Feeding high-oleic peanuts to meat-type broiler chickens enhances the fatty acid profile of the meat produced

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ABSTRACT Early feeding trials using peanut meal prepared from normal-oleic peanuts helped to identify peanuts as a suitable alternative feed ingredient for poultry. Yet no studies to date have examined the use of high-oleic peanuts (**HO-PN**) as a feed ingredient for meat type chickens. Therefore, this study aimed to determine the effect of feeding whole unblanched HO-PN on the fatty acid profile of the meat produced from broilers. At hatch male chicks were randomly placed in raised wire cages, in 10 replicate pens per treatment with 10 chicks per pen, and fed with one of the 3 isocaloric, isonitrogenous diets ad libitum for 42 days: (1) conventional control of soybean meal + corn, (2) 10 to 12% HO-PN and corn diet, or (3) control diet spiked with ≈6.0% oleic acid oil. All body weights (**BW**) were collected, and broiler selection for processing was determined by individual BW within one-half a standard deviation of the experiment 42-D mean BW, with one bird selected per pen (10 replicate pens per treatment, 3 treatments, 10 birds selected per treatment, yielding a total sample size of 30 birds). Performance was determined weekly and breast samples were analyzed for fatty acid and amino acid profile. All data was analyzed using analysis of variance, with t-test mean comparisons at $P < 0.05$. BW were similar between broilers fed the HO-PN and control diet, while feed conversion ratio of broilers fed the HO-PN diet was significantly higher at weeks 2, 4, and 6 in comparison to the other treatments ($P \leq 0.03$). Broilers fed with HO-PN diet had reduced carcass and pectoralis major weights in comparison to the other treatments. Chicken breast from broilers fed the HO-PN diet had significantly reduced saturated and trans fatty acid content in comparison to the controls ($P \leq 0.0002$). Although additional studies must be conducted, this study suggests that feeding whole unblanched HO-PN to broiler chickens may serve as a means to enrich the meat produced with unsaturated fatty acids.

Key words: broiler chicken, feed ingredient, chicken breast, meat fatty acid profile, high-oleic peanut

2020 Poultry Science 99:2236–2245
https://doi.org/10.1016/j.psj.2019.11.015

INTRODUCTION

Although soybean meal and corn are traditional components of poultry diets that are used to meet protein and energy requirements, research has demonstrated many suitable feed ingredient alternatives to meet the nutritional requirements of poultry. In some countries, other plant protein sources from oilseeds such as canola, groundnut cake (peanut meal), or animal protein ingredients, such as fish meal or blood meal, are commonly used. In various parts of the world such as India, Ghana, and Nigeria, peanut meal from normal-oleic peanuts (groundnuts) are commonly used as a protein source for feeding poultry (Cilly et al., 1977; Aletor and Olonimoyo, 1992; Venkataraman et al., 1994; Donkoh et al., 1999; Naulia and Singh, 2002). Peanuts and soybeans are legumes and oilseeds providing twice as much protein as grains, while also providing dietary energy. However, very few studies have been conducted in the US examining the use of whole unblanched peanuts as an alternative feed ingredient for poultry to enhance the nutritional content or quality of the meat and/or eggs produced.

Earlier poultry feeding studies by Pesti et al., (2003) and Costa et al., (2001) identified peanut meal prepared from normal-oleic peanuts (52% oleic acid and 27% linoleic acid) as a suitable poultry feed ingredient. Nevertheless, few studies have examined the use of modern high-oleic peanut (**HO-PN**) cultivars (80% oleic acids

Received June 24, 2019.
Accepted November 3, 2019.

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Table 1. Feed formulation of broiler starter diets.

Feed Ingredient	[1]Control (%)	[5]HO peanut + corn (%)	[6]Oleic acid oil (%)
Corn, yellow	52.53	53.90	50.22
Wheat middlings	0.10	0.00	3.10
Soybean meal (47% protein)	32.50	26.20	31.80
Poultry meal (63% protein)	6.00	6.00	6.00
Salt	0.30	0.20	0.30
Limestone	0.90	0.90	0.90
HO peanut	0.00	10.20	0.00
Sodium bicarbonate	0.10	0.26	0.10
Dicalcium phosphate	0.97	1.05	0.96
DL-Methionine	0.37	0.39	0.37
L-Lysine	0.22	0.35	0.23
L-Threonine	0.11	0.15	0.12
Choline chloride	0.10	0.10	0.10
Vitamin premix[2]	0.05	0.05	0.05
Mineral premix[3]	0.20	0.20	0.20
Selenium premix[4]	0.05	0.05	0.05
Poultry fat	5.50	0.00	0.00
Oleic acid oil	0.00	0.00	5.50

A mash starter diet (3,120 kcal/kg, 23% protein, 1.27% digestible lysine) was formulated to feed from approximately 0 to 14 D.

[1]Control diet was formulated to contain 1.15% of total lysine (digestible: 0.98%), 0.54% of total methionine (digestible: 0.50%), 0.88% of total methionine and cystine (digestible: 0.76%), 0.79% of total threonine (digestible: 0.66%), 0.25% of total tryptophan (digestible: 0.20%), 1.41% of total arginine (digestible: 1.27%), and 2, 074 mg/kg of total choline.

[2]Vitamin premix supplied the following per kg of diet: 13,200 IU of vitamin A, 4,000 IU of vitamin D_3, 33 IU of vitamin E, 0.02 mg of vitamin B_{12}, 0.13 mg of biotin, 2 mg of menadione (K_3), 2 mg of thiamine, 6.6 mg of riboflavin, 11 mg of D-pantothenic acid, 4 mg of vitamin B_6, 55 mg of niacin, and 1.1 mg of folic acid.

[3]Mineral premix supplied the following per kg of diet: manganese, 120 mg; zinc, 120 mg; iron, 80 mg; copper, 10 mg; iodine, 2.5 mg; and cobalt, 1 mg.

[4]Selenium premix provided 0.2 mg Se (as Na_2SeO_3) per kg of diet.

