P < 0.03$), which actually increased in production rates between Phases II and III. This result might have been due to flaxseed type used at the end of the trial (data not shown).

No significant dietary effects on hen weights (Table 3) were observed until the second phase of the study, at which time a dietary effect ($P < 0.003$) was observed. Overall, diet had a significant effect ($P < 0.01$) on hen weight. Control hens (1.616 kg) were significantly heavier than hens fed flaxseed (1.559 kg) ($P < 0.004$). During Phase III, there was a significant strain main effect ($P < 0.01$) in addition to previously reported differences. DD hens (1.596 kg) weighed less than HL hens (1.657 kg). Control

TABLE 2. Average production data (Phases I, II, and III)

	Feed consumption (g)				Egg production (%)			
Diet	I	II	III	Average	I	II	III	Average
DeKalb Deltas								
Control[1] (C)	91.4	105.6	106.9	98.9	89.5	88.9	80.8	87.9
10% Flax[2] (F)	95.9	107.4	108.5	101.9	87.6	87.1	86.4	87.2
Flax + Ca[3]	93.9	105.2	103.4	99.4	84.7	82.6	78.8	83.0
Flax + vitamin D[4]	93.0	107.7	108.0	100.6	84.4	87.6	84.9	85.6
Flax + Ca + vitamin D	93.9	106.9	108.8	100.9	84.1	80.9	84.2	83.0
Hy-Line W-36								
Control	92.1	106.9	106.4	99.6	89.1	87.5	82.9	87.6
10% Flax	93.9	107.3	106.2	100.6	88.2	85.9	85.1	86.9
Flax + Ca	94.4	109.4	107.9	101.9	89.6	89.3	86.5	89.0
Flax + vitamin D	94.3	108.3	107.5	101.3	90.8	87.1	85.4	88.6
Flax + Ca + vitamin D	91.8	107.9	107.0	99.9	88.6	86.5	80.8	86.6
Pooled SEM	1.095	1.005	1.243	0.927	1.81	2.09	2.73	1.40
Diets								
Control	91.8	106.3	106.7	99.3	89.3	88.2	81.9	87.8
10% Flax	94.9	107.4	107.4	101.3	87.9	86.5	85.8	87.1
Flax + Ca	94.2	107.3	105.7	100.7	87.2	86.0	82.7	86.0
Flax + vitamin D	93.7	108.0	107.8	101.0	87.6	87.4	84.7	87.1
Flax + Ca + vitamin D	92.9	107.4	107.9	100.4	86.4	83.7	82.5	84.8
Strain								
DeKalb	93.6	106.6^{b}	107.0	100.3	86.7^{b}	85.4	83.0	85.3
Hy-Line	93.3	108.0^{a}	107.1	100.7	89.3^{a}	87.3	84.1	87.7
Main effects								
Diet	$P < 0.09$	NS	NS	NS	NS	NS	NS	NS
Strain	NS	$P < 0.04$	NS	NS	$P < 0.04$	NS	NS	$P < 0.08$
Strain × diet	NS	NS	$P < 0.09$	NS	NS	NS	NS	NS
Contrasts								
Control vs. flax diets	$P < 0.02$	NS	NS	$P < 0.04$	NS	NS	NS	NS
Control vs. flax	$P < 0.005$	NS	NS	$P < 0.03$	NS	NS	NS	NS

[a,b]Means within a column and within a source with no common superscript differ significantly.

[1]Corn/soybean diet [3.8% Ca (Phases 1 and 2); 3.9% Ca (Phase 3)].

[2]Control diet containing 10% flax.

[3]4.5% Ca (Phases 1 and 2); 4.6% Ca (Phase 3).

[4]Additional 22,000 IU vitamin D_3/kg diet.

