Effect of Feeding Muscovy Ducklings Different Protein Sources: Performance, ω-3 Fatty Acid Contents, and Acceptability of Their Tissues[1]

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ABSTRACT: One hundred Muscovy ducklings, 5-wk-old, from each gender were assigned to five dietary treatments. Each treatment of each sex contained two replicates of 10 ducklings each. Ducks were fed, from 4–9 wk of age, five isonitrogenous diets that differed in protein source, i.e., commercial protein concentrate (CPC), soybean meal, meat meal (MM), herring fish meal (HFM), and mixed herring fish and meat meals (HFM + MM). At the end of the experiment, four ducks per treatment were slaughtered for carcass evaluation and the fatty acid profiles of their meat, adipose tissue, and plasma. Final body weight of both sexes showed no difference among protein sources, although males fed CPC or MM diets had the largest weight gain. No differences in feed consumption and conversion between sexes were shown, although differences in ω-3 fatty acid consumption due to protein source were significant. Feeding fish meal reduced the sensory acceptance of meat, whereas the plant protein diet improved it. Total lipid and cholesterol contents of the meat of males showed no differences between protein sources. Correlation between ω-3 fatty acid consumption and plasma cholesterol was negative ($r = 0.91$; $P = 0.03$). Moreover, correlation between plasma cholesterol and plasma lipid was positive ($r = 0.97$; $P = 0.01$). Feeding fish meal enriched total unsaturated fatty acid of adipose tissues, ω-3 fatty acid of adipose and meat tissues, and total unsaturated fatty acid of thigh meat. Total unsaturated fatty acid and ω-3 fatty acid of blood plasma from females were also enriched by feeding fish meal-containing diets.

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Recently, nutrition and health concerns have had an increasing influence on consumers' food choices. This trend is associated with the relationship between dietary type and amount of fats and fatty acids of animal tissue. Carcass composition of poultry meat can be modified by type of dietary fat fed (1). Consuming saturated fat is correlated with human health diseases. Increasing ω-3 fatty acid intake could benefit human health (2).

Ducks exhibit large adipose tissue in the abdominal cavity or under the skin. The main aim of duck producers is to increase breast yield and to reduce carcass fat and to improve feed conversion without decreasing growth rate. If the adipose tissues of poultry meat could be further enriched with ω-3 fatty acids, it could serve as a supplemental source of these fatty acids in human nutrition.

The main purpose of the current study was to investigate the possibility of modifying the fatty acid composition of duck tissues by feeding Muscovy ducks different protein sources.

EXPERIMENTAL PROCEDURES

Birds and diets. One experiment was carried out during 1994 at El-Nozha Hydrome, Ministry of Agriculture, near Alexandria, Egypt. One hundred Muscovy ducklings of each sex were leg-banded and weighed at 4 wk of age and distributed randomly to five dietary treatments. Each treatment of each sex contained two replicates of 10 ducklings each. Ducks were fed commercial starter diet *ad libitum* from 0–3 wk-old. During 4–9 wk, five isonitrogenous diets were tested that differed in protein sources, i.e., commercial protein concentrate (CPC), soybean meal (SBM), meat meal (MM), herring fish meal (HFM), and mixed HFM AND MM. Diets were formulated based on tabulated values for feedstuffs (3), except for commercial broiler concentrate (Top Notch®; British Egyptian Hatcheries Company, Alexandria, Egypt) for which values cited by its producing company were used. Diet formulations and fatty acid profiles of different protein sources are shown in Tables 1 and 2, respectively.

Measurements. Birds were weighed weekly, residual feed was weighed per replicate, and feed conversion was calculated for each sex. At the end of the experiment, four ducks from each treatment, two of each sex, were slaughtered for carcass evaluation according to Saleh *et al.* (4). Abdominal fat included intestinal, heart, and gizzard besides the fat in the

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TABLE 1
Composition of the Experimental Diets Fed to Muscovy Ducks (from 4–9 wk of age)

Ingredients	CPC	SBM	MM	HFM	HFM + MM
Yellow corn	63.9	55.0	60.0	64.5	62.5
Soybean meal (SBM) (44%)	26.1	40.0	27.0	25.5	27.0
Commercial protein concentrate (CPM) (52%)[a,b]	10.0	—	—	—	—
Meat meal (MM) (60%)	—	—	8.80	—	3.00
Herring fish meal (HFM) (72.0%)	—	—	—	7.30	4.20
Vegetable oil	—	1.55	1.00	—	0.75
Bone meal	—	2.50	0.07	2.00	1.15
Limestone	—	0.35	0.53	0.60	0.50
NaCl	—	0.50	—	—	0.50
Vitamin + mineral[b]	—	0.10	0.10	0.10	0.10
Sand	—	—	2.50	—	0.30
Total	100.0	100.0	100.0	100.0	100.0
Calculated values					
Metabolizable energy (kcal/kg)	2988.0	2870.9	2982.0	2962.3	2992.1
Crude protein (%)	22.31	22.44	22.44	22.17	22.37
C/P ratio	133.9	128.0	133.0	133.6	133.8
Methionine (%)	0.397	0.370	0.372	0.448	0.415
TSAA (%)	0.745	0.728	0.694	0.773	0.741
Lysine (%)	1.293	1.304	1.233	1.318	1.282
Ca (%)	0.988	0.998	1.016	1.072	0.956
Available P (%)	0.464	0.476	0.432	0.507	0.449
Crude fat (%)	3.187	3.960	4.772	3.385	4.196

[a]Consists mainly of HFM, MM, and SBM and contains 52% cp, 2653 kcal/kg, 1.00 methionine, 1.72% TSAA, 3.75 lysine, 9.00% calcium, 3.35% available phosphorus, 3% NaCl, 5.5% fat, and 1% vitamin + mineral mix.
[b]Vitamin and mineral mixture provides, per kilogram of diet: vitamin A (as all-*trans*-retinyl acetate), 5,500 IU; vitamin E (all *rac*-α-tocopherol acetate), 11 IU; menadione (as menadione sodium bisulfite), 1.1 mg; vitamin D, 1,100 ICU; riboflavin, 4.4 mg; Ca pantothenate, 12 mg; nicotinic acid, 44 mg; choline chloride, 191 mg; vitamin B_{12}, 12.1 μg; vitamin B_6, 2.2 mg; thiamine (as thiamine mononitrate), 2.2 mg; folic acid, 0.55 mg; d-biotin, 0.11 mg. Trace minerals (mg per kg of diet): Mn, 60; Zn, 50; Fe, 30; Cu, 5; Se, 0.3.