[5]High-oleic peanut (HO-PN) diet was formulated to contain 1.15% of total lysine (digestible: 0.98%), 0.55% of total methionine (digestible: 0.51%), 0.88% of total methionine and cystine (digestible: 0.76%), 0.74% of total threonine (digestible: 0.61%), 0.23% of total tryptophan (digestible: 0.19%), 1.53% of total arginine (digestible: 1.36%), and 1,874.8 mg/kg of total choline.

[6]Oleic acid oil (OA)–supplemented diet was formulated to contain 1.15% of total lysine (digestible: 0.98%), 0.54% of total methionine (digestible: 0.50%), 0.88% of total methionine and cystine (digestible: 0.76%), 0.79% of total threonine (digestible: 0.65%), 0.25% of total tryptophan (digestible: 0.20%), 1.41% of total arginine (digestible: 1.26%), and 2,075 mg/kg of total choline.

and 2% linoleic acid) as a feed ingredient for meat-type chickens and determined their effect on the chemical composition and quality of the meat produced. Poultry feeding studies conducted in the Market Quality & Handling Research Unit-Agricultural Research Service demonstrated that eggs produced from layer hens fed with a diet containing HO-PN and corn had 1.35-fold higher β-carotene content, 2-fold higher yolk color intensity and monounsaturated oleic acid oil (**OA**) content than eggs produced from layer hens fed with a conventional soybean meal and corn diet (Toomer et al., 2019). Therefore, in this study, we aimed to determine the effect of feeding broiler chickens with a diet containing HO-PN and corn or with a conventional broiler diet supplemented with OA on the chicken breast composition and quality.

MATERIALS AND METHODS

Experimental Design, Animal Husbandry, and Dietary Treatments

This experiment was conducted in the summer of 2018 in the environmentally controlled animal wing at the North Carolina State University (**NCSU**) Poultry Research Unit. All procedures used in this study were reviewed and approved by the NCSU Institutional Animal Care and Use Committee before the onset of this study. Male broiler chicks (Ross 708) were randomly placed on the day of hatch in 30 raised wire cages (10 replicate cages per treatment), with 10 broilers per cage. Broiler pens were blocked by location and fed *ad libitum* (in replicates of 10 pens) with one of the 3 isocaloric and isonitrogenous formulated mash starter diets (3,120 kcal/kg, 23% protein) from days 0 to 14. Formulated mash grower diets (3,190 kcal/kg, 21% protein) were fed from days 15 to 42 (starter diet: Table 1, grower diet: Table 2) to meet or exceed NRC requirements for broilers (NRC, 1994). The antioxidant Santoquin (Novus International, Saint Charles, MO) was added to each of the diets at a concentration of 1% to protect from oxidative rancidity.

Broilers were fed for 6 wk with a control diet containing conventional soybean meal and corn (Control), a diet containing 10 to 12% HO-PN and corn diet, or a control diet spiked with ≈6% OA. The diet containing HO-PN and corn was prepared using aflatoxin-free whole nonroasted HO-PN with the testa (skin) intact, crushed using a roller mill to produce peanut crumbles. Finished broiler grower feed samples were analyzed for nutritional

Table 2. Feed formulation of broiler grower diets.

Feed ingredient	[1]Control (%)	[5]HO peanut + corn (%)	[6]Oleic acid oil (%)
Corn, yellow	56.790	56.845	54.485
Wheat middlings	1.00	2.40	4.20
Soybean meal (47% protein)	26.20	18.40	25.30
Poultry meal (63% protein)	7.50	7.50	7.50
Salt	0.30	0.20	0.30
Limestone	0.80	0.80	0.80
HO peanuts	0.00	12.00	0.00
Sodium bicarbonate	0.00	0.20	0.00
Dicalcium phosphate	0.79	0.87	0.78
DL-Methionine	0.21	0.24	0.22
L-Lysine	0.005	0.15	0.02
L-Threonine	0.00	0.00	0.00
Choline chloride	0.10	0.10	0.10
Vitamin premix[2]	0.05	0.05	0.05
Mineral premix[3]	0.20	0.20	0.20
Selenium premix[4]	0.05	0.05	0.05
Poultry fat	6.00	0.00	0.00
Oleic acid oil	0.00	0.00	6.00

A mash grower diet (3,190 kcal/kg, 21% protein, 0.9795% digestible lysine) was formulated to feed from approximately 15 to 42 D.

[1]Control diet was formulated to contain 1.15% of total lysine (digestible: 0.98%), 0.54% of total methionine (digestible: 0.50%), 0.88% of total methionine and cystine (digestible: 0.76%), 0.79% of total threonine (digestible: 0.66%), 0.25% of total tryptophan (digestible: 0.20%), 1.41% of total arginine (digestible: 1.27%), and 2, 074 mg/kg of total choline.

[2]Vitamin premix supplied the following per kg of diet: 13,200 IU of vitamin A, 4,000 IU of vitamin D_3, 33 IU of vitamin E, 0.02 mg of vitamin B_{12}, 0.13 mg of biotin, 2 mg of menadione (K_3), 2 mg of thiamine, 6.6 mg of riboflavin, 11 mg of D-pantothenic acid, 4 mg of vitamin B_6, 55 mg of niacin, and 1.1 mg of folic acid.

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[5]High-oleic peanut (HO-PN) diet was formulated to contain 1.15% of total lysine (digestible: 0.98%), 0.55% of total methionine (digestible: 0.51%), 0.88% of total methionine and cystine (digestible: 0.76%), 0.74% of total threonine (digestible: 0.61%), 0.23% of total tryptophan (digestible: 0.19%), 1.53% of total arginine (digestible: 1.36%), and 1,874.8 mg/kg of total choline.

