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Research Article
The Effect of Feeding a Sweet Potato and/or High-Oleic Peanut Diet on Layer Performance and the Quality and Chemistry of Eggs Produced

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Abstract

Background and Objective: Demand for high energy poultry feed ingredients has increased with increased competition. Hence in this study we aimed to examine the effect of high oleic peanuts (HOPN) and sweet potato by-products (SWP) on hen production and egg quality. **Materials and Methods:** Seven hundred twenty hens were fed one of 5 treatments for 6 weeks, a conventional control (C1), a soy protein-isolate control (C2), 4% SWP diet, an 8% HOPN diet and a 4% HOPN+4% SWP diet. Eggs, body and feed weights were collected bi-weekly. Eggs were analyzed for quality and chemistry. All data were analyzed using an ANOVA at $p<0.05$ significance level. **Results:** Hens fed the C2 and HOPN diets produced significantly more eggs ($p<0.01$), relative to the other treatments. There were no treatment differences in body or egg weights. Feed conversion was similar between the HOPN, SWP and SWP+HOPN diets. At week 4 and 6, SWP eggs had increased egg yolk color relative to the HOPN and SWP+HOPN treatments ($p<0.01$). Stearic fatty acid levels were lowest in eggs produced from hens fed the HOPN and SWP+HOPN diets ($p<0.0001$). **Conclusion:** Egg yolk color may be enhanced with feeding laying hens a SWP supplemented diet relative to a HOPN-containing diet.

Key words: Alternative feed ingredients, high-oleic peanuts, layers, shell eggs, sweet potato by-products

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

As the poultry industry continues to grow, competition for high energy feed ingredients, like corn, has caused an increase in feed costs[1]. Corn is used in many ways including high levels of human consumption, livestock consumption and ethanol production in the United States[2]. The increase in feed costs can cause a decrease in poultry production as well as an increase in cost for the consumer. Some countries that do not have food security have shut down some of their broiler facilities because of the increased feed costs[3]. Because of the shortage of high energy grains, such as corn, it has become imperative to find alternative feed ingredients that can replace these grains without reducing the performance or production or increasing costs. Past research has looked at sweet potato (*Ipomoea batatas*) and how it effects the performance and production of broilers and layers. Sweet potato is thought to be a good candidate because it has similar metabolizable energy levels as corn[4]. Sweet potato storage roots were found to be good sources of carbohydrates, vitamins and β-carotene[5,6]. Research conducted with layers determined that peeled sweet potato meal can replace 75% of corn in the diet without adversely affecting hen performance[7]. Another study demonstrated that 100% replacement of corn in diet with sun dried sweet potato meal did not adversely affect egg production, egg weight, feed intake or eggshell thickness, Haugh unit, or total feed consumed/dozen eggs in a 12-week layer trial[8]. A trial conducted by Hassan and Abd-El Galil[9] looked at different levels of sun-dried sweet potato peel waste (0, 15, 20, 25, 30%) in another 12-week layer trial and they determined that up to 25% of the sweet potato peel waste could replace corn in the diet without negatively affecting layer performance or egg quality. However, final body weights declined with increasing levels of sweet potato peel waste.

North Carolina has ranked as the number 1 sweet potato producing state in the U.S. since 1971, providing nearly 60% of the U.S. annual supply[10]. Sweet potato waste by-products are generated annually in the form of culled whole sweet potatoes or remnants from food manufacture processing. Culled whole sweet potatoes are rejected due to damage during harvest, transportation or storage, inferior size or weight, or damage from insects, or mold, while sweet potato peels and/or chunks from whole sweet potato flesh are generated during processing[11], producing approximately 7,000 metric tons of sweet potato waste by-products[12] annually worldwide.

North Carolina also ranks within the top 6 peanut producing states within the United States: Georgia, Florida, Alabama, Texas, North Carolina and South Carolina[13]. In our previous layer feeding trials, we demonstrated the efficacious use of unblanched high-oleic peanuts as a suitable alternate layer feed ingredient to enrich the eggs produced with unsaturated fats, β-carotene and enhanced yolk color[14,15]. Nevertheless, while body weights and feed consumption of hens fed a 24% unblanched high-oleic peanut-containing diet was similar to that of hens fed a control diet containing soy protein isolate, hens fed the high-oleic peanut diet produced significantly less eggs[16]. Therefore, in this study we aimed to compare layer performance (body weights, feed intake and egg production) between a conventional control layer diet of defatted soybean meal and yellow corn to a control diet containing defatted soybean meal, yellow corn and soy protein isolate. Also, we aimed to determine the effect of sweet potato by-products on layer performance and the quality and chemistry of the eggs produced. Moreover, we aimed to determine the effects of feeding one-third of the previous inclusion level of unblanched high-oleic peanuts in the diet (8%) of layers to determine the effects on layer production performance, egg chemistry and quality.

MATERIALS AND METHODS

The procedures used in these studies were approved by the North Carolina State University Institutional Animal Care and Use Committee (IACUC No. 17-001A) following an accredited internal research animal protocol review in accordance with the standards within the "Guide for the Care of Use of Agricultural Animals in Research and Teaching" set forth by the American Dairy Science Association, the American Society of Animal Science and the Poultry Science Association.