TABLE 2
Fatty Acid Profile (in %) of Lipid Extracted from the Experimental Diets

	Protein source				
Fatty acid	CPC	SBM	MM	HFM	HFM + MM
Myristic ($C_{14:0}$)	3.77	4.10	5.30	3.39	4.03
Palmitic ($C_{16:0}$)	20.40	19.10	18.80	15.05	19.58
Palmitoleic ($C_{16:1}$)	9.70	10.04	9.27	7.00	10.81
Stearic ($C_{18:0}$)	11.03	12.00	12.56	11.22	11.12
Oleic ($C_{18:1}$)	34.75	30.20	33.00	35.55	29.98
Linoleic ($C_{18:2}$)	13.05	14.89	15.52	16.00	12.22
Linolenic ($C_{18:3}$)	5.72	9.87	5.55	10.07	8.75
Arachidonic ($C_{20:0}$)	0.87	u.d.[a]	u.d.	1.47	0.59
Gadoleic ($C_{20:1}$)	0.71	u.d.	u.d.	0.25	2.92
Saturated (S)	36.07	35.20	36.66	31.13	35.32
Unsaturated (US)	63.93	64.80	63.34	68.87	64.68
S/US ratio (%)	56.42	54.32	57.88	45.20	54.61
ω-3	5.72	9.87	5.55	10.07	8.75

[a]u.d., Undetected level. See Table 1 for other abbreviations.

abdominal cavity. Sensory evaluation of meat was carried out according to Tilgner (5), with 10 trained persons. A descriptive scale was used to score taste, flavor, tenderness, and general acceptance. The scale was from 1–10 with 9–10 being excellent, 7–8 very good, 5–6 good, 3–4 poor and 1–2 very poor. Cooking losses were measured by cooking 1-g samples by the boiling method under identical conditions. Plasma total lipid and cholesterol were determined according to the methods of Chabrol and Charonnat (6) and Ratllif and Hall (7), respectively. Total lipid and cholesterol of tissues were determined according to the methods of Folch *et al.* (8) and Ajuyah *et al.* (9), respectively.

Determination of fatty acids in the diets and tissues was carried out after extraction of total lipids by the method of Folch *et al.* (8). Fatty acid methyl esters were analyzed by gas chromatography with a Shimadzu gas–liquid chromatograph, model GC4 (Tokyo, Japan), equipped with flame-ionization detector (FID) and a column, 3 m × 3 mm i.d., backed with 10% silar 5 cp.

Statistical analysis. Experimental data from each sex were subjected to analysis of variance by the one-way analysis of variance (GLM) procedure of SAS® (10). In the model, the main effects were replication and treatments. Duncan's new multiple range test (11) was applied to test mean differences. Correlation coefficients among ω-3 fatty acid, saturated and unsaturated fatty acid consumption, and lipid, cholesterol and fatty acids of plasma and tissue were calculated.

RESULTS AND DISCUSSION

Performance of ducks fed different protein sources. Results of body weight, body weight gain, feed and ω-3 fatty acid consumption and feed conversion ratio are shown in Tables 3 and 4. Final body weights showed insignificant differences among different protein sources. However, body weight gains of males fed CPC and MM diets were significantly superior to the other protein sources, which showed no differences among them. The absence of female responses to dietary protein source may be due to the differences in growth rate between sexes; thus, all protein sources met nutrient requirements. These findings agree with those of Leclercq and De Carville (12), who reported that males had higher protein requirements than females. Similarly, fish meal addition to an isonitrogenous broiler diet increased growth rate, but feed conversion was not affected (13).

Total feed consumption showed no differences, but males fed the SBM diet consumed significantly more ω-3 fatty acid than those fed MM and CPC diets. ω-3 Fatty acid consump-

TABLE 3
Performance of Male Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)

	Protein source					
Age of ducks (wk)	CPC	SBM	MM	HFM	HFM + MM	SEM
			Body weight (g)			
4	1551.3	1548.0	1548.8	1556.0	1552.5	21.1
9	4210.5	4017.5	4234.0	4070.0	4017.5	52.1
			Body weight gain (g)[b]			
4–9[a]	2659.2[a]	2469.5[b]	2685.2[a]	2514.0[b]	2465.0[b]	48.2
			Feed consumption (g)			
4–9	8130	8010	8260	8350	8020	67.5
			ω-3 Fatty acid consumption (g)[b]			
4–9[a]	14.82[c]	31.31[a]	21.87[b]	28.47[a,b]	29.45[a,b]	0.56
			Feed conversion ratio g/g			
4–9	3.057	3.244	3.076	3.321	3.254	0.10

[a]Significant at $P = 0.001$. Significant at $P = 0.0001$.
[b]Means within a row with no common superscripts [a,b,c]differ significantly ($P = 0.05$) based on Duncan's separation of means. SEM: standard error of the mean. See Table 1 for other abbreviations.