[6]Oleic acid (OA)–supplemented diet was formulated to contain 1.15% of total lysine (digestible: 0.98%), 0.54% of total methionine (digestible: 0.50%), 0.88% of total methionine and cystine (digestible: 0.76%), 0.79% of total threonine (digestible: 0.65%), 0.25% of total tryptophan (digestible: 0.20%), 1.41% of total arginine (digestible: 1.26%), and 2,075 mg/kg of total choline.

content (Table 3) and lipid and fatty acid analysis (Table 4) by the commercial vendor ATC Scientific (Little Rock, AR) using standard methods for feed analysis. Experimental diets were analyzed and determined to be free of aflatoxin and microbiological contaminants by the North Carolina Department of Agriculture and Consumer Services, Food and Drug Protection Division Laboratory (Raleigh, NC).

Table 3. Nutritional analysis of experimental diets[1].

	Broiler mash starter diet			Broiler mash grower diet		
Nutritional content	Control	HO-PN	OA	Control	HO-PN	OA
CP, %	23.1	23.0	23.0	21.0	21.0	21.0
Crude fat, %	8.12	7.36	8.17	8.87	8.46	8.93
Crude fiber, %	3.66	3.30	3.81	3.50	3.15	3.66
Ash, %	6.04	5.72	6.08	5.58	5.25	5.64
Calcium, %	0.95	0.95	0.95	0.93	0.93	0.93
Total P, %	0.65	0.66	0.65	0.63	0.65	0.63
ME (kcal/kg)	3,120	3,120	3,120	3,190	3,190	3,190
Dig Lys, %	1.27	1.27	1.27	0.98	0.98	0.98
Dig Met + Cys, %	0.95	0.95	0.95	0.76	0.76	0.76
Dig Threo, %	0.83	0.83	0.83	0.66	0.61	0.65
Tryp, %	0.23	0.22	0.23	0.20	0.19	0.20
Na, %	0.19	0.19	0.19	0.17	0.17	0.17
Cl, %	0.28	0.24	0.29	0.26	0.21	0.26
K, %	0.84	0.79	0.85	0.75	0.7	0.76

Abbreviations: Cl, chloride; CP, crude protein; Dig Met + Cis, digestible methionine + cystine; Dig Lys, digestible lysine; Dig Threo, digestible threonine; HO-PN, high-oleic peanut; K, potassium; ME, metabolizable energy (kcal/kg); OA, oleic acid oil; Na, sodium; Total P, total phosphorous; Tryp, tryptophan.

[1]The nutritional content of each experimental diet was analyzed by the commercial vendor ATC Scientific (Little Rock, AR) using standard analysis procedures to validate that starter and grower mash diets were isonitrogenous and isocaloric.

Table 4. Chemical lipid and fatty acid analysis of broiler grower dietary treatments[1].

Treatment	Soybean meal + corn (Control)	HO-PN	Oleic acid oil (OA)
Palmitic acid (C16:0), %	22.44	9.46	16.78
Palmitoleic acid (C16:1), %	5.35	1.05	2.36
Stearic acid (C18:0), %	5.76	3.11	4.66
Oleic acid (C18:1), %	36.65	64.48	32.52
Elaidic acid (n9 trans), %	1.86	0.85	1.30
Linoleic acid (C18:2), %	22.96	12.81	24.89
Linolenic acid (C18:3), %	1.07	0.48	1.17
Omega-3 fatty acids, %	1.35	0.64	1.48
Omega-6 fatty acids, %	23.72	13.05	30.50
Beta-carotene[1] (ppm)	<5.0	<5.0	<5.0
Total cholesterol (mg/100 g)	54.40	21.15	19.20

A composite finished broiler feed sample was analyzed for lipid and fatty acid levels by the commercial vendor ATC Scientific (Little Rock, AR) using standard methods.

Abbreviations: HO-PN, high-oleic peanut; OA, oleic acid oil.

[1]A composite finished broiler feed sample was analyzed for lipid and fatty acid levels by the commercial vendor ATC Scientific (Little Rock, AR) using standard methods.

Meat Processing

At day 42, one broiler from each pen (10 birds per pen, 10 replicate pens per treatment, 3 treatments, 10 birds selected per treatment, yielding a total sample size of 30 birds) was selected for processing. Broiler selection was determined by individual body weight (**BW**), being within one-half a standard deviation of the experiment 42-D mean BW. Selected broilers were given 10 h of lairage time (feed was removed, and water was supplied) before transport to the NCSU commercial-style pilot processing facility. Broilers were reweighed directly before being shackled, stunned, and bled. The bleeding time was approximately 2 min before entry into an agitated scald bath at 62.2 degrees C for 1 min and 20 s to remove feathers using in-line processing equipment. Hot carcass weights (**HCW**) were recorded. The carcasses were then chilled in an ice bath at 0.5°C for approximately 4 h. The chilled carcasses were removed from the ice bath after 4 h; their temperature was verified to be less than 4.5°C, and they were reweighed. The left pectoralis major portion was vacuum packaged and used for proximate analysis.

Chicken Breast Protein and Amino Acid Analysis

Chicken breast samples were composited from the left pectoralis major, vacuum packaged, and stored at −20°C until analysis. Total protein was determined by titration using a CEM Sprint Analyzer (CEM Corporation, Matthews, NC). The sample composites were first oxidized with performic acid and then digested with 6 N HCl for determination of amino acid content using modified methods (Van der Meer, 1990; Kasper et al., 2009; Otter, 2012). Digestion was performed using a CEM Discover model hydrolyzer (CEM Corporation, Matthews, NC). The digests were then diluted with 0.02 N HCl and analyzed using a Hitachi Model L8900 (Hitachi High Technologies Corporation, Schaumburg, IL) by postcolumn derivatization with ninhydrin. Individual amino acids were identified based on retention time and quantified against standard curves prepared by dilutions of Pierce H amino acid standard (Thermo Fisher Scientific, Pierce Biotechnology, Rockford, IL). In addition, the sample composites were analyzed for tryptophan content after hydrolysis with 4.2 N NaOH (Kuminek, et al, 2011). The hydrolysates were diluted with 0.2 M phosphate buffer (pH 7), and tryptophan content was determined by reversed-phase high-performance liquid chromatography with UV detection at 280 nm. A Thermo Finnigan high-performance liquid chromatography system (Thermo Quest, San Jose, CA) fitted with a C18, 250 × 4.6 mm, 5-μm particle size column was used for the analysis of tryptophan content. The injection volume was 10 μL, and the column oven temperature was set to 30°C. The mobile phase was 90% of 0.02 M phosphate buffer (pH 3.3) and 10% of acetonitrile at a flow rate of 1.5 mL/min. Tryptophan content in the samples was determined using an external standard curve, prepared using an authentic tryptophan standard (Sigma Chemical Corporation, St. Louis, MO).