Experimental design, animal husbandry and dietary treatments: This study was conducted at the North Carolina Department of Agriculture and Consumer Services Piedmont Research Station facility in Salisbury, NC (USA) for the routine rearing breeding of egg laying hens and egg production. Prior to the onset of this study, all experimental protocols and procedures were approved by the North Carolina State University Institutional Animal Care and Use Committee (IACUC No.19-761-A, approved 11/27/2019, expires 11/27/2022). Seven hundred and twenty Shaver laying hens (28 to 34 weeks of age) were randomly assigned to one of the five dietary treatments (144 hens per treatment), with four

replicates of thirty-six birds each. Hens were housed in two Conventional Tri-Deck Stacked Layer Cage Systems with 66.04×121.92 cm^2 (26×48 in^2) per cage, with 18 birds per cage allowing a space of 447.31 cm^2 per hen. Each cage unit consisted of two rows, with 2 cages per upper and lower row with a treatment replicate of 36 hens on each row, for a total of 4 replicates per treatment. Each row had a feeding trough measuring 48 inches (122 cm) in length and 21 inches (53.34 cm) in height. The study was conducted in a standard height, windowless enclosed ventilated house.

Throughout the feeding trial, birds were provided 14 L:10 D and feed and water *ad libitum* for 6 weeks. Pen body and feed weights were recorded once every two weeks. Shell eggs were collected and enumerated daily from each pen and replicate and totaled each week. Total number of eggs produced per replicate for each treatment was calculated for the total 6 week feeding trial. The average feed conversion ratio (FCR) was calculated as:

$$\text{Total feed} = \frac{\text{Consumed over the 6-week feeding trial (kg)}}{\text{Total dozens of eggs}}$$

Five experimental diets were formulated in Concept 5 (level 2, version 10.0) to be isocaloric (2,922 kcal kg^{-1}) and isonitrogenous (19.5% crude protein) with an estimated particle size between 800 and 1000 µm (Table 1). All experimental diets were prepared with yellow corn and solvent extracted defatted soybean meal. For comparison two experimental control diets were prepared with (Control-2) and without (Control-1) Soy Protein Isolate (ADM, Chicago, Illinois, USA). The sweet potato by-product containing diet (SWP) was prepared using 4% dried Covington sweet potato by-products+solvent extracted defatted soybean meal+yellow corn. Covington sweet potato peelings, skins and small tubers were donated from Yamco, LLC. (Snow Hill, NC). These sweet potato by-products were thawed at 4°C and ground using a Buffalo meat grinder and dried to a moisture level below 10% using blowers at ambient temperatures during the summer months. The nutritional content for dehydrated ground Covington sweet potato by-products was analyzed by ATC Scientific (Little Rock, AR, USA) prior to formulation and preparation of the experimental diets (0.96% crude fat, 11.0% crude protein, 10.4% ash, 66.8% carbohydrates, 102 ppm β-carotene, gross energy 3447 kcal kg^{-1}).

A high oleic peanut experimental diet (HOPN) was prepared using 8% unblanched (skin intact) high-oleic peanuts+solvent extracted defatted soybean meal+yellow corn. An additional experimental diet was prepared using 4% SWP+4% HOPN diet for comparison. Aflatoxin-free

Table 1: Composition of formulated experimental laying hen diets

	Treatments[1]				
Feed ingredient	Control-1	HOPN	SWP	SWP+HOPN	Control-2
	g kg^{-1} DM				
Yellow corn	518	518	465	467	542
Soybean meal	322	278	322	300	288
Calcium carbonate	96	89	96	94	96
Dicalcium phosphate	18	26	18	20	18
SWP	0.0	0.0	40	40	0.0
HOPN	0.0	80	0.0	40	0.0
Sodium chloride	2.5	2.5	2.5	2.5	2.5
L-lysine	0.0	0.8	0.0	0.3	0.2
DL-methionine	1.8	2.0	1.9	1.9	1.7
ADM soy protein[2]	0.0	0.0	0.0	0.0	16
Soybean Oil	37	0.0	51	31	31
Santoquin®[3]	0.5	0.5	0.5	0.5	0.5
Choline chloride	0.5	0.5	0.5	0.5	0.5
Mineral premix[4]	20	20	20	20	20
Vitamin premix[5]	0.5	0.5	0.5	0.5	0.5
Selenium premix[6]	0.5	0.5	0.5	0.5	0.5
ME (kcal kg^{-1})	2922	2922	2922	2922	2922

[1]Five experimental isonitrogenous (19.5% crude protein) diets were formulated: Control-1: Conventional diet containing defatted soybean meal+corn, HOPN: Diet containing 8% unblanched (skin intact) high oleic peanuts+defatted soybean meal+corn, SWP: Diet containing 4% sweet potato by-products (peelings, small tubers)+defatted soybean meal+corn, SWP+HOPN: Diet of 4% sweet potato by-products +4% HOPN+defatted soybean meal+yellow corn, Control-2: Diet containing defatted soybean meal+corn+soy protein isolate. Aflatoxin-free peanuts were used in the preparation of all peanut-containing diets, [2]Soy Protein Isolate: Purchased from ADM, Chicago, Illinois, USA, [3]Santoquin®: Feed antioxidant and preservative to prevent fat oxidation in stored feed (Novus International, St. Charles, MO, USA), [4]Mineral premix provides per kg of diet: Manganese: 120 mg, Zinc: 120 mg, Iron: 80 mg, Copper: 10 mg, Iodine: 2.5 mg and cobalt, [5]Vitamin premix provides per kg of diet: Vitamin A: 13,200 IU, Vitamin D3: 4000 IU, Vitamin E: 33 IU, Vitamin B_{12}: 0.02 mg, Biotin: 0.13 mg, Menadione (K3): 2 mg, Thiamine: 2 mg, Riboflavin: 6.6 mg, d-pantothenic acid: 11 mg, Vitamin B_6: 4 mg, Niacin: 55 mg and Folic acid: 1.1 mg, [6]Selenium premix: 1 mg Selenium premix provides 0.2 mg Se (as Na_2 SeO_3) per kg of diet, ME: Metabolizable energy

unblanched peanuts were used in all peanut-containing experimental diets and crushed using a Roller Mill to form crumbles, prior to inclusion in the finished diets. Each experimental diets were supplemented with vitamin, mineral and selenium premixes manufactured at the NC State University Feed Mill (Raleigh, NC, USA) to meet and/or exceed poultry requirements for vitamins, minerals and selenium. All experimental diets were analyzed by the North Carolina Department of Agriculture and Consumer Services and the Food and Drug Protection Division Laboratory (Raleigh, NC, USA) for aflatoxin and microbiological contaminants. All feed ingredients and feed samples were verified to be free of microbiological contaminants.