TABLE 4
Performance of Female Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)

	Protein source					
Age of ducks (wk)	CPC	SBM	MM	HFM	HFM + MM	SEM
			Body weight (g)			
4	1300.3	1299.0	1301.5	1298.5	1297.5	18.7
9	2604.5	2657.5	2620.0	2648.5	2557.5	69.7
			Body weight gain (g)			
4–9	1304.2	1358.5	1318.5	1350.0	1260.0	57.2
			Feed consumption (g)			
4–9	5.950	5.440	6.520	6.090	6.170	0.22
			ω-3 Fatty acid consumption (g)[b]			
4–9[a]	10.85[c]	21.26[a,b]	17.26[b]	20.76[a,b]	22.66[a]	0.36
			Feed conversion ratio g/g			
4–9	4.562	4.004	4.945	4.511	4.897	0.14

[a]Significant at $P = 0.001$.
[b]Means within a row with no common superscripts [a,b,c]differ significantly ($P = 0.05$) based on Duncan's separation of means. See Tables 1 and 3 for abbreviations.

tion of female ducks fed HFM + MM was higher than those fed MM and CPC. Differences between the latter groups were significant. There were no significant differences in feed conversion due to dietary protein source. Coinciding with the current results, Olomu and Offiong (14) found that flax oil had no effect on body weight, feed consumption, and conversion of broiler chickens during 2–21 d of age. Feed intake and body weight were not affected by dietary polyunsaturated fatty acids (PUFA), although the feed-to-gain ratio exhibited a linear increase with increasing PUFA intake (15). Moreover, feeding red fish meal as a source of ω-3 fatty acid had no effect on overall mortality rate or feed efficiency, but it decreased body weight of broiler chicks (16).

No differences were found in mortality rate among protein sources, and body weight gain of males fed fish meal was the lightest, which confirms the results of Hulan *et al.* (16). Overheating during fish meal processing is known to affect its nutritional values (17). Moreover, Waldroup *et al.* (18) and Proudfoot *et al.* (19) found that large amounts of fish meal in broiler diets decreased body weight and impaired feed conversion. The data indicated that attention should be given when fish meal or SBM is to be fed as a sole source of protein to male Muscovy ducks.

Carcass characteristics and sensory evaluation. Data for carcass characteristics are presented in Tables 5 and 6. There were insignificant differences on drawn weight, breast, thigh, liver, heart, spleen and pancreas percentages. Abdominal fat percentage of male and female ducks fed a fish meal-containing diet was the highest, although the differences were only significant among male treatments. The current results agreed with the results of Leclercq and De Carville (12) and Wilson (20), who reported that protein level had no effect on carcass quality or edible parts, including abdominal fat, breast muscle, and leg and thigh percentages. Not only the protein source but also the protein level had no significant effect on carcass components of broiler chicks and ducks (14,21,22). Clear gender differences were shown in drawn, abdominal fat and spleen percentages; males had a larger drawn percentage and smaller spleen and abdominal fat percentages.

Data for sensory evaluation are shown in Tables 5 and 6. The results indicate that plant protein diet significantly improved flavor, tenderness, juiciness and general acceptability of meat, while fish meal-containing diets impaired these parameters. The results also indicated that MM increased the cooking loss percentage. This may be due to higher saturated fatty acid levels in the tissues of MM-fed ducks. Similarly, Ratnayake and Ackman (23) reported that taste panel scores of female white and dark meat was the lowest when 8 and 12% red fish meal were fed when compared to 0 and 4% levels. Although fishy flavor was not detected, even when the higher levels were fed, a level of 1.5% fish oil will taint broiler carcasses, so it should be removed from the diets 4 wk before slaughter (24). Moreover, Hammershøj (25) showed a weakly fishy/oily taste of eggs produced with a diet that contained 3% fish oil and resulted in an insignificant decrease in taste and general impression of the eggs. Differences between this study and others (23–25) with broilers could be expected based on differences in fish meal intakes. Ducks are known to consume 1.5–2-fold more feed during 4–9 wk of age than broiler chicks eat during their entire life. Hence, consumer choice of duck meats could be affected.

Total lipid and cholesterol of different duck tissues. Total lipid and cholesterol of different Muscovy tissues are summarized in Tables 7 and 8. Differences in plasma total lipid due to protein source were significant. Ducks that were fed CPC diet had the highest value. This may be due to lower unsaturated fatty acids and higher saturated fatty acids in the CPC diet (Table 2). Similarly, fish oil as a source of ω-3 fatty

TABLE 5
Carcass Parameters[a] and Sensory Evaluation of Meats from Male Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)

	Protein source					
Criteria	CPC	SBM	MM	HFM	HFM + MM	SEM
Drawn weight (%)[b]	56.09	53.32	55.36	55.40	55.83	1.73
Breast meat (%)	22.9	21.90	22.4	22.1	22.2	0.40
Thigh + leg meat (%)	21.8	21.4	21.7	21.3	21.7	0.62
Abdominal fat (%)**[c]	1.61[b]	2.64[b]	2.90[b]	5.23[a]	2.39[b]	0.40
Heart (%)	0.56	0.54	0.69	0.61	0.66	0.10
Liver (%)	1.67	2.03	2.27	2.40	1.79	0.17
Spleen (%)	0.07	0.11	0.11	0.07	0.11	0.001
Pancreas (%)	0.12	0.20	0.25	0.19	0.13	0.001
Flavor***[c]	7.43[b]	7.90[a]	5.57[c]	4.90[e]	5.27[d]	0.03
Tenderness***[c]	6.70[b]	8.00[a]	8.20[a]	5.00[d]	6.40[c]	0.10
Juiciness***[c]	7.40[b]	8.20[a]	8.50[a]	6.40[c]	5.35[d]	0.07
General acceptability***[c]	7.18[c]	8.03[a]	7.42[b]	5.40[e]	5.67[d]	0.10
Cooking loss (%)**	19.80[c]	19.56[c]	32.50[a]	26.01[b]	34.80[a]	1.18

[a]Percentages as related to live body weight. Means within a row with no common superscripts [a,b,c,d,e]differ significantly ($P = 0.05$), based on Duncan's separation of means. See Table 1 for abbreviations.
[b]Oven-ready for cooking without giblets, head, neck, wings (the cut of wings was made at the end of the humerus bone), viscera, and feet + shanks.
[c]**Significant at $P = 0.01$. ***Significant at $P = 0.001$. See Tables 1 and 3 for abbreviations.