TABLE 3. Hen and egg weight data (Phases I, II, and III)

	Hen weight (kg)				Egg weight (g)			
Diet	I	II	III	Average	I	II	III	Average
DeKalb Deltas								
Control[1] (C)	1.518	1.588	1.612	1.565	55.94	61.46	60.81	58.61
10% Flax[2] (F)	1.519	1.565	1.608	1.555	56.26	62.82	63.49	59.63
Flax + Ca[3]	1.510	1.550	1.590	1.542	56.10	62.02	63.13	59.21
Flax + vitamin D[4]	1.484	1.521	1.544	1.511	55.52	61.91	61.92	58.72
Flax + Ca + vitamin D	1.535	1.591	1.624	1.576	58.03	63.69	63.13	60.79
Hy-Line W-36								
Control	1.558	1.698	1.742	1.666	54.93	61.39	62.07	58.25
10% Flax	1.502	1.581	1.615	1.566	54.99	61.12	62.01	58.18
Flax + Ca	1.505	1.588	1.644	1.579	54.81	61.43	63.28	58.38
Flax + D	1.492	1.576	1.594	1.546	54.59	60.61	61.98	57.78
Flax + Ca + vitamin D	1.521	1.616	1.692	1.593	54.51	60.80	62.17	57.84
Pooled SEM	0.021	0.028	0.025	0.023	0.624	0.823	0.791	0.676
Diets								
Control	1.538	1.643[a]	1.677[a]	1.616[a]	55.44	61.43	61.44	58.43
10% Flax	1.511	1.537[bc]	1.612[bc]	1.561[bc]	55.63	61.97	62.75	58.91
Flax + Ca	1.508	1.569[bc]	1.617[bc]	1.561[bc]	55.46	61.73	63.21	58.80
Flax + D	1.488	1.549[c]	1.569[c]	1.529[c]	55.06	61.26	61.95	58.25
Flax + Ca + vitamin D	1.528	1.604[ab]	1.658[ab]	1.585[ab]	56.27	62.25	62.65	59.32
Strain								
DeKalb	1.513	1.563	1.596[b]	1.550	56.37[b]	62.38	62.50	59.39
Hy-Line	1.516	1.612	1.657[a]	1.590	54.77[a]	61.07	62.31	58.09
Main Effects								
Diet	NS	$P < 0.003$	$P < 0.002$	$P < 0.01$	NS	NS	NS	NS
Strain	NS	NS	$P < 0.01$	NS	$P < 0.05$	NS	NS	NS
Strain × diet	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts								
Control vs. flax diets	NS	$P < 0.001$	$P < 0.003$	$P < 0.004$	NS	NS	$P < 0.02$	NS
Control vs. flax	NS	$P < 0.006$	$P < 0.01$	$P < 0.02$	NS	NS	$P < 0.05$	NS

[a–c]Means within a column and within a source with no common superscript differ significantly.

[1]Corn/soybean diet [3.8% Ca (Phases 1 and 2); 3.9% Ca (Phase 3)].

[2]Control diet containing 10% flax.

[3]4.5% Ca (Phases 1 and 2); 4.6% Ca (Phase 3).

[4]Additional 22,000 IU vitamin D_3/kg diet.

hens significantly increased in weight more rapidly between Phases I and II compared to flaxseed-fed hens ($P < 0.0001$; data not shown). HL hens gained more weight during the trial than did the DD hens ($P < 0.005$; data not shown). During the experiment, hens fed the control diet increased weight more rapidly than flaxseed fed hens ($P < 0.002$; data not shown).

During Phase I a strain effect ($P < 0.05$) indicated that DD hens produced significantly heavier eggs compared to HL hens. During Phase III, flaxseed-fed hens (62.6 g) produced heavier eggs than controls (61.4 g). Eggs from hens consuming the flaxseed diet increased in weight more between Phases II and III than eggs from control-fed hens ($P < 0.03$; data not shown). Also between Phase II and III, addition of Ca increased egg weight (P < 0.02; data not shown). Eggs from HL hens weighed increased in weight more between Phases II and III than did DD hens ($P < 0.04$; data not shown). Egg weights from DD hens on flaxseed-based diets increased more during the study compared to those of control hens, but the opposite occurred with eggs from HL hens ($P < 0.02$; data not shown).

Egg mass (Table 4) showed no significant overall diet effect. Differences between Phases II and III revealed a significant diet effect, with flaxseed fed hens increasing slightly in egg mass compared to controls, which decreased ($P < 0.01$; data not shown).