Association of Official Analytical Chemists (AOAC)[17]-approved methods for nuts and seeds with crude fat determination using Gravimetric methods for nuts-AOAC[17] 948.22, protein was determined using Kjeldahl method for nuts-AOAC[17] 950.48, mineral was determined by elemental analysis of mineral by atomic absorption spectroscopy, carbohydrates were determined using standard colorimetric assay determination and spectroscopy, enzymatic-gravimetric methods were used for carbohydrate determination (AOAC 991.43[17]), standard bomb calorimetry methods were used to determine gross energy and β-carotene was determined using standard high-performance liquid chromatography and spectrophotometry methods.

Egg quality and grading: Egg quality was conducted at weeks 0, 2, 4 and 6 using a 120 sub-sample of eggs randomly selected from each treatment (6 eggs/replicate) in the Egg Quality Lab, Prestage Department Poultry Science, NC State University (Raleigh, NC, USA). Egg quality parameters measured included shell strength, vitelline membrane elasticity (VME), vitelline membrane hardness (VMH), vitelline membrane work of penetration (VMW), egg weight, albumen height, Haugh unit (HU), yolk color, shell color and shell thickness. Eggshell strength was determined using a texture analyzer (TA-HDplus) with a 250 kg load cell measuring in grams of force. The TA-HDplus has a trigger force of 0.02 kg and a testing speed of 1 mm sec^{-1}. Vitelline membrane strength was determined using the TA.XTplus Texture Analyzer (Stable Micro Systems, Surrey, United Kingdom) with a 1 mm blunt probe with a 5 kg load cell per the manufacturer's instructions. The trigger force was 0.0001 kg with a 3.2 mm sec^{-1} testing speed. Haugh Unit and albumen height were analyzed using the TSS QCD System (Technical Services and Supplies, Dunnington, York, UK). HU is calculated using the following calculation = 100Log (h-1.7w+7.6), with h = egg albumen height and w = weight of egg, with values ranging from 0-130 and HU scores below 60 for un-fresh eggs[18] Yolk color was also determined using the TSS QCD System yolk color scan. Yolk color scan was calibrated using the DSM Yolk Color Fan that determines the color density from lightest to darkest with a range of 1-15[19]. Shell color was determined using refractometry of black, blue and red wavelengths combined to provide a score from 83.3% (white) to 0% (black). USDA shell egg grading and sizing were conducted on a 120 sub-sample of eggs randomly selected from each treatment group (30 eggs/replicate) once every two weeks.

β-carotene, lipid and fatty acid analysis: At week 0 and week 6, a total of 144 eggs were randomly selected, with 16 eggs per treatment (4 eggs randomly selected per replicate) for lipid content (total cholesterol, crude fat and fatty acid profile) and β-carotene analysis by ATC Scientific using AOAC[17] approved methods. Each egg sample was mixed for homogeneity in a Whirl-pak® (Millipore Sigma, St. Louis, MO, USA) bag for 30 sec in a Smasher™ Lab Blender (Weber Scientific, Hamilton, NJ, USA), the homogenous egg sample was pipetted into a 50ml conical tube and frozen at -20°C and stored until analysis within 2 weeks of collection. Frozen homogenous egg samples were shipped on dry ice overnight to vendor for analysis. Total cholesterol, crude fat and fatty acid analysis was conducted using direct methylation methods, as described by Toomer *et al.*[14]. Total cholesterol was measured as mg cholesterol/100 g sample weight (feed or egg), while crude fat was measured as a percentage of gram crude fat/gram sample weight (feed or egg). Fatty acid content was measured as a percentage of gram of fatty acid/gram total lipid content of a sample (feed or egg). Methods used to determine β-carotene content in eggs are detailed in the AOAC[17] 958.05 color of egg yolk method. Egg fat hydrolysis methods were determined using the AOAC[17] method 954.02.

Animal welfare statement: The authors confirm that the ethical policies of the journal have been adhered too and the North Carolina State University's Institutional Animal Care and Use Committee: (#19-761-A) reviewed and approved the policies of the trial.

Statistical analysis: Each treatment replicate (36 hens) served as the experimental unit for all variables (body weights, egg weights, feed intake, total dozens of eggs produced, feed conversion ratio). All performance data were evaluated for significance by one-way analysis of variance (ANOVA) at a

significance level of $p<0.05$ using JMP statistical software (version 15.2.1, SAS, Cary, NC, USA). If ANOVA results were significant ($p<0.05$), a Tukey's multiple comparisons t-test was conducted to compare the mean of each treatment group with the mean of every other treatment at $p<0.05$ significance level. Each egg was used as an experimental unit for analyzing all egg quality measurements (120 eggs per treatment, 30 eggs/replicate at each time point) and egg chemistry data (16 eggs per treatment, 4 eggs/replicate at each time point of collection) including crude fat, total cholesterol, fatty acid profile and β-carotene content.