TABLE 6
Carcass Parameters[a] and Sensory Evaluation of Meats from Female Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)

	Protein source					
Criteria	CPC	SBM	MM	HFM	HFM + MM	SEM
Drawn weight, (%)[b]	55.43	52.52	53.60	54.15	53.60	1.37
Breast meat (%)	22.8	21.8	22.3	22.1	22.1	0.55
Thigh + legs meat (%)	21.7	21.2	21.8	21.7	21.8	0.49
Abdominal fat (%)	3.42	4.05	3.87	5.53	3.59	0.75
Heart (%)	0.72	0.70	0.95	0.87	0.80	0.16
Liver (%)	1.55	2.65	1.88	1.84	1.79	0.001
Spleen (%)	0.12	0.12	0.18	0.12	0.10	0.001
Pancreas (%)	0.17	0.20	0.21	0.24	0.19	0.02
Flavor***[c]	7.19[b]	7.60[a]	5.29[c]	4.90[e]	4.64[d]	0.03
Tenderness***[c]	6.70[b]	7.60[a]	7.45[a]	5.32[c]	4.80[d]	0.07
Juiciness***[c]	7.60[b]	8.60[a]	7.92[b]	4.45[e]	5.20[d]	0.07
General acceptability***[c]	7.20[b]	7.90[a]	6.88[b]	4.89[c]	4.88[c]	0.04
Cooking loss (%)***	20.60[d]	18.75[e]	27.70[b]	25.75[c]	35.90[a]	0.21

[a]Percentages as related to live body weight. Means within a row with no common superscripts [a,b,c,d,e] differ significantly ($P = 0.05$), based on Duncan's separation of means. See Tables 1 and 3 for abbreviations.
[b]Oven-ready for cooking without giblets, head, neck, wings (the cut of wings was made at the end of the humerus bone), viscera, and feet + shanks.
[c]***Significant at $P = 0.001$.

TABLE 7
Total Lipid and Cholesterol of Blood Plasma, Breast, and Thigh Meat, Subcutaneous Breast and Thigh Fat and Abdominal Fat of Male Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)[a]

	Protein source					
Criteria	CPC	SBM	MM	HFM	HFM + MM	SEM
Plasma lipid (mg/100 mL)***	737.4[a]	637.4[b]	620.4[b]	618.9[b]	640.9[b]	50.6
Plasma cholesterol (mg/100 mL)	284.5	153.2	213.9	170.2	212.2	6.81
Breast lipid (%)	5.48	7.13	7.14	6.67	6.66	1.96
Breast cholesterol[b]	109.8	100.4	137.4	117.2	118.9	5.41
Thigh lipid[a] (%)	5.54	11.04	7.81	6.69	7.35	2.81
Thigh cholesterol[b]	109.3	105.5	150.4	120.6	122.4	12.5
Subcut. breast lipid[a] (%)	76.53	71.15	92.32	71.03	88.36	8.68
Subcut. breast cholesterol***[b,c]	209.8[b]	200.4[b]	253.0[a]	210.6[b]	218.9[b]	7.19
Subcut. thigh lipid[a] (%)	91.09	86.99	87.51	71.98	86.42	10.3
Subcut. thigh cholesterol***[b,c]	212.4[b]	205.1[b]	262.7[a]	215.2[b]	240.2[b]	6.84
Abdominal fat lipid[a] (%)	79.97	80.82	78.00	79.68	78.96	6.40
Abdominal fat cholesterol[b]	93.43	92.64	90.90	92.22	91.70	11.9

[a]As related to fresh weight. Means within a row with no common superscripts [a,b]differ significantly ($P = 0.05$), based on Duncan's separation of means. See Table 1 for abbreviations.
[b]As mg/100 g.
[c]***Significant at $P = 0.001$.

acid decreased serum triglyceride and cholesterol levels (26). PUFA of fish oils were also effective in lowering serum triglyceride and cholesterol levels of men (27).

Differences in plasma cholesterol level due to protein source were insignificant. However, there was a clear trend in both sexes, indicating that CPC and MM increased plasma total cholesterol. This correlated with the higher saturated fatty acid of CPC and MM diets (Table 2). Correlation between ω-3 fatty acid consumption and abdominal fat lipid and cholesterol was negative ($r = 0.86$; $P = 0.06$) for both variables. Correlation between unsaturated fatty acid consumption and thigh cholesterol was negative ($r = 0.99$; $P = 0.001$). Similarly, diets rich in saturated fatty acids were positively correlated with plasma cholesterol level (28).

There were insignificant differences in breast and thigh lipids and cholesterol of males and breast and thigh lipid of females due to protein source. Breast and thigh cholesterol levels of female ducks showed significant differences (Table 8), which indicate a lowering effect of plant protein diets. The low metabolizable energy value of SBM diet may also be contributing factor. The highest cholesterol level was shown by the group fed HFM + MM. Similarly, Deaton *et al.* (29) re-

TABLE 8
Total Lipid and Cholesterol of Blood Plasma, Breast and Thigh Meat, Subcutaneous Breast and Thigh Fat, and Abdominal Fat of Female Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)[a]