Egg Components

Albumen (Table 4) overall showed a main effect of strain and strain by diet interaction, $P < 0.001$ and $P < 0.03$, respectively. DD hens had a significantly higher percentage of albumen (61.3%) compared to HL hens (59.4%) throughout the study. When comparing controls to the average of flaxseed-fed hens, 59.9 and 60.5%, respectively, there was a significant average increase in albumen percentage in eggs produced from hens fed flaxseed. Between Phases II and III, a main effect of diet was observed ($P < 0.04$) with eggs from flaxseed-fed hens having decreased albumen percentage compared to controls (Data not shown).

Percentage wet yolk (Table 4) showed a main effect of strain ($P < 0.001$) overall. DD hens (25.0%) produced eggs with significantly less percentages of wet yolk compared to those of HL hens (26.9%). During Phase II, there was a significant decrease ($P < 0.03$) in wet yolk percentage produced by flaxseed fed hens (26.8%) compared to controls (27.3%). The difference between Phases II and III revealed a dietary effect ($P < 0.03$). Addition of Ca to the flaxseed diets increased the rate at which wet yolk percentage increased with age over that of diets without Ca (Diets 2 and 4; data not shown). Between Phases I and II, hens that consumed the flaxseed-based diets increased wet yolk less than controls ($P < 0.002$; data not shown). During the entire trial, DD hens increased wet yolk percentage less than HL hens ($P < 0.05$; data not shown).

Dried egg yolk components (dry yolk, yolk solids, and solids per gram of egg) were all lower in DD hens than in HL hens (Table 5). Between Phases I and II, flaxseed-fed hens had increased ($P < 0.007$) dry yolk with age at a rate slower rate than controls (data not shown). Overall, the increase in dry yolk was less ($P < 0.03$) in flaxseed-fed hens (Diet 2) than in controls. A similar result was observed for strain, as wet yolk increased with age during the trial more for HL hens compared to DD hens ($P < 0.04$; data not shown).

Yolk solids, overall, were affected ($P < 0.03$) by diet with supplemental Ca (4.5% Ca, 53% vs. 3.8% Ca, 52.7%), and in Phase II there was a strain by diet interaction ($P < 0.02$). DD hens had minimal response to additional Ca, whereas HL hens showed an increase in percentage yolk solids. From Phases II to III, eggs from DD hens increased in percentage of yolk solids less compared to eggs from HL hens (data not shown).

Solids per gram of egg were consistently greater from HL hens than from DD hens. Hens fed Diet 5 (flaxseed plus Ca plus Vitamin D) had fewer ($P < 0.02$) solids per gram compared to Diet 2 (flaxseed only). Overall, the flaxseed-fed hens also had fewer solids per gram of egg ($P < 0.06$) than the control hens (7.18 and 7.3 g, respectively). During Phase II, flaxseed-fed hens produced fewer ($P < 0.04$) solids per gram of egg than controls. Between Phases II and III, addition of Ca ($P < 0.009$) or flaxseed ($P < 0.01$) to the diet increased the level of solids in eggs (data not shown).

Eggshell Quality

Overall (Table 6), DeKalb Delta hens (1.083) produced eggs with a greater specific gravity than those from HL hens (1.082) ($P < 0.05$). The decrease in specific gravity between Phases II and III was less for flaxseed-fed hens than for controls ($P < 0.003$; data not shown). No detrimental effects on specific gravity were noted as a result of the flaxseed-based diets. Flaxseed-fed hens produced eggs with less percentage of wet shell than controls. This effect on percentage wet shell was observed during Phases I and II and overall but not during Phase III. No diet or strain had an effect on percentage of dry shell overall (Table 6). However, during Phase I there was a significant effect of strain ($P < 0.03$) with DD hens (9.3%) producing eggs with increased dry shell percentage compared to HL hens (9.1%).