Chicken Breast Lipid and Fatty Acid Analysis

Total fat in the sample composites was determined as per AOAC 960.39 (AOAC, 1990) using petroleum ether in a Büchi Model E-816 Extractor (Büchi Corporation, New Castle, DE). Before extraction, the samples were weighed in aluminum weighing dishes, mixed with washed sand (Fisher Chemical Corporation, Fair Lawn, NJ), and dried in a vacuum oven (VWR Model 1430, VWR Scientific, Radnor, PA) for 6 h at 100°C.

The total fat extracted from sample composites was analyzed for fatty acid analysis per AOCS Ce 2.66 methods (AOCS, 2004). In brief, the lipid was saponified with methanolic sodium hydroxide (Fisher Chemical Corporation, Fair Lawn, NJ). The resulting fatty acids were converted to their methyl esters using methanolic boron trifluoride (Sigma Chemical Corporation, St. Louis, MO) as the catalyst. The methyl esters were extracted into hexane (Fisher Chemical Corporation, Fair Lawn, NJ). The hexane extracts were dried over sodium sulfate crystals (Sigma Chemical Corporation, St.

Table 5. Effect of high-oleic peanut (HO-PN) diet on broiler performance[1].

Body weight				
Dietary ttreatment[2]	Units	Control (n = 100)	HO-PN (n = 100)	OA (n = 100)	$P > F$
Week 2	g	478 ± 7.3[a]	419 ± 7.3[b]	471 ± 7.3[a]	0.0002
Week 3	kg	0.94 ± 0.02[a]	0.84 ± 0.02[b]	0.94 ± 0.02[a]	0.002
Week 4	kg	1.43 ± 0.02[a]	1.31 ± 0.02[b]	1.41 ± 0.02[a]	0.0006
Week 6	kg	2.55 ± 0.04[a,b]	2.43 ± 0.04[b]	2.59 ± 0.04[a]	0.034
Feed conversion ratio (FCR)*					
Week 2		1.428 ± 0.03[b]	1.536 ± 0.03[a]	1.412 ± 0.03[b]	0.031
Week 3		1.52 ± 0.03[b]	1.62 ± 0.03[a]	1.50 ± 0.03[b]	0.005
Week 4		1.42 ± 0.02[b]	1.58 ± 0.02[a]	1.43 ± 0.02[b]	<0.0001
Week 6		1.56 ± 0.03[b]	1.62 ± 0.03[a]	1.56 ± 0.03[b]	<0.01

[a,b]Means within the same row lacking a common superscript differ significantly ($P < 0.05$).

There were no mortalities at any experimental time points (week 0–week 6) within any of the treatment groups in this study. Average body weights and feed conversion ratio (FCR) were calculated for 100 birds per treatment at each experimental time point (week 2, week 3, week 4, and week 6). Each value represents the weekly average of body weights ± standard error of the mean.

*FCR = kg of feed consumed/kg of body weight gain ± standard error of the mean.

[1]Isocaloric, isonitrogenous experimental diets were fed to 100 (10 birds/pen with 10 pens per treatment) broiler chickens per treatment (3 treatments for 300 birds in total) for 6 wk: conventional corn and soybean diet (Control), high-oleic peanut + corn (HO-PN), or control diet spiked with 6% oleic acid oil (OA).

Louis, MO) and transferred to crimp-top autosampler vials. The fatty acid methyl esters were analyzed by gas chromatography using a Perkin Elmer XL Autosampler system (PerkinElmer Corporation, Shelton, CN) fitted with an SGE 70% cyanopropyl column (30 m length, 0.25 mm inner diameter, 0.25 um film thickness, Trajan Scientific Americas, Austin, TX). The carrier gas was helium, at a flow rate of 20 mL/min with a split flow rate of 40 mL/min. The detection was performed by flame ionization. Compound identification was performed based on retention times when compared with commercial standards (Kel Fir Fame 6, Matreya LLC, State College, PA). The content of each fatty acid identified was determined based on normalization of each peak area as to the total peak area based on AOCS Ce 1f-96 (AOCS, 2004).

Statistical Analysis

Individual dependent variables (BW, carcass and piece weights, percentage piece yields) were analyzed by one-way analysis of variance using the Proc Mixed procedure of SAS, version 9.4 (SAS, 2009) and pen as a random variable (SAS Institute, Cary, NC). Percentage data were subjected to arcsine transformation wherever necessary before analysis. Means were separated with Tukey's adjustment for multiple comparison tests ($P < 0.05$). Treatment comparisons between chicken breast amino acid and fatty acid profile were evaluated for significance by one-way analysis of variance. Means were separated with Tukey's adjustment for multiple comparison tests at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

Analysis of Experimental Diets and Broiler Performance Parameters

Nutritional analysis of each treatment determined that all experimental diets were isocaloric and isonitrogenous (Table 3). Moreover, all experimental diets had equivalent nutritional levels of calcium, total phosphorus, digestible lysine, digestible methionine and cystine, digestible threonine (starter diet), digestible tryptophan, and sodium (Table 3). All experimental diets had very similar nutritional quantities of crude fat, crude fiber, ash, digestible threonine (grower diet), chloride, and potassium (Table 3). The control and oleic acid–supplemented diets had a higher content of saturated fatty acids (palmitic acid and stearic acid) and trans-fat (n9 trans-elaidic acid) relative to the HO-PN diet (Table 4). The HO-PN diet contained the highest content of monounsaturated oleic acid and lowest content of total cholesterol relative to the other treatment groups (Table 4).