RESULTS

Dietary treatments and hen performance: Chemical analysis of the experimental diets revealed that diets containing the high-oleic peanuts (HOPN, SWP+HOPN) had higher levels of oleic fatty acid and crude fat relative to the other dietary treatments (Table 2). Dietary levels of calcium and phosphorus of all experimental diets were adequate, meeting the National Research Council[20] nutrient requirements for laying hens for calcium (≈2.0% of 2900 kcal kg^{-1} diet) and phosphorus (≈0.35% of 2900 kcal kg^{-1} diet). Moreover, the high-oleic peanut containing diets (HOPN, SWP+HOPN) had the lowest levels of palmitic and stearic saturated fatty acids relative to the other treatment groups. As expected, the experimental diets containing high-oleic peanuts (HOPN, SWP+HOPN) had the highest levels of oleic fatty acids relative to the other diets.

There were no significant treatment differences in body weights at any of the two-week time points measured (Table 3). Hens fed the control-2 (containing soy-protein isolate) and HOPN diets produced significantly more eggs ($p<0.01$), relative to the other treatment groups over the

Table 2: Chemical analysis of sweet potato and/or peanut-containing layer diets

	Treatments[1]				
	Control-1	HOPN	SWP	SWP+ HOPN	Control-2
Nutrient	g kg^{-1} DM				
Crude fat[2]	56	81	69	81	52
Calcium	28	33	30	22	34
Phosphorous	6.3	7.6	6.2	5.7	6.7
Palmitic acid (16:0)*	122	95	111	99	109
Palmitoleic acid (16:1)*	7.5	6.9	2.0	2.6	3.5
Stearic acid (18:0)*	43	31	42	36	39
Oleic acid (18:1)*	230	593	208	356	219
Elaidic acid (C18:1 trans)*	0.5	0.8	0.3	0.6	0.9
Linoleic acid (18:2)*	510	198	541	416	533
Linolenic acid (18:3)*	62	13	71	50	63
GLA*	0.4	0.7	0.4	0.6	0.6

[1]Dietary treatments: Control-1: Conventional diet containing defatted soybean meal and corn, HOPN: Diet containing defatted soybean meal, corn and 8% unblanched (skin intact) high oleic peanuts, SWP: Diet containing defatted soybean meal, corn and 4% dried sweet potato by-products, SWP+HOPN: Diet containing defatted soybean meal, corn, 4% dried sweet potato by-products and 4% unblanched high-oleic peanuts, Control-2: Diet containing defatted soybean meal, corn and soy protein isolate, Five dietary treatments were chemically analyzed by AOAC-certified lab, (ATC Scientific, Little Rock, AR, USA) using standard AOAC-approved methods,

[2] Crude Fat content: $\frac{\text{g crude fat}}{\text{g total sample weight}} \times 100$, *Fatty acid content = $\frac{\text{g of fatty acid}}{\text{g total lipid content}} \times 100$, GLA: Homo-gamma (ɣ)-linolenic acid (18:3n-6)

Table 3: Body weights of hens fed a sweet potato and/or peanut-containing diet for 6-weeks

	Treatments[1]						
	Control-1	HOPN	SWP	SWP+HOPN	Control-2	SEM	p-value*
	(kg)						
Week 0	1.64	1.64	1.67	1.67	1.62	0.02	0.07
Week 2	1.57	1.58	1.55	1.59	1.57	0.03	0.75
Week 4	1.58	1.66	1.65	1.66	1.62	0.05	0.47
Week 6	1.61	1.64	1.65	1.62	1.64	0.04	0.85

Seven hundred and twenty white Shaver laying hens (28 to 34 weeks of age) were assigned to one of 5 treatments with 4 replicates/treatment and provided feed and water *ad libitum* for 6-weeks. Body weights were recorded once every two weeks for each pen (18 hens per pen), [1]Dietary treatments: Control-1: Conventional diet containing defatted soybean meal and corn, HOPN: Diet containing defatted soybean meal, corn and 8% unblanched (skin intact) high oleic peanuts, SWP: Diet containing defatted soybean meal, corn and 4% dried sweet potato by-products, SWP+HOPN: Diet containing defatted soybean meal, corn, 4% dried sweet potato by-products and 4% unblanched high-oleic peanuts, Control-2: Diet containing defatted soybean meal, corn and soy protein isolate, Each value represents the replicate (36 hens) mean±standard error, *p-value: Statistically significant differences $p<0.05$ by analysis of variance (ANOVA)

Table 4: Production performance of hens fed a sweetpotato and/or peanut-containing diet

Treatments[1]	Total dozen eggs produced	Hen day production[2] (%)	Feed consumed[3] (g bird^{-1} day^{-1})	Mortality[4] (%)	Feed conversion ratio[5] (egg grams/feed g)	Average egg weight[6] (g)
Control-1	120^{b}	92.9^{b}	96.4^{c}	1.74	0.560^{a}	58.100
HOPN	126^{a}	95.9^{ab}	106.2^{a}	0.00	0.526^{b}	58.500
SWP	119^{bc}	92.0^{b}	101.1^{bc}	1.04	0.539^{ab}	58.200
SWP + HOPN	117^{c}	94.1^{ab}	103.2^{ab}	3.13	0.530^{b}	58.200
Control-2	128^{a}	97.9^{a}	102.3^{ab}	0.00	0.559^{a}	58.600
SEM	1.90	1.13	1.29	0.89	0.0097	0.405
p-value	0.006	0.0055	0.0001	0.0909	0.0547	0.349