TABLE 4. Egg components (Phases I, II, and III)

	Egg mass (g)				Albumen (%)				Wet Yolk (%)			
Diet	I	II	III	Average	I	II	III	Average	I	II	III	Average
DeKalb Deltas												
Control[1]	50.29	54.08	49.71	51.58	62.16^{b}	60.09^{bc}	59.65	61.00^{b}	23.91^{de}	26.16	26.59	25.17
10% Flax[2]	49.34	54.54	54.83	51.98	62.44^{b}	59.88^{bc}	60.47	61.18^{b}	24.50^{cd}	26.19	26.06	25.37
Flax + Ca[3]	47.44	50.97	49.63	49.02	62.10^{b}	60.13^{bc}	60.37	61.10^{b}	24.08^{de}	25.72	25.88	24.96
Flax + vitamin D[4]	47.00	53.70	53.24	50.28	62.04^{b}	60.24^{c}	59.82	61.03^{b}	24.57^{bcd}	26.02	26.39	25.39
Flax + Ca + vitamin D	48.90	51.14	53.81	50.40	63.58^{a}	61.58^{a}	60.94	62.24^{a}	23.25^{e}	24.98	25.87	24.30
Hy-Line W-36												
Control	49.10	53.41	51.49	50.99	60.26^{c}	57.22^{e}	57.70	58.74^{c}	25.95^{a}	28.51	28.53	27.30
10% Flax	48.60	52.60	52.57	50.69	61.06^{c}	58.35^{de}	58.47	59.66^{c}	25.57^{ab}	27.71	28.08	26.76
Flax + Ca	49.16	54.67	54.37	51.87	60.72^{c}	58.90^{bcd}	58.30	59.67^{c}	25.76^{a}	27.83	28.02	26.87
Flax + vitamin D	49.61	52.59	52.92	51.15	61.05^{c}	58.66^{cd}	58.05	59.69^{c}	25.31^{ab}	27.59	27.93	26.57
Flax + Ca + vitamin D	48.32	52.10	50.20	49.95	60.32^{c}	58.03^{de}	57.84	59.08^{c}	26.01^{a}	27.94	28.17	27.06
Pooled SEM	0.99	1.32	1.73	0.83	0.30	0.42	0.44	0.32	0.28	0.34	0.37	0.29
Diets												
Control	49.70	53.75	50.60	51.29	61.21	58.66	58.68	59.87	24.93	27.34	27.56	26.24
10% Flax	48.97	53.57	53.70	51.34	61.75	59.12	59.47	60.42	25.04	26.95	27.07	26.07
Flax + Ca	48.30	52.82	52.00	50.45	61.41	59.52	59.34	60.39	24.92	26.78	26.95	25.92
Flax + vitamin D	48.31	53.15	53.08	50.72	61.55	59.45	58.94	60.36	24.94	26.81	27.16	25.98
Flax + Ca + vitamin D	48.61	51.62	52.01	50.18	61.95	59.81	59.39	60.66	24.63	26.46	27.02	25.68
Strain												
DeKalb	48.59	52.89	52.24	50.93	62.46^{a}	60.38^{a}	60.25^{a}	61.31^{a}	24.06^{b}	25.81^{b}	26.16^{b}	25.04^{b}
Hy-Line	48.96	53.07	52.31	50.74	60.68^{b}	58.23^{b}	58.07^{b}	59.37^{b}	25.72^{a}	27.91^{a}	28.15^{a}	26.91^{a}
Main Effects												
Diet	NS	NS	NS	NS	$P < 0.06$	NS	NS	NS	NS	NS	NS	NS
Strain	NS	NS	NS	NS	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$
Strain × diet	NS	NS	NS	$P < 0.06$	$P < 0.01$	$P < 0.05$	NS	$P < 0.03$	$P < 0.01$	NS	NS	NS
Contrasts												
Control vs. flax diets	NS	NS	NS	NS	$P < 0.06$	$P < 0.02$	NS	$P < 0.02$	NS	$P < 0.03$	NS	NS

[a–e]Means within a column and within a source with no common superscript differ significantly.

[1]Corn/soybean diet [3.8% Ca (Phases 1 and 2); 3.9% Ca (Phase 3).

[2]Control diet containing 10% flax.

[3]4.5% Ca (Phases 1 and 2); 4.6% Ca (Phase 3).