There were no mortalities at any experimental time points (week 0 to week 6) within any of the treatment groups in this study. However, there were significant treatment differences ($P < 0.05$) in broiler performance over the experimental time period. Broilers fed with the HO-PN diet had significantly lower average BW in comparison with the controls and OA diet–fed broilers at weeks 2, 3, and 4 (Table 5, $P < 0.05$). However, after 42 D of feeding the experimental diets, broilers fed with the control and HO-PN diets had similar average BW, whereas average BW of broilers fed with the OA diet were significantly higher than the BW of broilers fed with the HO-PN diet (Table 5). Feed conversion ratio (kg of feed consumed/kg of BW gain) was significantly higher in broilers of the HO-PN treatment group than in those of the other treatment groups, from each experimental time point (Table 5). While performance of broilers fed the HO-PN diet was significantly different than the other dietary treatments, average broiler performance at 39 D of age is typically a body weight of 2.5 kg with a feed conversion ratio of approximately 1.6, within the commercial poultry industry (Best, 2011). Thus, the feed conversion ratio of approximately 1.6 at week 6 for each of the dietary treatment groups would be acceptable as per industry standards (Best, 2011).

Table 6. Effect of high-oleic peanut (HO-PN) diet on carcass section weights and yields[1].

Section[3]	Units	Dietary treatment[2] Control (n = 10)	HO-PN (n = 10)	OA (n = 10)	*P*-value
LW	g	2,515 ± 19.2[a]	2410 ± 19.2[b]	2,514 ± 19.2[a]	<0.01
HCW	g	2,018 ± 16.9[a]	1925 ± 16.9[b]	2,019 ± 16.9[a]	<0.01
CCW	g	2,029 ± 17.3[a]	1927 ± 17.3[b]	2,028 ± 17.3[a]	<0.01
Pickup	%	0.538 ± 0.2	0.129 ± 0.2	0.454 ± 0.2	0.34
Breast major	g	552 ± 10.5[a]	510 ± 10.5[b]	561 ± 10.5[a]	<0.01
Breast minor	g	128 ± 2.2[a]	120 ± 2.2[b]	126 ± 2.2[a,b]	0.03
Breast yield	%	27.15 ± 0.4	26.46 ± 0.4	27.62 ± 0.4	0.12
Leg quarter	g	589 ± 7.1	576 ± 7.1	588 ± 7.1	0.35
Leg yield	%	29.06 ± 0.3[b]	29.92 ± 0.3[a]	29.00 ± 0.3[b]	0.05
Wing	g	185 ± 1.9[a,b]	181 ± 1.9[b]	190 ± 1.9[a]	<0.01
Skin	g	111 ± 2.8	104 ± 2.8	105 ± 2.8	0.21
Fat pad	g	22.2 ± 1.9	22.3 ± 1.9	22.2 ± 1.9	1.00
Frame	g	439 ± 5.3[a]	416 ± 5.3[a]	433 ± 5.3[a,b]	<0.01
Frame yield	%	21.7 ± 0.3	21.6 ± 0.3	21.4 ± 0.3	0.69

[a,b]Means within the same row lacking a common superscript differ significantly ($P < 0.05$).

Each value represents the treatment average mean ± standard error of the mean for 30 birds.

[1]At day 42, all body weights (BW) were collected, and broiler selection for processing was determined by individual BW within one-half a standard deviation of the experiment 42-D mean BW, with one bird selected per pen (10 replicate pens per treatment, 3 treatments, 10 birds selected per treatment, yielding a total sample size of 30 birds) for processing and proximate analysis.

[2]Isocaloric, isonitrogenous experimental diets: conventional corn and soybean diet (Control), high-oleic peanut + corn (HO-PN), or control diet spiked with 6% oleic acid oil (OA).

[3]LW: live weights; Pickup (%): (CCW-HCW)/HCW*100; HCW: hot carcass weights; CCW: cold carcass weights; Frame yield: frame (g)/HCW (g) X100%.

Live weights, HCW, cold carcass weights, and cutout weights (breast major, breast minor, breast yield, leg quarter, leg yield, and wing) are represented in Table 6. Of the 30 broiler chickens selected for processing, birds of the HO-PN treatment group had significantly reduced average live weights, HCW, cold carcass weight, and size of breast pectoralis major sections in comparison with those of the other treatment groups (Table 6, $P < 0.01$). The average size of breast pectoralis minor sections was statistically similar between the HO-PN and OA treatment groups. However, the average size of breast pectoralis minor sections of the HO-PN treatment group was significantly reduced in comparison with that of the those of the control treatment group (Table 6, $P = 0.03$) Nevertheless, there were no significant differences between the percentage of breast yields relative to total BW between the treatment groups (Table 6, $P = 0.12$). Average weights of wing sections were similar in size from broilers fed with the HO-PN and control diets. The average size of wing sections from broilers fed with the HO-PN diet was significantly reduced in comparison with that from broilers fed with the OA diet, but was statistically similar to the average size of wing sections from the control group (Table 6, $P < 0.01$). The average frame mass (g) was significantly reduced in broilers of the HO-PN treatment group in comparison with those of the control group (Table 6, $P < 0.01$), whereas the average frame weights were statistically similar between the HO-PN and OA treatment groups. The average percentage of moisture pickup ($P = 0.34$), average mass of fat pad sections ($P = 1.0$), skin ($P = 0.21$), and the average percentage of frame mass relative to HCW ($P = 0.69$) were statistically similar among all treatment groups (Table 6).