	Protein source					
Criteria	CPC	SBM	MM	HFM	HFM + MM	SEM
Plasma lipid (mg/100 mL)***[c]	665.8[a]	525.7[b]	570.8[b]	530.2[b]	575.3[b]	38.8
Plasma cholesterol (mg/100 mL)	217.3	158.0	196.6	180.7	139.7	3.52
Breast lipid[a] (%)	6.58	5.28	7.19	6.85	9.43	2.45
Breast cholesterol***[b,c]	130.0[a,b]	116.5[b]	134.3[a,b]	118.6[b]	142.6[a]	6.41
Thigh lipid[a] (%)	13.66	6.09	7.96	7.82	8.45	2.35
Thigh chiolesterol***[b,c]	130.8[b]	108.2[b]	128.0[b]	113.7[a,b]	145.8[a]	6.72
Subcut. breast lipid **[a,c] (%)	59.25[b]	50.94[b]	62.43[b]	74.80[a]	69.37[a,b]	10.1
Subcut. breast cholesterol[b,c]	188.4[b]	170.5[c]	280.3[a]	240.7[a]	185.3[b]	5.62
Subcut. thigh lipid **[a,c] (%)	61.49[b]	72.13[b]	84.40[a]	82.16[a]	89.40[a]	10.1
Subcut. thigh cholesterol[b]	200.6	172.8	290.5	250.8	190.7	5.21
Abdominal fat lipid[a] (%)	79.50	80.01	77.48	79.93	78.27	6.07
Abdominal fat cholesterol[b]	94.60	94.25	93.75	94.28	91.90	16.7

[a]As related to fresh weight. Means within a row with no common superscripts [a,b,c]differ significantly ($P = 0.05$), based on Duncan's separation of means. See Tables 1 and 3 for abbreviations.
[b]As mg/100 g.
[c]**Significant at $P = 0.01$. ***Significant at $P = 0.001$.

ported that body fat increased as dietary tallow content increased. On the other hand, Ajuyah *et al.* (9) showed no differences in the lipid contents of meats of broilers that were fed menhaden and soybean oil or chicken fat. Addition of red fish meal had an insignificant effect on lipids of breast and thigh meat, compared to their respective controls (16). The differences in responses between sexes in breast and thigh cholesterol may be due to the effect of sex hormones on fat metabolism.

Feeding an MM-containing diet increased total cholesterol contents of subcutaneous breast and thigh fats of ducks, and subcutaneous thigh lipids of females. The plant diet had a lowering effect on lipid and cholesterol parameters of plasma and tissues (Tables 7 and 8). Similarly, Keren-Zvi *et al.* (30) reported that increasing dietary soybean oil decreases fat depositions. Skin lipid was significantly increased by feeding red fish oils (16). This agrees with the current findings. The recent results indicate the efficacy of plant and ω-3 rich diets in lowering total lipid and cholesterol of different Muscovy tissues.

Gender differences in meat lipid and cholesterol indicated that females had higher lipid and cholesterol contents (Tables 7 and 8). Significant differences in lipid and cholesterol contents of different duck tissues were shown, indicating that breast meat had lower total lipid and cholesterol contents than thigh meat. Similar observations were found by others (9,16), who reported that there were structural, functional, and metabolic characteristic differences between white and dark fibers (meat).

Fatty acid profile of different duck tissues: Plasma fatty acid profile. Plasma fatty acid profiles of both sexes are shown in Tables 9 and 10. Saturated fatty acids of males fed

TABLE 9
Fatty Acid Profile of Lipid Extracted from Blood Plasma of Male Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)[a]

		Protein source				
Fatty acid		CPC	SBM	MM	HFM	HFM + MM
Myristic	($C_{14:0}$)	5.74	6.33	6.21	3.93	3.03
Palmitic	($C_{16:0}$)	32.26	25.29	20.55	23.29	24.64
Palmitoleic	($C_{16:1}$)	9.45	10.27	10.23	5.86	8.93
Stearic	($C_{18:0}$)	11.13	12.60	7.54	8.40	9.99
Oleic	($C_{18:1}$)	14.93	18.91	30.85	20.90	29.78
Linoleic	($C_{18:2}$)	18.61	11.70	18.21	20.39	17.59
Linolenic	($C_{18:3}$)	6.56	12.77	4.87	8.45	3.80
Arachidonic	($C_{20:0}$)	0.39	1.22	0.79	4.85	0.24
Gadoleic	($C_{20:1}$)	0.93	1.91	0.75	3.93	2.00
Saturated	(S)	49.52	44.44	35.09	40.47	37.90
Unsaturated	(US)	50.48	55.56	64.91	59.53	62.10
S/US ratio (%)	(S/US)	98.10	79.99	54.06	67.98	61.03
ω-3		6.56	12.77	4.87	8.45	3.80

[a]See Table 1 for other abbreviations.

TABLE 10
Fatty Acid Profile of Lipid Extracted from Blood Plasma of Female Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)

Fatty acid		Protein source				
		CPC	SBM	MM	HFM	HFM + MM
Myristic	($C_{14:0}$)	5.92	6.23	6.56	4.25	9.28
Palmitic	($C_{16:0}$)	15.65	20.62	11.08	12.62	13.58
Palmitoleic	($C_{16:1}$)	11.90	7.45	9.87	8.92	11.30
Stearic	($C_{18:0}$)	7.50	9.54	13.23	12.35	8.25
Oleic	($C_{18:1}$)	35.86	42.16.	36.74	31.00	32.11
Linoleic	($C_{18:2}$)	15.00	7.63	15.30	20.71	8.75
Linolenic	($C_{18:3}$)	6.67	5.84	4.39	8.57	12.70
Arachidonic	($C_{20:0}$)	0.50	u.d.[a]	0.60	0.30	1.00
Gadoleic	($C_{20:1}$)	1.00	0.53	2.23	1.28	3.03
Saturated	(S)	29.57	36.39	31.47	29.52	32.11
Unsaturated	(US)	70.43	63.61	68.53	70.48	67.89
S/US ratio (%)	(S/US)	41.98	57.21	45.92	41.88	47.30
ω-3		6.67	5.84	4.39	8.57	12.70

[a]Undetected level. See Table 1 for other abbreviations.

CPC diet and females fed SBM diet were the highest. Fatty acids (ω-9 and ω-6) were enriched by feeding MM and HFM to males and SBM or HFM to females, respectively.