Seven hundred and twenty white Shaver laying hens (28-34 weeks of age) were assigned to one of 5 treatments with 4 replicates/treatment, 36 birds/replicate and provided feed and water *ad libitum* for 6-weeks. Eggs were collected daily and enumerated and weighed weekly from each replicate pen. Feed intake was calculated weekly for each pen (≈18 hens/pen) per bird, [1]Dietary treatments: Control-1: Conventional diet containing defatted soybean meal and corn, HOPN: Diet containing defatted soybean meal, corn and 8% unblanched (skin intact) high oleic peanuts, SWP: Diet containing defatted soybean meal, corn and 4% dried sweet potato by-products, SWP+HOPN: Diet containing defatted soybean meal, corn, 4% dried sweet potato by-products and 4% unblanched high-oleic peanuts, Control-2: Diet containing defatted soybean meal, corn and soy protein isolate. Each value represents the Mean±standard error, [2]Hen day production: Total number of eggs laid for the 6-week feeding trial/total number of egg-producing birds, [3]Total feed consumed over 6-week feeding trial: total grams feed consumed per treatment/144 birds/42 days, [4]$\text{Mortality}(\%) = \frac{\text{Total No. deaths}}{\text{No. of live chickens per treatment}} \times 100$, [5]$\text{Feed conversion ratio (FCR)} = \frac{\text{Total grams egg weights for each treatment}}{\text{g total feed consumed over the 6-week feeding trial}}$, [6]Average egg weight: Egg weights represent the Mean±standard error of 120 sub-sample of eggs collected once every two weeks with 30 eggs randomly selected from each treatment replicate, *p-value: Statistically significant differences p<0.05 by analysis of variance (ANOVA), [a,b]Means within the same column lacking a common superscript differ significantly (p<0.05)

Table 5: USDA grading of eggs produced from hens fed a sweet potato and/or peanut-containing diet[1]

Treatments	Grade A	Grade B	Cracks	Ex-large	Large	Medium	Small
	----------Percentage (%)[§]----------						
Control-1	96.5	1.88	1.67	5.83	89.0	4.38	0.83
HOPN	96.3	3.13	0.63	4.17	90.0	5.42	0.42
SWP	97.9	0.63	1.46	7.32	86.8	4.39	1.46
SWP+HOPN	96.0	1.88	2.08	4.17	90.6	4.12	0.63
Control-2	98.1	0	1.88	5.00	90.8	3.96	0.21
SEM	1.65	1.65	0.562	2.05	1.61	1.44	0.42
p-value*	0.837	0.705	0.437	0.795	0.423	0.959	0.311

Seven hundred and twenty white Shaver laying hens (28 to 34 weeks of age) were assigned to one of 5 treatments with 4 replicates/treatment and provided feed and water *ad libitum* for 6-weeks. Eggs were collected daily and enumerated and weighed weekly for each pen (18 hens housed/pen). Once every two weeks (week 0, 2, 4, 6), a sub-sample of 120 eggs (30 eggs/replicate) per treatment were assessed for USDA grading and sizing for a total 480 eggs, [1]Dietary treatments: Control-1: conventional diet containing defatted soybean meal and corn, HOPN: Diet containing defatted soybean meal, corn and 8% unblanched (skin intact) high oleic peanuts, SWP: Diet containing defatted soybean meal, corn and 4% dried sweet potato by-products, SWP+HOPN: Diet containing defatted soybean meal, corn, 4% dried sweet potato by-products and 4% unblanched high-oleic peanuts, Control-2: Diet containing defatted soybean meal, corn and soy protein isolate, [§]Percentage of the 480 egg sub-sample per treatment, *p-value: Statistically significant differences p<0.05 by analysis of variance (ANOVA)

6-week feeding trial (Table 4). Interestingly, in this study egg production was not similar between the control groups, with control-1 group producing less eggs than those of the control-2 treatment. Hens fed the SWP+HOPN experimental diet produced the least number of eggs over the 6-week feeding trial.

Hen egg production was only significantly different between hens of the control-2 treatment group relative to the control-1 and SWP treatment groups, with a greater egg production rate in the control-2 treatment group ($p<0.01$). Hens fed the HOPN diet consumed more feed (grams feed bird^{-1} day^{-1}) relative to hens fed the control-1 and SWP treatment groups over the 6-week feeding trial ($p\leq0.0001$). There were no significant treatment differences in mortality rates between the treatment groups over the 6-week feeding trial (Table 4). However, the feed conversion ratio (FCR) was higher and thus better for hens fed the control treatment groups (control-1, control-2), relative to the HOPN and SWP+HOPN ($p = 0.0547$) treatment groups. FCR was similar between hens fed the HOPN, SWP and SWP+HOPN treatment groups over the 6-week feeding trial. There were no significant treatment differences in the average egg weights over the 6-week feeding trial.

USDA grading and egg quality: There were no significant treatment differences in the USDA grading or size of eggs sub-sampled once every two weeks, with greater than 96% of all eggs categorized as USDA Grade A eggs (Table 5). More than 86% of all eggs sub-sampled biweekly were large size eggs, with less than 7% extra-large and 2% small sized eggs produced. At the onset of the study (week 0), there were significant treatment differences in vitelline membrane elasticity (VME) and shell thickness egg quality parameters ($p<0.05$) only (Table 6). However, by week 2 of the study, there

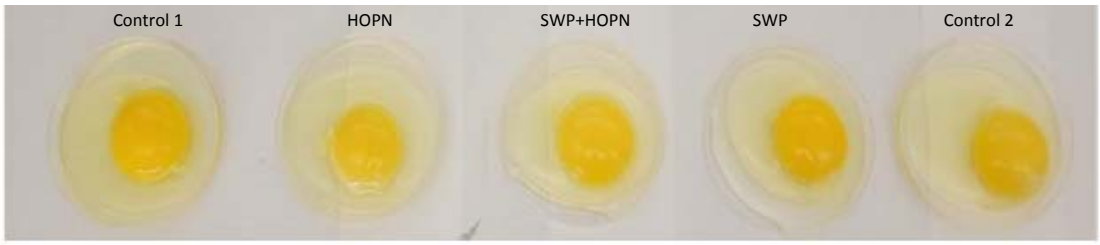

Fig. 1: Representative images of yolk color from whole egg samples from each treatment group at week 6 of the feeding trial
A Total of 720 white shaver laying hens (28-34 weeks of age) were assigned to one of 5 treatments with 4 replicates/ treatment and provided feed and water *as libitum* for 6 weeks. At 6-weeks, one whole egg was randomly selected for this photograph as a representative of yolk color observations seen on the day of egg processing with 120 eggs per treatment. This image is not representative of any other egg quality parameters measured. Dietary treatment: Control 1: conventional diet containing defatted soybean meal and corn, HOPN: Diet containing defatted soybean meal, corn +8% unbalanced (skin intact) high oleic peanuts, SWP+HOPN: Diet containing defatted soybean meal, corn and 4% dried sweet potato by products, Control-2: Diet containing defatted soybean meal, corn and soy protein isolate