[4]Additional 22,000 IU vitamin D_3/kg diet.

TABLE 5. Egg solids results (Phases I, II, and III)

	Dry yolk (%)				Yolk solids (%)				Solids/egg (g)			
Diet	I	II	III	Average	I	II	III	Average	I	II	III	Average
DeKalb Deltas												
Control[1]	12.37^{cd}	13.55	13.86	13.08	53.21	51.80^{cd}	52.11	52.47	6.22	7.45^{b}	8.39	7.06
10% Flax[2]	12.82^{bc}	13.49	13.68	13.22	53.56	51.52^{d}	52.49	52.59	6.27	7.44^{b}	8.66	7.12
Flax + Ca[3]	12.53^{cd}	13.29	13.51	12.99	53.63	51.70^{cd}	52.20	52.64	5.83	6.92^{c}	8.47	6.69
Flax + vitamin D[4]	12.73^{bc}	13.48	13.78	13.19	53.22	51.79^{cd}	52.19	52.49	5.83	7.42^{b}	8.49	6.89
Flax + Ca + vitamin D	12.10^{d}	12.49	13.66	12.68	53.20	51.78^{cd}	52.80	52.58	5.84	6.76^{c}	8.60	6.66
Hy-Line W-36												
Control	13.62^{a}	14.81	15.08	14.33	53.60	51.95^{bc}	52.86	52.83	6.60	8.02^{a}	9.38	7.61
10% Flax	13.54^{a}	14.45	14.92	14.12	53.67	52.16^{ab}	53.14	52.99	6.61	7.83^{ab}	9.26	7.53
Flax + Ca	13.50^{a}	14.62	14.93	14.15	53.95	52.50^{a}	53.04	53.24	6.66	8.06^{a}	9.44	7.65
Flax + vitamin D	13.25^{ab}	14.24	14.79	13.89	53.49	51.60^{cd}	52.96	52.66	6.54	7.64^{ab}	9.13	7.40
Flax + Ca + vitamin D	13.72^{a}	14.68	14.93	14.29	53.98	52.52^{a}	53.01	53.25	6.56	7.80^{ab}	9.30	7.50
Pooled SEM	0.17	0.18	0.22	0.16	0.26	0.17	0.17	0.15	0.17	0.17	0.17	0.12
Diets												
Control	13.00	14.18	14.47	13.71	53.41	51.88	52.49	52.65	6.41	7.74	8.89	7.34
10% Flax	13.18	13.97	14.30	13.67	53.62	51.84	52.82	52.79	6.44	7.64	8.96	7.33
Flax + Ca	13.02	13.96	14.22	13.57	53.79	52.10	52.62	52.94	6.25	7.49	8.96	7.17
Flax + vitamin D	12.99	13.86	14.29	13.54	53.36	51.70	52.78	52.58	6.19	7.53	8.81	7.15
Flax + Ca + vitamin D	12.91	13.59	14.30	13.49	53.59	52.15	52.91	52.92	6.20	7.28	8.95	7.08
Strain												
DeKalb	12.51^{b}	13.26^{b}	13.70^{b}	13.03^{b}	53.36	51.72^{b}	52.36^{b}	52.55^{b}	6.00^{b}	7.20^{b}	8.52^{b}	6.88^{b}
Hy-Line	13.53^{a}	14.56^{a}	14.93^{a}	14.16^{a}	53.74	52.15^{a}	53.00^{a}	52.99^{a}	6.59^{a}	7.87^{a}	9.30^{a}	7.54^{a}
Main Effects												
Diet	NS	NS	NS	NS	NS	$P < 0.06$	NS	NS	NS	NS	NS	NS
Strain	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	NS	$P < 0.01$	$P < 0.001$	$P < 0.004$	$P < 0.01$	$P < 0.01$	$P < 0.001$	$P < 0.003$
Strain × diet	$P < 0.02$	NS	NS	NS	NS	$P < 0.02$	NS	NS	NS	$P < 0.004$	NS	NS
Contrasts												
Ca main effect	NS	NS	NS	NS	NS	$P < 0.004$	NS	$P < 0.03$	NS	NS	NS	NS
Control vs. flax diets	NS	$P < 0.05$	NS	NS	NS	$P < 0.02$	$P < 0.07$	NS	NS	$P < 0.04$	NS	$P < 0.06$
Control vs. Flax	NS	NS	NS	NS	NS	NS	$P < 0.05$	NS	NS	NS	NS	NS

[a–d]Means within a column and within a source with no common superscript differ significantly.