Plasma unsaturated fatty acids of males fed MM and females fed CPC or HFM were the greatest. Feeding females mixed animal protein, and males plant protein enhanced plasma ω-3 fatty acids. This may indicate different sex mechanisms in plasma fatty acid regulation. Similarly, Phetteplace and Watkins (31) found that feeding menhaden oil enriched ω-3 PUFA in plasma of high- and low-body weight lines of chickens. Unsaturated fatty acid consumption correlated negatively with plasma saturated fatty acids ($r = 0.90$; $P = 0.04$) and positively with plasma unsaturated fatty acids for males ($r = 0.90$; $P = 0.04$). Correlation between plasma saturated fatty acids and plasma unsaturated fatty acids was negative ($r = 0.99$; $P = 0.001$).

Breast and thigh meat fatty acid profile. Breast fatty acid profile percentages of Muscovies are shown in Tables 11 and 12. Saturated fatty acids were higher for males fed MM + HFM and for females fed CPC. Unsaturated fatty acids of males fed HFM and females fed MM were the highest. Fatty acids (ω-9 and ω-3) were enriched by feeding Muscovies HFM, while feeding CPC diet enhanced ω-6 fatty acids. These results emphasize the role of feeding fish meal to enrich breast meat content of desirable ω-3 fatty acids. Saturated fatty acid consumption correlated negatively with breast meat ω-3 fatty acids ($r = 0.74$; $P = 0.01$). Correlation between saturated and unsaturated fatty acids of breast meat was negative ($r = 0.99$; $P = 0.001$).

Thigh fatty acid profile percentages of Muscovies are shown in Tables 13 and 14. Saturated fatty acids of both sexes fed mixed animal protein sources were the highest. ω-9 Fatty acids of males fed HFM + MM and females fed MM and HFM + MM were the greatest, while ω-6 fatty acids of males fed HFM and females fed SBM were the highest. Unsaturated fatty acids of males fed CPC and HFM and those of females fed HFM were enriched. Feeding HFM enriched ω-3 of thigh meat of both genders. Correlation between saturated and un-

TABLE 11
Fatty Acid Profile of Lipid Extracted from Breast Meat of Male Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)[a]

Fatty acid		Protein source				
		CPC	SBM	MM	HFM	HFM + MM
Myristic	($C_{14:0}$)	0.20	4.27	0.47	2.94	3.55
Palmitic	($C_{16:0}$)	19.42	22.41	22.87	14.85	20.28
Palmitoleic	($C_{16:1}$)	6.24	6.07	7.36	3.12	9.38
Stearic	($C_{18:0}$)	13.56	12.18	11.12	12.83	17.86
Oleic	($C_{18:1}$)	29.13	33.03	34.83	36.43	25.78
Linoleic	($C_{18:2}$)	20.45	17.07	14.83	16.52	18.27
Linolenic	($C_{18:3}$)	8.18	3.14	4.16	10.10	1.42
Arachidonic	($C_{20:0}$)	2.39	0.48	0.47	1.88	1.28
Gadoleic	($C_{20:1}$)	0.43	1.35	3.89	1.33	2.18
Saturated	(S)	35.57	39.34	34.93	32.50	42.97
Unsaturated	(US)	64.43	60.66	65.07	67.50	57.03
S/US ratio (%)	(S/US)	55.21	64.85	53.68	48.15	75.35
ω-3		8.18	3.14	4.16	10.10	1.42

[a]See Table 1 for other abbreviations.

TABLE 12
Fatty Acid Profile of Lipid Extracted from Breast Meat of Female Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)

Fatty acid		Protein source				
		CPC	SBM	MM	HFM	HFM + MM
Myristic	($C_{14:0}$)	3.53	6.44	3.52	7.22	5.24
Palmitic	($C_{16:0}$)	30.48	22.85	17.00	20.07	18.62
Palmitoleic	($C_{16:1}$)	12.55	14.00	12.30	6.00	8.48
Stearic	($C_{18:0}$)	9.75	11.32	13.43	9.64	14.74
Oleic	($C_{18:1}$)	12.90	30.63	28.99	33.05	24.80
Linoleic	($C_{18:2}$)	22.80	8.70	12.37	8.69	17.08
Linolenic	($C_{18:3}$)	5.85	5.00	7.83	12.31	9.31
Arachidonic	($C_{20:0}$)	0.82	u.d.[a]	2.55	1.02	0.62
Gadoleic	($C_{20:1}$)	1.32	1.06	2.01	u.d.	1.11
Saturated	(S)	44.58	40.61	36.50	39.95	39.22
Unsaturated	(US)	55.42	59.39	63.50	60.05	60.78
S/US ratio (%)	(S/US)	80.44	68.38	57.48	66.53	64.53
ω-3		5.85	5.00	7.83	12.31	9.31

[a]Undetected level. See Table 1 for other abbreviations.

TABLE 13
Fatty Acid Profile of Lipid Extracted from Thigh Meat of Male Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)

Fatty acid		Protein source				
		CPC	SBM	MM	HFM	HFM + MM
Myristic	($C_{14:0}$)	2.05	8.32	10.22	5.37	2.00
Palmitic	($C_{16:0}$)	20.00	17.90	16.00	15.83	30.26
Palmitoleic	($C_{16:1}$)	8.88	6.32	5.52	3.60	3.41
Stearic	($C_{18:0}$)	14.06	10.06	12.90	13.35	9.82
Oleic	($C_{18:1}$)	22.76	19.30	18.54	12.80	23.00
Linoleic	($C_{18:2}$)	27.36	30.94	27.86	39.19	28.28
Linolenic	($C_{18:3}$)	4.87	5.86	6.93	8.24	3.23
Arachidonic	($C_{20:0}$)	0.02	1.30	0.94	1.62	u.d.
Gadoleic	($C_{20:1}$)	u.d.[a]	u.d.	1.09	u.d.	u.d.
Saturated	(S)	36.13	37.58	40.06	36.17	42.08
Unsaturated	(US)	63.87	62.42	59.94	63.83	57.92
S/US ratio (%)	(S/US)	56.57	60.21	66.83	56.67	72.65
ω-3		4.87	5.86	6.93	8.24	3.23

[a]Undetected level. See Table 1 for other abbreviations.