were significant treatment differences in albumen height, Haugh unit, yolk color and shell thickness. Albumen height was similar between the control groups (control-1, control-2) and the albumen height of eggs produced from hens fed the control-1 was significantly greater than the albumen height of eggs produced from hens fed the other treatment groups. At week 2, egg Haugh Unit (HU) was also similar between the control groups (control-1, control-2), while HU was statistically similar between the control-2, HOPN and SWP treatments groups. Egg HU was significantly different between the control-1 and SWP+HOPN treatments at week 2 ($p<0.01$), with lower HU in eggs from the SWP+HOPN treatment group in comparison to control-1 eggs. At week 2, egg yolk color was significantly greater in eggs produced from hens fed the SWP treatment group in comparison to eggs produced from hens fed the HOPN and SWP+HOPN treatment groups ($p<0.01$), however egg yolk color was similar between the SWP and control treatment groups (control-1, control-2). Egg shell thickness was significantly different and greater in eggs produced from hens fed the SWP diet in comparison to the eggshell thickness of eggs produced from the HOPN treatment at week 2 ($p<0.05$).

At week 4 and 6 (Fig. 1 week 6), eggs produced from hens fed the SWP treatment had increased egg yolk color relative to the HOPN containing treatment groups (HOPN, SWP+HOPN). At week 4 of the feeding trial, eggs produced from hens fed the SWP diet had greater yolk color scores relative to the HOPN and SWP+HOPN treatment groups ($p\leq0.001$), while egg yolk color was similar between the control (control-1, control-2) and SWP treatment groups. At week 6, eggs produced from hens fed the SWP treatment had significantly greater yolk color than eggs produced from hens fed the SWP+HOPN treatment group only (Table 6), while egg yolk color was similar between the other treatment groups ($p<0.01$).

Egg chemistry: At the onset of the study (week 0), eggs in the HOPN had significantly greater palmitic acid levels (Table 7), relative to the SWP and SWP+HOPN treatment groups, while levels were similar between the HOPN and control (control-1, control-2) treatment groups ($p\leq0.001$). Also, at week 0, egg linoleic acid levels were significantly greater in control-1 and HOPN treatment groups, relative to the SWP treatment group ($p\leq0.01$). There were no significant treatment differences in egg fatty acid, crude fat, total cholesterol, or β-carotene levels at week 0 of the study. There were significant treatment differences in egg stearic acid ($p<0.0001$), linoleic acid ($p<0.0001$), total omega 3 fatty acids ($p<0.001$) and nervonic acid ($p<0.0001$) levels at week 6 of the feeding trial (Table 7). Similar to our previous studies Toomer *et al.*[14], saturated stearic fatty acid levels were lowest in eggs produced from hens fed the high-oleic peanut containing diets, (HOPN and SWP+HOPN) treatment groups, relative to eggs from the SWP treatment group at week 6. Eggs produced from hens fed the SWP and control-1 diets had significantly higher levels of linoleic acid in comparison to eggs from the HOPN, SWP+HOPN and control-2 treatment groups at week 6. Interestingly, eggs produced from hens fed the SWP diet had significantly higher omega 3 fatty acid levels compared to the HOPN and control-2 treatment groups. At week 6, nervonic acid levels were significantly higher in eggs produced from hens fed the control-1, SWP and SWP+HOPN treatment groups in comparison to eggs from the HOPN and control-2 treatment groups (Table 7).

Table 6: Quality of eggs produced from hens fed a control of sweet potato and/or peanut-containing diet