Studies by Kheri and Alibeyghi (2017) demonstrated in parallel to studies by Kidd et al., (1997) that dietary lysine and/or threonine supplementation (at an inclusion level of 120% of that recommended in NRC, 1994) can achieve optimal live weights, carcass weights, and carcass component yields (breast, thigh, liver, and heart). In this study, In this study, all experimental diets were supplemented with synthetic amino acids, lysine, threonine and methionine (Table 1 and Table 2), while the HO-PN diet had the highest level of supplementation of these dietary amino acids (exception of threonine content in grower phase diet). Hence, this may account for the increased leg carcass yield of broilers fed with the HO-PN diets. Nonetheless, nutritional analysis of the 3 broiler starter and grower mash diets determined negligible differences in the levels of digestible lysine, digestible methionine and cysteine, or digestible threonine (Table 3) among the treatment groups. Yet preliminary data from other poultry feeding trials conducted in the Market Quality & Handling Research Unit have determined that layers (Control = 2,807 cal/g, HO-PN = 2,844 cal/g, OA = 2,576 cal/g; $P < 0.001$) and broilers (Control = 3,193.5 cal/g, HO-PN = 3,260.8 cal/g, OA = 3,157.4 cal/g; $P = 0.019$) fed with HO-PN-supplemented diets had significantly improved apparent metabolizable energy relative to birds fed with the conventional and oleic acid–supplemented diets (data not published), which may greatly influence carcass yields (Table 6).

In the past, poultry products were generally marketed on a whole carcass basis. However, today, the poultry industry produces broilers with improved feed conversion efficiency and increased breast muscle mass (Gous et al., 1999), in response to a shift in consumer preference

Table 7. Amino acid profile of chicken breast from broilers fed with a high-oleic peanut– or oleic acid oil–supplemented diet[1].

Dietary treatments[2]	Control	HO-PN	OA	*P*-value
	g/100 g of tissue weight			
Total protein	23.7 ± 0.24	24.0 ± 0.21	24.3 ± 0.19	0.26
Cysteine	0.40 ± 0.0[a]	0.35 ± 0.01[b]	0.37 ± 0.0[b]	0.03
Methionine	0.73 ± 0.0[a]	0.66 ± 0.01[b]	0.67 ± 0.01[b]	0.0005
Aspartate	2.05 ± 0.02	2.15 ± 0.03	2.11 ± 0.03	0.07
Threonine	0.79 ± 0.01[b]	0.87 ± 0.02[a]	0.80 ± 0.04[a,b]	0.03
Serine	0.89 ± 0.01	0.91 ± 0.02	0.89 ± 0.02	0.54
Glutamic acid	3.14 ± 0.03[b]	3.39 ± 0.05[a]	3.34 ± 0.04[a]	0.001
Glycine	0.90 ± 0.01	0.95 ± 0.02	0.95 ± 0.01	0.05
Alanine	1.25 ± 0.02[b]	1.35 ± 0.03[a]	1.34 ± 0.03[a]	0.02
Valine	1.02 ± 0.03	0.98 ± 0.02	0.98 ± 0.02	0.44
Isoleucine	0.78 ± 0.02[b]	0.86 ± 0.03[a]	0.76 ± 0.03[b]	0.02
Leucine	1.67 ± 0.02[b]	1.84 ± 0.02[a]	1.85 ± 0.02[a]	0.0001
Tyrosine	0.66 ± 0.02	0.69 ± 0.03	0.67 ± 0.01	0.42
Phenylalanine	1.38 ± 0.03	1.28 ± 0.05	1.23 ± 0.08	0.37
NH_3	0.40 ± 0.01[b]	0.43 ± 0.08[b]	0.84 ± 0.11[a]	0.0008
Lysine	2.39 ± 0.03[a]	2.22 ± 0.03[b]	2.10 ± 0.03[b]	<0.0001
Histidine	0.78 ± 0.02[a]	0.68 ± 0.02[b]	0.82 ± 0.02[a]	0.0005
Arginine	1.41 ± 0.02	1.49 ± 0.03	1.43 ± 0.03	0.09
Proline	0.78 ± 0.01	0.79 ± 0.01	0.81 ± 0.01	0.11
Tryptophan	0.224 ± 0.01	0.240 ± 0.01	0.225 ± 0.01	0.39

[a,b]Means within the same row lacking a common superscript differ significantly ($P < 0.05$).
Each value represents the treatment average mean ± standard error of the mean.
[1]At day 42, all body weights (BW) were collected, and broiler selection for processing was determined by individual BW within one-half a standard deviation of the experiment 42-D mean BW, with one bird selected per pen (10 replicate pens per treatment, 3 treatments, 10 birds selected per treatment, yielding a total sample size of 30 birds) for processing and proximate analysis.
[2]Isocaloric, isonitrogenous experimental diets: conventional corn and soybean diet (Control), high-oleic peanut + corn diet (HO-PN), or control diet spiked with 6% oleic acid oil (OA).

from whole chicken to processed chicken parts and products. Breast muscle is considered the most valuable portion of chicken with small increases in breast meat yield having a significant impact on economic returns. Previous studies have shown that line, sex, age, health, nutrition, BW, and environment influence poultry carcass yields (Brake et al., 1995; Havenstein et al., 2003; Nikolova and Pavlovski, 2009). Thus, numerous research studies have been conducted with aims to optimize these factors with improved carcass yield.

Few studies have examined the use of peanut meal (Douglas and Harms, 1959; Carew et al., 1988; El Boushy and Raterink 1989; Costa et al., 2001; Pesti et al., 2003) and/or whole peanuts (Toomer et al., 2019) as an economical and adequate poultry feed ingredient. Earlier studies by Costa et al., (2001) demonstrated that broilers fed with 16% peanut meal diet had reduced carcass weight compared with broilers fed with 24% soybean meal diet and 24% peanut meal diets, whereas breast yields and leg quarter weights were similar between broilers fed with 20 and 24% soybean meal diets and 24% peanut meal diet.

Similarly, this study demonstrates that broilers fed a HO-PN diet had reduced BW and breast yield relative to the broilers fed the control soybean meal diet. However, unlike studies conducted by Costa et al., (2001), this feeding study only used one inclusion level of whole HO-PN crumbles in the diet (12.0% HO-PN, 18.4% soybean meal) for 6 wk. Although similarities exist between these feeding studies, no other studies to date have examined the use of whole normal-oleic peanuts or HO-PN as an energy-rich protein feed ingredient.