[1]Corn/soybean diet [3.8% Ca (Phases 1 and 2); 3.9% Ca (Phase 3)].

[2]Control diet containing 10% flax.

[3]4.5% Ca (Phases 1 and 2); 4.6% Ca (Phase 3).

[4]Additional 22,000 IU vitamin D_3/kg diet.

TABLE 6. Shell quality response variables (Phases I, II, and III)

	Specific gravity				Wet shell (%)				Dry shell (%)			
Diet	I	II	III	Average	I	II	III	Average	I	II	III	Average
DeKalb Deltas												
Control[1]	1.085	1.084	1.081	1.084	12.71	12.80	12.06	12.64	9.37	9.18	8.88	9.22
10% Flax[2]	1.084	1.083	1.083	1.083	12.27	12.57	11.88	12.32	9.20	9.14	8.91	9.13
Flax + Ca[3]	1.085	1.083	1.081	1.084	12.55	12.52	12.06	12.46	9.48	9.21	9.02	9.31
Flax + vitamin D[4]	1.084	1.083	1.081	1.083	12.39	12.25	12.08	12.29	9.24	9.02	8.92	9.11
Flax + Ca + vitamin D	1.084	1.083	1.082	1.083	12.06	12.47	11.88	12.18	9.13	9.14	9.02	9.12
Hy-Line W-36												
Control	1.083	1.083	1.080	1.082	12.43	13.05	12.10	12.61	9.04	9.15	8.88	9.06
10% Flax	1.082	1.083	1.080	1.082	12.22	12.59	11.96	12.32	9.00	9.03	8.91	9.00
Flax + Ca	1.083	1.082	1.079	1.082	12.40	12.65	12.03	12.43	9.07	9.03	8.82	9.02
Flax + vitamin D	1.083	1.082	1.080	1.082	12.40	12.79	12.30	12.53	9.04	8.99	8.97	9.01
Flax + Ca + vitamin D	1.084	1.084	1.081	1.083	12.57	12.64	12.18	12.53	9.26	9.07	8.92	9.14
Pooled SEM	0.06	0.06	0.09	0.06	0.15	0.16	0.18	0.13	0.10	0.10	0.10	0.08
Diets												
Control	1.084	1.084	1.081	1.083	12.57	12.93	12.08	12.63	9.21	9.17	8.88	9.14
10% Flax	1.083	1.083	1.082	1.083	12.25	12.58	11.92	12.32	9.10	9.09	8.91	9.07
Flax + Ca	1.084	1.083	1.080	1.083	12.48	12.59	12.05	12.45	9.28	9.12	8.92	9.17
Flax + vitamin D	1.084	1.083	1.081	1.083	12.40	12.52	12.19	12.41	9.14	9.01	8.95	9.06
Flax + Ca + vitamin D	1.084	1.084	1.082	1.083	12.32	12.56	12.03	12.36	9.20	9.11	8.97	9.13
Strain												
DeKalb	1.084[b]	1.083	1.082	1.083[b]	12.40	12.52	11.99	12.38	9.28[b]	9.14	8.95	9.18
Hy-Line	1.083[a]	1.083	1.080	1.082[a]	12.40	12.74	12.11	12.48	9.08[a]	9.05	8.90	9.05
Main Effects												
Strain	$P < 0.02$	NS	NS	$P < 0.05$	NS	$P < 0.06$	NS	NS	$P < 0.03$	NS	NS	NS
Strain × diet	NS	NS	NS	NS	$P < 0.06$	NS	NS	NS	NS	NS	NS	NS
Contrasts												
Control vs. flax diets	NS	NS	NS	NS	$P < 0.04$	$P < 0.005$	NS	$P < 0.01$	NS	NS	NS	NS
Control vs. Flax	NS	NS	NS	NS	$P < 0.01$	$P < 0.03$	NS	$P < 0.01$	NS	NS	NS	NS

[a,b]Means within a column and within a source with no common superscript differ significantly.