	Treatment[1]						
	Control-1	HOPN	SWP	SWP+HOPN	Control-2	SEM	p-value*
Week 0							
Shell Sth. (g force)	5298	5011	5592	5275	5442	219	0.107
VME (mm)	0.29^{a}	0.27^{ab}	0.25^{b}	0.26^{b}	0.26^{b}	0.01	0.004
VMH (g)	2.18	1.94	2.17	2.02	2.12	0.13	0.289
VMW (g sec^{-1})	1.70	1.48	1.72	1.49	1.68	0.16	0.334
Shell color (%)	82.3	83.3	82.0	83.8	84.7	1.14	0.130
Albumen Ht. (mm)	8.15	8.49	8.68	7.94	8.45	0.30	0.110
Haugh unit (HU)	90.9	92.5	94.0	89.5	92.3	1.6	0.060
Yolk color (1-15)	5.88	6.17	6.29	6.46	6.21	0.21	0.090
Shell thick (mm)	0.37^{b}	0.38^{b}	0.44^{a}	0.38^{b}	0.44^{a}	0.01	<0.0001
Weeks 2							
Shell Sth. (g force)	5473	5350	4936	5457	5432	301	0.352
VME (mm)	0.235	0.232	0.248	0.235	0.241	0.01	0.477
VMH (g)	2.45	2.40	2.25	2.38	2.22	0.17	0.690
VMW (g sec^{-1})	1.96	1.94	1.78	1.91	1.75	0.19	0.733
Shell color (%)	83.3	81.6	83.5	83.1	83.2	0.79	0.144
Albumen Ht. (mm)	8.85^{a}	8.47^{b}	8.68^{b}	8.08^{b}	8.73^{ab}	0.25	0.015
Haugh unit (HU)	94.7^{a}	92.6^{ab}	93.9^{ab}	90.5^{b}	94.4^{a}	1.3	0.007
Yolk color (1-15)	6.83^{ab}	6.50^{b}	7.13^{a}	6.54^{b}	6.88^{ab}	0.18	0.003
Shell thick (mm)	0.39^{ab}	0.37^{b}	0.39^{a}	0.39^{ab}	0.39^{ab}	0.01	0.022
Week 4							
Shell Sth. (g force)	5466	5582	5629	5336	5554	187	0.550
VME (mm)	0.217	0.222	0.225	0.217	0.226	0.01	0.473
VMH (g)	2.31	2.48	2.29	2.26	2.32	0.15	0.604
VMW (g sec^{-1})	1.91	2.09	1.89	1.84	1.91	0.18	0.691
Shell color (%)	84.7	85.0	85.6	85.3	85.5	0.45	0.249
Albumen Ht. (mm)	8.71	8.61	8.48	8.37	8.43	0.213	0.490
Haugh unit (HU)	93.5	93.0	91.6	91.8	92.0	1.21	0.436
Yolk color (1-15)	6.96^{ab}	6.67^{b}	7.25^{a}	6.17^{b}	7.08^{ab}	0.15	0.001
Shell thick (mm)	0.397	0.396	0.396	0.393	0.393	0.01	0.918
Week 6							
Shell Sth. (g force)	5252	5164	5487	5508	5282	273	0.649
VME (mm)	0.214	0.226	0.227	0.222	0.217	0.01	0.531
VMH (g)	2.29	2.40	2.28	2.45	2.20	0.13	0.343
VMW (g sec^{-1})	1.89	2.02	1.80	2.06	1.77	0.17	0.317
Shell color (%)	83.7	84.1	83.8	83.6	84.3	0.76	0.825
Albumen Ht. (mm)	8.34	8.26	8.16	8.48	8.33	0.23	0.740
Haugh unit (HU)	91.5	90.9	90.0	91.9	91.5	1.18	0.503
Yolk color (1-15)	6.92^{a}	6.50^{ab}	7.00^{a}	6.33^{b}	6.79^{ab}	0.19	0.003
Shell thick (mm)	0.394	0.383	0.383	0.382	0.388	0.01	0.403

[1]Dietary treatments: Control-1: Conventional diet containing defatted soybean meal and corn, HOPN: Diet containing defatted soybean meal, corn and 8% unblanched (skin intact) high oleic peanuts, SWP: Diet containing defatted soybean meal, corn and 4% dried sweet potato by-products, SWP+HOPN: Diet containing defatted soybean meal, corn, 4% dried sweet potato by-products and 4% unblanched high-oleic peanuts; Control-2=diet containing defatted soybean meal, corn and soy protein isolate, 720 white Shaver laying hens (28-34 weeks of age) were assigned to one of 5 treatments with 4 replicates/treatment and provided feed and water *ad libitum* for 6-weeks. Bi-weekly at 120 sub-sample of eggs were collected from each treatment group for quality assessment using technical services and supplies QCD system, with calibration with the DSM color Fan for yolk color, Yolk color: Index 1-15 (lightest to darkest color intensity), Shell Sth: Shell strength; VME: vitelline membrane elasticity, VMH: Vitelline membrane hardness, VMW: Vitelline membrane work of penetration, Albumen Ht.: Albumen height, Shell thick: Shell thickness. Each value represents the bi-weekly average ±the standard error with 120 eggs/treatment, *p-value: Statistically significant differences p<0.05 by analysis of variance (ANOVA), [a,b]Means within the same column lacking a common superscript differ significantly (p<0.05)

DISCUSSION

In this study hens fed the soy protein containing control diet and the HOPN (8%) diets produced significantly more total dozens of eggs with similar egg weights, in comparison to the other treatments. However, in our previous peanut and peanut by-product layer feeding trials, hens fed the unblanched high-oleic peanut supplemented diet (24%) produced significantly less eggs with reduced egg weights relative to the control group containing soy-protein isolate[16].

Table 7: The β-carotene, lipid and fatty acid analysis of eggs produced from hens fed a sweet potato and/or peanut-containing diet

	Treatments[1]						
	Control-1	HOPN	SWP	SWP+HOPN	Control-2	SEM	p-value*
Week 0							
Crude fat %[2]	5.2	4.3	5.4	5.5	6.4	0.78	0.169
Palmitic (%) (16:0)	22.7^{ab}	23.2^{a}	21.2^{b}	21.6^{b}	22.2^{ab}	0.47	0.001
Stearic (%) (18:0)	9.2	9.6	9.1	9.0	9.3	0.23	0.142
Oleic (%) (18:1)	28.4	29.6	27.5	28.1	28.8	0.68	0.33
Elaidic (%)(C18:1trans)	0.18	0.09	0.23	0.21	0.10	0.06	0.09
Linoleic (%) (18:2)	24.3^{a}	24.5^{a}	22.5^{b}	23.4^{ab}	23.9^{ab}	0.57	0.01
Omega 3 (%) (18:3)	1.8	1.6	1.9	2.0	1.7	0.18	0.10
Nervonic (%) (24:1)	1.0	1.1	1.1	1.1	1.2	0.04	0.0483
β-carotene (ppm)	2.20	1.99	1.92	1.83	2.0	0.26	0.70
Cholesterol (mg/100 g)	192	175	184	191	253	36	0.27
Week 6							
Crude fat %[2]	6.1	7.1	5.7	6.6	5.8	0.87	0.46
Palmitic (%) (16:0)	21.4	21.2	21.0	20.6	21.8	0.50	0.15
Stearic (%) (18:0)	8.6^{ab}	7.0^{b}	9.0^{a}	7.9^{b}	8.4^{ab}	0.29	<0.0001
Oleic (%) (18:1)	30.3	37.6	28.2	34.4	37.2	5.0	0.27
Elaidic (%)(C18:1trans)	0.16	6.8	0.16	0.14	0.11	4.6	0.47
Linoleic (%) (18:2)	20.4^{ab}	11.8^{c}	23.7^{a}	19.2^{b}	17.4^{b}	1.4	<0.0001
Omega 3 (%) (18:3)	1.8^{ab}	1.0^{c}	2.0^{a}	1.6^{abc}	1.2^{bc}	0.23	0.0008
Nervonic (%) (24:1)	1.1^{a}	0.73^{c}	1.1^{a}	1.0^{ab}	0.88^{b}	0.05	<0.0001
β-carotene (ppm)	2.4	2.5	2.7	2.7	2.2	0.40	0.65
Cholesterol (mg/100 g)	264	244	212	291	252	33	0.21