Proximate Analysis of Chicken Breast

With increasing national income and advancements in poultry production and genetics, the national rate of chicken breast consumption has increased as a desired dietary protein source providing all 9 essential amino acids (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine) required in the human diet (USDA, 2015; Aliu et al., 2018). The essential amino acids are required in the diet to maintain vital physiological functions and cannot be produced *de novo*.

There were no significant differences in the content of amino acids valine ($P = 0.44$), tryptophan ($P = 0.39$), and phenylalanine ($P = 0.37$) in chicken breast produced from the 3 dietary treatments (Table 7). There were highly significant differences in the content of amino acids methionine ($P = 0.0005$), leucine ($P = 0.0001$), lysine ($P < 0.0001$), and histidine ($P = 0.0005$) in chicken breast from the 3 dietary treatments (Table 7). Chicken breast from broilers fed with the HO-PN and OA diets had significantly higher levels of leucine than the leucine content in chicken breast from control diet–fed broilers. There were significant differences in threonine levels ($P = 0.03$) among dietary treatments, with chicken breast produced from broilers fed with the HO-PN diet having significantly higher levels of threonine relative to that produced from the controls, with similar levels of threonine between chicken breast from broilers fed with the HO-PN diet and that from those fed with OA diet (Table 7). Nevertheless, although there were differences in the amino acid content of

Table 8. Fatty acid profile of chicken breast from broiler chickens fed with a high-oleic peanut– or oleic acid oil–supplemented diet[1].

Dietary treatments[2]	Control	HO-PN	OA	*P*-value
Palmitic acid (16:0), %	24.84 ± 0.7^{a}	19.41 ± 0.7^{b}	16.23 ± 0.3^{c}	<0.0001
Stearic acid (18:0), %	7.66 ± 0.4^{a}	6.13 ± 0.3^{b}	5.50 ± 0.2^{b}	0.0002
Oleic acid (18:1, cis), %	35.89 ± 2.5^{b}	55.12 ± 1.7^{a}	55.29 ± 0.6^{a}	<0.0001
Elaidic acid (18:1, trans), %	0.67 ± 0.15^{a}	0.02 ± 0.01^{b}	0.51 ± 0.13^{a}	0.0001
Linoleic acid (18:2), %	17.04 ± 1.4^{a}	10.63 ± 0.8^{b}	13.58 ± 0.2^{a,b}	0.0005
α-Linolenic acid (18:3), %	0.77 ± 0.1^{a}	0.37 ± 0.05^{b}	0.39 ± 0.01^{b,}	0.0009
Margaric acid (17:0), %	0.25 ± 0.04^{a}	0.09 ± 0.02^{c}	0.17 ± 0.01^{b}	0.0007
Myristic acid (14:0), %	0.52 ± 0.01^{a}	0.33 ± 0.03^{c}	0.42 ± 0.01^{b}	<0.0001
Gondoic acid (20:1), %	0.28 ± 0.02^{c}	0.78 ± 0.06^{a}	0.43 ± 0.02^{b}	<0.0001
Lignoceric acid (24:0), %	0.78 ± 0.2^{a}	0.43 ± 0.03^{b}	0.23 ± 0.1^{c}	0.001

^{a,b}Means within the same row lacking a common superscript differ significantly ($P < 0.05$).
Each value represents the treatment average mean ± standard error of the mean.
[1]At day 42, all body weights (BW) were collected, and broiler selection for processing was determined by individual BW within one-half a standard deviation of the experiment 42-D mean BW, with one bird selected per pen (10 replicate pens per treatment, 3 treatments, 10 birds selected per treatment, yielding a total sample size of 30 birds) for processing and proximate analysis.
[2]Isocaloric, isonitrogenous experimental diets: conventional corn and soybean diet (Control), high-oleic peanut + corn diet (HO-PN), or control diet spiked with 6% oleic acid oil (OA).

chicken breast produced from broilers fed with the control, HO-PN, or OA diets, the levels of all essential amino acids in chicken breast produced from broilers fed with all dietary treatments were adequate.

The major muscle lipids found within chicken meat are (18:1) oleic acid, (16:0) palmitic acid, (18:2) linoleic acid, (18:0) stearic acid, and (20:4) arachidonic acid (Zhao et al., 2011; Amorim et al., 2016). Saturated fatty acid content (palmitic acid, $P < 0.0001$; stearic acid, $P = 0.0002$; margaric acid, $P = 0.0007$; myristic acid, $P < 0.0001$; and lignoceric acid, $P = 0.001$) was significantly higher in chicken breast produced from broilers of the control group, than in chicken breast produced from broilers of the HO-PN and OA dietary treatment groups (Table 8). In parallel, the broiler control grower feed sample had the highest content of saturated fatty acids relative to the broiler grower diets of the HO-PN and OA dietary treatment groups (Table 4). Saturated fatty acids contain no chemical double bonds within the carbon backbone, are saturated with hydrogen molecules, and are found chiefly in meats, animal fat, and butterfat (Milićević et al., 2014). Studies have demonstrated that higher dietary intakes of saturated fatty acids are positively correlated with increased risk of coronary heart disease (Zong et al., 2016) and elevated blood low-density lipoprotein cholesterol levels (Mensink et al., 2003).

The saturated fatty acid lignoceric acid (24:0) is a very-long-chain fatty acid (Dhaunsi et al., 2005), with a chemical formula of $C_{24}H_{48}O_2$, and is found in small amounts in natural fats and wood tar. Interestingly, lignoceric acid is found in small concentrations (1.1–2.2%) in peanut oil (Beare-Rogers et al., 2001). Thus, significantly enhanced levels of lignoceric acid would be expected in chicken breast of broilers fed with the HO-PN and OA diets. In contrast, chicken breast from broilers of the OA group had significantly less lignoceric acid content than that from those of the other treatment groups, and chicken breast from broilers fed with the HO-PN diet had significantly lower levels of saturated lignoceric acid than that from the controls ($P = 0.001$, Table 8). Feeding studies have demonstrated that the presence of saturated fatty acids in poultry meat is greatly dependent on their presence in the diet and/or synthesis in the liver (Sheehy et al., 1993; Milićević et al., 2014). It has been shown that hepatic saturated fatty acid synthesis is inhibited during the digestion of dietary unsaturated fatty acids by inhibiting the activity of the hepatic 9-desaturase complex, thus reducing body fat composition in poultry (Sim and Qi, 1995).