[1]Corn/soybean diet [3.8% Ca (Phases 1 and 2); 3.9% Ca (Phase 3)].

[2]Control diet containing 10% flax.

[3]4.5% Ca (Phases 1 and 2); 4.6% Ca (Phase 3).

[4]Additional 22,000 IU vitamin D_3/kg diet.

DISCUSSION

Few trials have focused on how manipulation of the egg, in particular egg yolk, may affect egg production parameters and egg quality over extended periods. Jiang et al. (1991) reported no detrimental effects of flaxseed feeding on egg production, egg weight, or specific gravity in a trial with 16-mo-old hens that lasted only 4 wk. Scheideler and Froning (1996) reported a positive effect of feeding flaxseed (10 to 20%) on egg production in 43-wk-old hens for 6 wk but a decrease in feed consumption that resulted in a decrease in hen weights. Aymond and Van Elswyk (1995), using 22-wk-old hens, reported a decrease in egg production within 2 wk when fed hens were given a 15% flaxseed diet for 5 wk. To date, only one long-term feeding trial has been reported utilizing flaxseed as an oil source. Caston et al. (1994) also reported no change in egg production feeding a 10 or 20% flaxseed diet to 19-wk-old Leghorns for 48 wk.

Feed consumption was significantly higher for flaxseed-fed hens compared to controls in this trial, which might have been the result of over estimating the energy supplied by flaxseed. Feed consumption for the each flock (DD and HL) was less compared to breeder standards during the first phase of feeding. By 38 wk of age, the hens were consuming at or slightly above breeder standard. Flax-fed hens consumed more than the control-fed hens during the trial, which might have been the result of an over estimation of energy in flaxseed. Caston et al. (1994) reported similar results with formulated diets that were isonitrogenous and isoenergetic. Analysis of the diets, however, showed a significantly lower metabolizable energy value for the 10 and 20% flaxseed diet than expected. Similar results were also reported by Barbour and Sim (1991), who investigated the true metabolizable energy in canola and flaxseed diets fed to poultry. A decrease in metabolizable energy in the rations containing flaxseed might have contributed to the decrease in weight gain for flaxseed-fed hens in this trial.

Egg production was not affected by flaxseed supplementation. Egg production, for each individual strain, was within breeder standards during the trial. DD hens peaked at 27 wk of age at 92.3%, which is slightly greater compared to breeder guide standards, whereas the HL hens peaked at 29 wk of age at 92.1%, which was slightly lower than standards. Hens fed the control diet peaked at 95%, which was higher compared to flax-fed hens (91.5%). Although the control hens peaked at a higher rate of lay, it was a very brief peak.

Overall, egg weights were not affected by diet in this study, although there was an increase in egg weight in Phase I with additions of Ca and vitamin D to flaxseed diets. Flaxseed-fed hens actually produced significantly heavier eggs during Phase III compared to controls hens.

The difference between Phases II and III was due to a greater increase in egg weights produced by flaxseed-fed hens than controls. Egg weights when compared to breeder standards were lower during the entire study. Decreased egg size might have been the result of reduced body weights due to reduced feed intake during Phase 1. These results are in contrast to those reported by Scheideler and Froning (1996), who reported a decrease in egg weights with flaxseed supplementation (5 and 15% ground or whole flaxseed diets). They attributed the decrease in egg weight to hormone metabolism regulation by dietary phytoestrogens, mainly estrogen. Caston et al. (1994) reported that during the last period (44 to 48 wk) of their trial, flaxseed-fed hens had significantly lighter eggs compared to controls. The change in flaxseed type (Omega to Neche) during the last half of the present trial might have contributed to the maintenance of egg weight. Neche flax might have been supplying more protein (amino acids) or energy (not analyzed), which provided needed nutrients for a balanced ration when combined with the corn/soybean meal that met or exceeded the requirements for production and egg protein synthesis.