Seven hundred and twenty white Shaver laying hens (28-34 weeks of age) were assigned to one of 5 treatments with 4 replicates/treatment and provided feed and water *ad libitum* for 6-weeks, 16 eggs/treatment were chemically analyzed at each time point of collection. Egg samples were chemically analyzed by an AOAC-certified lab, (ATC Scientific, Little Rock, AR, USA) using standard AOAC-approved methods, Each value represents the Mean±standard error, [1]Dietary treatments: Control-1: Conventional diet containing defatted soybean meal and corn, HOPN: Diet containing defatted soybean meal, corn and 8% unblanched (skin intact) high oleic peanuts, SWP: Diet containing defatted soybean meal, corn and 4% dried sweet potato by-products, SWP+HOPN: Diet containing defatted soybean meal, corn, 4% dried sweet potato by-products and 4% unblanched high-oleic peanuts, Control-2: Diet containing defatted soybean meal, corn and soy protein isolate,

[2] Crude fat content = $\frac{\text{g crude fat}}{\text{g total sample weight}} \times 100$, Fatty acid content = $\frac{\text{g of fatty acid}}{\text{g total lipid content}} \times 100$, *p-value: Statistically significant differences $p<0.05$ by analysis of variance (ANOVA), [a,b]Means within the same column lacking a common superscript differ significantly ($p<0.05$)

Hence, suggesting that lower dietary inclusion levels of unblanched high-oleic peanuts does not alter egg production in layers or egg weights. Interestingly, in this study FCR was similar between both control groups (control-1 and control-2) and was improved relative to the other treatment groups, which parallels our previous feeding trial demonstrating improved FCR in the soy protein isolate containing control group[14].

In parallel to our previous peanut layer feeding trials[14-16], there were no major treatment differences on USDA grading or egg quality parameters, apart from egg yolk color in this study. In general egg yolk color score was higher and egg yolks were visibly darker yellow/orange color in eggs produced from hens fed the 4% SWP experimental treatment group relative to the other treatment groups, with exception of the controls. In parallel, Kaya and Yildirim[21] demonstrated that 4% inclusion of dried sweet potato tubers and vines in the diet of layers did not alter yolk pigmentation in comparison to conventional control eggs. In contrast, other studies have shown that feeding sweet potato meal at 50% inclusion in layer diets significantly enhanced yolk pigmentation relative to conventional control eggs[22]. Hence in the future we aim to conduct additional sweet potato waste by-product layer feeding trials at higher inclusion levels to determine the effect on overall egg production, quality and specifically yolk color. In our previous feeding trials[14,15], egg yolk color score was significantly higher and visibly darker in eggs produced from hens fed a 24% unblanched high-oleic peanut diet in comparison to the conventional controls, while in this study yolk color was similar between eggs produced from hens fed the control diets (control-1 and control-2), the 4% sweet potato by-product diet and the 8% unblanched high-oleic peanut diet at week 6. Therefore, suggesting that higher dietary inclusion levels (24%) of unblanched high-oleic peanuts rich in unsaturated fatty acids enriches egg yolk color, while lower dietary inclusion levels (8%) do not alter egg yolk color. In the last decade, consumers have shown a preference in egg yolk color[23], with egg producers catering to this trend using carotenoid-rich feed additives[24] to produce dark yellow/orange yolks.

While stearic saturated fatty acid levels were lowest in eggs from hens fed the HOPN diet, stearic acid levels did not

differ significantly from the controls at week 6 of the feeding trial. Unlike our previous feeding trials[14-16], oleic acid levels were similar between eggs from each treatment group at week 6. Linoleic unsaturated fatty acid levels were highest in eggs produced from the SWP treatment group, however, there were not significantly different from the controls (control 1) at week 6. Lastly, while there were significant treatment differences in the omega 3 and nervonic acid levels in eggs, the content of these fatty acids in the eggs produced were very low (less than 1.2% nervonic acid and less than 2.1% omega 3 acid) at week 6.

CONCLUSION

In conclusion, hen body weights, total number of eggs produced, USDA grade, egg size or egg quality (exception yolk color) were not adversely affected by the inclusion of 4% sweet potato by-products in layer diets with 6 weeks of feeding. Nevertheless, more work needs to be performed to identify optimal inclusion levels of sweet potato by-products in the diet of layers for ideal performance, egg yolk color and chemistry. More importantly, this study supports agricultural sustainability within North Carolina and the US Southeast with the use of agricultural products and waste by-products that are common within these regions as a value-added feed ingredient for poultry and other livestock.

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