Monounsaturated oleic acid (18:1, cis) content was significantly higher in chicken breast from broilers fed with the HO-PN and OA diets than in those from the controls ($P < 0.0001$), while the oleic acid content was similar in chicken breast produced from broilers fed with the HO-PN and OA diets (Table 8). Trans-fat elaidic acid (18:1, n9 trans) content was significantly reduced in chicken breast from broilers of the HO-PN group relative to that from those of the control and OA groups ($P = 0.0001$, Table 8). Gondoic acid (20:1) content was significantly different among all treatment groups ($P < 0.0001$), with gondoic acid content the highest in chicken breast produced from broilers fed with the HO-PN diet, the lowest in chicken breast produced from broilers fed with the control diet, at intermediate levels in chicken breast from broilers fed with the OA diet (Table 8).

Oleic acid (18:1), elaidic acid (18:1, n9 trans), gondoic acid (20:1), and nervonic acid (24:1) all belong to a family of unsaturated fatty acids known as omega-9 fatty acids, with a carbon-carbon bond at the omega-9 position, and are commonly found in animal fat and vegetable oil, peanut oil, and tree nut oils (Kris-Etherton, 1999). In this study, we demonstrate that chicken breast from broilers fed with the HO-PN and OA diets had significant ($P < 0.001$) enhancement in oleic acid and gondoic acid content relative to that from the controls (Table 8). In parallel, previous feeding studies have also demonstrated dietary fat content to be positively correlated with the fat content of the meat and carcass

of monogastric animals including chickens (Tuunainen et al., 2016; Semwogerere et al., 2019)

Unlike omega-3 and omega-6 fatty acids, omega-9 fatty acids are not essential fatty acids and can be synthesized in the human body from stearic acid via a reaction catalyzed by Δ9-desaturase (Delgado et al., 2017). Today, there is considerable debate regarding the health implications of omega-9 dietary intake (oleic, gondoic, and nervonic acid). In 2006, the American Heart Association recommended that <20% of the total dietary energy should be in the form of these monounsaturated fatty acids. In contrast, the National Institutes of Medicine (2005) stated, "There is no evidence to indicate that monounsaturated fatty acids (oleic, gondoic and nervonic acid) are essential in the diet and have no known preventative role in disease prevention." Yet studies by Schwingshackl and Hoffmann (2014) reported that dietary monounsaturated fatty acids (oleic, gondoic, and nervonic acid) reduced the overall risk of all-cause mortality (11%), cardiovascular mortality (12%), cardiovascular events (9%), and stroke (9%) collectively from 32 cohort studies with 841,211 subjects.

Elaidic acid (18:1, n9 trans) is the most commonly found trans-fat in hydrogenated vegetable oils and has been shown to increase serum lipids, low-density lipoprotein cholesterol, and total cholesterol and increase the risk of cardiovascular disease (Mauger et al., 2003). However, trans-unsaturated fatty acids are commonly prepared during the partial hydrogenation of vegetable oils within the food manufacturing industry to enhance shelf life, thermal stability, and the flavor profile of the foods produced. Both oleic acid and elaidic acid are 18-carbon fatty acids with a single double bond. However, oleic acids have a cis-double bond arrangement, in which the hydrogen atoms are positioned on the same side as the double bond, creating a kink in the linear structure, whereas elaidic acid has hydrogen atoms on opposite sides of the double bond at the 9 carbon, resulting in a linear structure, more similar to that of saturated fatty acids (Mozaffarian et al., 2006), hence altering the physiological properties and biological effects of elaidic acid when consumed in the diet (Han et al., 2002; Baer et al., 2004). Thus, current dietary guidelines recommend the avoidance of trans-fat and limiting the intake of saturated fats to less than 10% of daily caloric intake (U.S. Health and Human Services, USDA, 2015).

Polyunsaturated fatty acids contain more than one double bond within the hydrocarbon chain, appearing at the third (n-3) or sixth (n-6) position from the omega (n) end, omega-3 fatty acids predominately found within fish and omega-6 fatty acids found mainly in vegetable oils (Catalá, 2013). In this study, linoleic acid (18:2) content was significantly higher in chicken breast produced from broilers fed with the control diet ($P = 0.0005$), with similar contents between chicken breast produced from broilers fed with the control and OA diets (Table 8).

Generally, conventional chicken breast are considered to be nutritionally rich with high-quality, highly digestible proteins, iron, zinc, and copper (Marangoni et al., 2015). However, this study demonstrates that the meat of chicken breast can be enriched with unsaturated fatty acids by feeding meat-type chickens (broilers) with whole unblanched HO-PN and/or oleic acids during market production. Moreover, this study demonstrates that feeding broiler chickens with a diet containing whole unblanched HO-PN also reduces the content of trans-fat elaidic acid in chicken breast meat produced in comparison with conventional chicken breast meat. In summary, this study helps to validate the use of whole unblanched HO-PN as a valuable feed ingredient for broiler chickens and/or meat-type chickens as a means to enrich the meat produced with unsaturated fatty acids without adversely altering the protein and/or amino acid content of the meat produced.

ACKNOWLEDGMENTS

The authors would gratefully like to acknowledge the following for their contributions to this study: students and staff of the Prestage Department of Poultry Science, North Carolina State University; staff of the North Carolina State University Feed Mill; Birdsong Peanuts for donation of high-oleic peanuts; and the students and staff of the Market Quality & Handling Research Unit-Agricultural Research Service. This work was supported by funds from the North Carolina Peanut Growers Association (Funding Source 572099-87361) and the Market Quality & Handling Research Unit-Agricultural Research Service-United States Department of Agriculture (CRIS Project Number 6070-43440-011-00D).

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