Albumen percentage was affected by strain of bird and flaxseed supplementation. DD hens produced eggs with higher percentages of albumen than did HL hens during the entire trial. Scheideler et al. (1995) also reported a significant difference by strain, with DD hens producing more albumen and less yolk compared to HL and Babcock B300 hens. Scheideler and Froning (1996) reported similar changes in the proportion of albumen to yolk. Addition of flaxseed to hen diets in this study significantly increased egg albumen percentage, regardless of strain of hen. The addition of flaxseed to the diet of these hens did not significantly decrease yolk percentage, but it was numerically less compared to controls. DD hens produced eggs with a lower percentage of yolk than HL hens. The decrease in percentage yolk in these eggs is important to consumers because of total cholesterol in the yolk. Decreasing the relative amount of yolk and increasing albumen, while maintaining egg weight, would decrease the total cholesterol content of the egg. Previous reports have also noted decreases in egg yolk weight and percentage egg yolk with addition of flaxseed or other n-3 fatty acid-supplying feedstuffs. Herbert and Van Elswyk (1996) reported that in a 4-wk period dietary menhaden oil depressed egg weights and yolk weights in 24-wk-old hens, but 56-wk-old hens showed no such results. Caston et al. (1994) reported decreases in yolk percentage when a 10 or 20% flaxseed diet was fed only from 39 to 43 wk of age. Whitehead et al. (1993) reported decreased egg weight in response to dietary fish oils. They hypothesized that synthesis of yolk and albumen precursors take place at different sites and apparently shows a different response to long-chain fatty acids and, consequently, a decrease in estradiol synthesis. Flaxseed contains phytoestrogen components that may elicit the same response of lowering serum estrogen levels.

Yolk solids and grams of solids per gram of egg also showed significant strain effects, with DD hens producing eggs with less solids. The supplementation of flaxseed was also a contributing factor in decreasing grams of solids in the eggs with a significance of $P < 0.06$. Egg shell quality showed essentially no detrimental effects of feeding flaxseed, which is in agreement with some, but not all, reported research. By comparing the decrease in specific gravity in Phases I vs. III, the flaxseed-fed hens maintained better shell quality than the controls. Wet shell as a percentage of total egg weight was decreased in flaxseed fed hens, but after drying the shells there was no measurable difference. Albumen might have adhered less to the shell and contributed to the decrease in shell weight. Addition of Ca, vitamin D3, or both had little effect on shell parameters measured. Because of the smaller egg size produced by these two strains of hens compared to the breeder standards, shell as a percentage of whole egg would have been more, thus reducing the need for more Ca to deposit on shell. It is possible that Ca absorption was less due to increased viscosity associated with flaxseed feeding. Scheideler and Froning (1996) reported a decrease in eggshell percentage that they hypothesized was due to a laxative effect of flaxseed, with increased rate of passage in the gut, and decreased Ca uptake. Others have reported no detrimental effects of flaxseed (Jiang et al., 1991; Caston et al., 1994) on shell quality during short-term trials.

Addition of flaxseed caused no detrimental effects on egg mass or eggshell quality, which could cause alarm to commercial producers. The additional cost of supplying flaxseed in the diet could be overcome by the premium that is gained in a specialty egg market. Scheideler and Froning (1996) reported significant increases in egg yolk n-3 fatty acids (linolenic, DPA, and DHA) when feeding a 10% flaxseed diet compared to a corn/soybean meal control. Feeding hens flaxseed will provide the consumer another product containing high levels of n-3 fatty acids. A significant finding in this research was the production of an egg with less yolk and a small decrease in yolk solids. The production of an egg with decreased egg yolk may decrease the amount of cholesterol present per egg consumed. Supplementation of flaxseed and strain are very important factors in producing nutritious eggs for consumers.

In conclusion, the long-term effects of feeding diets with flaxseed on egg production and shell quality is minimal, and supplementing such diets with Ca and or vitamin D has little beneficial effect on shell quality or egg components. The Neche variety was used solely based on availability of flaxseed, but it is important to note that the use of Omega or Neche flaxseed had no detrimental effects on production parameters during this trial.

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