TABLE 14
Fatty Acid Profile of Lipid Extracted from Thigh Meat of Female Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)[a]

Fatty acid		Protein source				
		CPC	SBM	MM	HFM	HFM + MM
Myristic	($C_{14:0}$)	6.50	7.03	9.91	4.93	3.00
Palmitic	($C_{16:0}$)	22.10	15.25	17.55	13.29	28.64
Palmitoleic	($C_{16:1}$)	9.15	7.27	6.23	5.68	3.93
Stearic	($C_{18:0}$)	12.03	13.60	9.54	11.40	9.29
Oleic	($C_{18:1}$)	20.93	17.91	21.85	19.90	21.78
Linoleic	($C_{18:2}$)	22.61	31.24	25.21	28.39	27.44
Linolenic	($C_{18:3}$)	5.56	4.77	6.87	9.45	3.38
Arachidonic	($C_{20:0}$)	0.29	1.12	0.89	4.15	1.24
Gadoleic	($C_{20:1}$)	0.83	1.81	1.95	2.81	1.30
Saturated	(S)	40.92	37.00	37.89	33.77	42.17
Unsaturated	(US)	59.08	63.00	62.11	66.23	57.83
S/US ratio (%)	(S/US)	69.26	58.73	61.00	50.99	72.92
ω-3		5.56	4.77	6.87	9.45	3.38

[a]See Table 1 for other abbreviations.

TABLE 15
Fatty Acid Profile of Lipid Extracted from Abdominal Fat of Male Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)

Fatty acid		Protein source CPC	SBM	MM	HFM	HFM + MM
Myristic	($C_{14:0}$)	2.56	3.30	1.34	1.92	2.11
Palmitic	($C_{16:0}$)	19.40	15.10	22.35	25.27	21.35
Palmitoleic	($C_{16:1}$)	6.77	15.87	11.50	8.16	8.71
Stearic	($C_{18:0}$)	14.08	11.97	14.10	9.36	15.73
Oleic	($C_{18:1}$)	41.37	35.27	31.16	23.45	30.26
Linoleic	($C_{18:2}$)	11.61	13.72	17.15	20.30	16.00
Linolenic	($C_{18:3}$)	3.40	3.14	1.79	10.80	4.54
Arachidonic	($C_{20:0}$)	0.79	0.33	0.61	0.18	0.70
Gadoleic	($C_{20:1}$)	0.02	1.30	u.d.[a]	0.56	0.60
Saturated	(S)	36.83	30.70	38.40	36.73	39.89
Unsaturated	(US)	63.17	69.30	61.60	63.27	60.11
S/US ratio (%)	(S/US)	58.30	44.30	62.34	58.05	66.36
ω-3		3.40	3.14	1.79	10.80	4.54

[a]Undetected level. See Table 1 for other abbreviations.

saturated fatty acids of thigh meat was negative ($r = 0.99$; $P = 0.001$).

The results indicate that including HFM in duck diets enhanced ω-3 fatty acids of breast and thigh meat. Manipulation of the fatty acid composition of duck meats may help to increase duck meat consumption. A large increase in the PUFA, especially linoleic acid, when ducks were fed diets that contained sunflower or a mixture of sunflower and SBM was reported by Olver *et al.* (32). Moreover, linseed oil, which is rich in α-linolenic acid and the precursor of the longer-chained ω-3 PUFA, such as EPA and DHA, can be used in duck diets to produce these important long-chain PUFA (33). Additionally, Hulan *et al.* (16) reported that breast meat lipids had more total ω-3 fatty acid than thigh meat. They added that addition of red fish meal increased the accumulation of eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA) and docosahexaenoic acid (DHA), and total ω-3 PUFA in breast and thigh meats.

Vegetable protein diet showed the highest level of ω-6 PUFA, while the high-fish meal diet showed a lower level of such acids (16), which indicated interference between the ω-3 family and the ω-6 family. The current data show a similar pattern. Fatty acid compositions of thigh muscle were related to dietary ω-3 fatty acid supplementation, and birds fed linseed oil had higher levels of total ω-3 PUFA than those fed the same level of menhaden oil (23). There may be real human cardiovascular benefits associated with increasing consumption of ω-3 fatty acids (26).

Fatty acid profile of adipose tissues. Fatty acid profiles of abdominal fat of ducks are shown in Tables 15 and 16. Saturated fatty acid of abdominal fat of males fed MM-containing diets and that of females fed fish meal-containing diets were the highest. ω-9 Fatty acids in abdominal fat of males fed CPC and that of females fed SBM were enhanced, while ω-6 fatty acids of males fed HFM and those of females fed HFM + MM were enriched.

TABLE 16
Fatty Acid Profile of Lipid Extracted from Abdominal Fat of Female Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)

Fatty acid		Protein source CPC	SBM	MM	HFM	HFM + MM
Myristic	($C_{14:0}$)	4.52	5.33	2.68	3.18	1.73
Palmitic	($C_{16:0}$)	18.43	14.79	13.72	16.50	20.38
Palmitoleic	($C_{16:1}$)	9.15	12.35	13.62	9.32	19.28
Stearic	($C_{18:0}$)	10.92	15.73	14.26	18.00	13.34
Oleic	($C_{18:1}$)	30.53	40.46	35.43	29.61	22.00
Linoleic	($C_{18:2}$)	15.97	5.00	13.37	11.85	18.00
Linolenic	($C_{18:3}$)	5.85	6.26	2.87	10.93	3.56
Arachidonic	($C_{20:0}$)	3.69	0.08	2.00	u.d.[a]	0.18
Gadoleic	($C_{20:1}$)	0.94	u.d.	2.05	0.61	1.53
Saturated	(S)	37.56	35.93	32.66	37.68	35.63
Unsaturated	(US)	62.44	64.07	67.34	62.32	64.37
S/US ratio (%)	(S/US)	60.15	56.08	48.50	60.46	55.35
ω-3		5.85	6.26	2.87	10.93	3.56

[a]Undetected level. See Table 1 for other abbreviations.

TABLE 17
Fatty Acid Profile of Lipid Extracted from Subcutaneous Breast Fats of Male Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)

Fatty acid		Protein source				
		CPC	SBM	MM	HFM	HFM + MM
Myristic	($C_{14:0}$)	7.30	2.80	1.67	6.18	5.36
Palmitic	($C_{16:0}$)	14.45	22.70	27.04	20.29	18.31
Palmitoleic	($C_{16:1}$)	12.02	11.40	6.22	6.18	9.38
Stearic	($C_{18:0}$)	9.33	16.40	17.31	8.65	13.46
Oleic	($C_{18:1}$)	33.04	26.40	31.68	44.62	22.72
Linoleic	($C_{18:2}$)	14.20	16.10	14.59	11.74	10.25
Linolenic	($C_{18:3}$)	5.54	1.70	0.99	2.22	6.75
Arachidonic	($C_{20:0}$)	0.89	1.10	0.50	u.d.[a]	7.40
Gadoleic	($C_{20:1}$)	3.23	1.40	u.d.	0.12	6.37
Saturated	(S)	31.97	43.00	46.52	35.12	44.53
Unsaturated	(US)	68.03	57.00	53.48	64.88	55.47
S/US ratio (%)	(S/US)	46.99	75.94	86.99	54.13	80.28
ω-3		5.54	1.70	0.99	2.22	6.75

[a]Undetected level. See Table 1 for other abbreviations.

ω-3 Fatty acids in abdominal fat of fish meal-fed Muscovies were enriched, which indicates that the role of ω-3-rich protein sources play in modifying the fatty acid composition of adipose tissues. In agreement with the current data, Furuse *et al.* (34) showed a lower proportion of saturated fatty acid and a higher unsaturated fatty acid profile of abdominal fat of broilers that were fed diets with 9% sorbose, compared to a 0% sorbose level. Moreover, Pinchasov and Nir (15) reported that saturated fatty acids of abdominal adipose tissue decreased with increasing dietary PUFA intakes, while ω-3 fatty acids showed a quadratic response.

The correlation between saturated fatty acids and unsaturated fatty acids in abdominal fat was negative ($r = 0.99$; $P = 0.001$). Unsaturated fatty acid consumption and unsaturated fatty acid of abdominal fat correlated positively ($r = 0.63$; $P = 0.05$). Moreover, ω-3 fatty acid consumption and unsaturated fatty acid of abdominal fat correlated positively ($r = 0.57$; $P = 0.07$).

Data for fatty acid profiles of subcutaneous breast fats are shown in Tables 17 and 18. Males fed MM-containing diets had higher saturated fatty acids in the subcutaneous breast fat. The results indicated that MM-containing diets raised the saturated-to-unsaturated fatty acid ratio. ω-3 Fatty acids of subcutaneous breast fat of males was enriched when HFM + MM was fed. Fish meal had a greater enhancing effect on ω-3 fatty acids of females. This was accompanied by a decrease in ω-6 fatty acids. Feeding HFM to male Muscovy ducks enhanced mostly ω-3 fatty acid contents of adipose tissues. In this connection, Bartov and Bornstein (35) showed that acidulated soybean soapstock markedly increased the concentration of ω-6 and ω-3 in carcass fat. Similar results were reported by Nir *et al.* (36). Saturated and unsaturated fatty acids of subcutaneous breast fat correlated negatively ($r = 0.90$; $P = 0.003$). Correlation between abdominal fat ω-3 fatty acids and ω-3 fatty acids from subcutaneous breast fat of females was positive ($r = 0.89$; $P = 0.05$). This indicates that nutritionally rich ω-3 sources can modify ω-3 of adipose tissues.

In conclusion, these results indicate that feeding HFM en-

TABLE 18
Fatty Acid Profile of Lipid Extracted from Subcutaneous Breast Fats of Female Muscovy Ducks Fed Different Protein Sources (from 4–9 wk of age)

Fatty acid		Protein source				
		CPC	SBM	MM	HFM	HFM + MM
Myristic	($C_{14:0}$)	2.70	2.40	3.00	4.14	2.38
Palmitic	($C_{16:0}$)	6.30	21.96	20.02	11.75	23.52
Palmitoleic	($C_{16:1}$)	9.00	10.22	14.75	8.36	9.36
Stearic	($C_{18:0}$)	14.00	11.48	14.56	15.34	14.33
Oleic	($C_{18:1}$)	57.00	39.55	29.87	40.00	34.66
Linoleic	($C_{18:2}$)	8.00	12.90	15.41	7.35	11.94
Linolenic	($C_{18:3}$)	3.00	1.06	1.20	9.55	3.09
Arachidonic	($C_{20:0}$)	u.d.[a]	0.43	1.19	2.83	0.25
Gadoleic	($C_{20:1}$)	u.d.	u.d.	u.d.	0.68	0.47
Saturated	(S)	23.00	36.27	38.77	34.06	40.48
Unsaturated	(US)	77.00	63.73	61.23	65.94	59.52
S/US ratio (%)	(S/US)	29.87	56.91	63.32	51.65	68.01
ω-3		3.00	1.06	1.20	9.55	3.09

[a]Undetected level. See Table 1 for other abbreviations.

riches ω-3 fatty acids and lowers cholesterol in different duck tissues. It is known that linolenic fatty acid cannot be synthesized and must be supplemented by dietary sources, to convert to long-chain ω-3 fatty acid. The consumption of saturated fats is correlated with human diseases, whereas increasing ω-3 fatty acid intake may benefit human health and decreases risk of coronary heart disease (2,37).

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