Effect of almond hulls on the performance, egg quality, nutrient digestibility, and body composition of laying hens

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ABSTRACT The objective of this study was to evaluate 2 varieties of almond hulls (prime and California type hulls) as an alternative feed ingredient on the performance, egg quality, nutrient digestibility, and body composition using a total of 100 23-week-old Hy-Line W36 hens. Treatments consisted of a control diet based on corn and soybean meal; T2 and T3 were formulated to contain 7.5 and 15% of prime hulls; and T4 and T5 contained 7.5 and 15% of California type hulls. Inclusion of prime hulls and California type hulls had no effects on feed intake, egg laying rate, and feed conversion ratio, but California type hulls at 7.5% decreased ($P < 0.001$) body weight gain compared to the control. Prime hulls at 7.5% and California type hulls at both levels improved ($P \leq 0.022$) AMEn and N digestibility. Both prime hulls and California type hulls had no effects on egg size, specific gravity, Haugh unit, and percentages of yolk, albumen and shell, but yolk color appeared greener and less yellow ($P \leq 0.009$) by prime hulls and less yellow ($P = 0.001$) by California type hulls. For body composition, prime hulls and California type hulls at both levels lowered ($P \leq 0.017$) body fat, and California type hulls at 7.5% decreased ($P = 0.001$) lean weight. In summary, inclusion of prime hulls and California type hulls up to 15% had no negative effect on egg production and egg quality while reduced the body fat percentage and mass.

Key words: almond hull, body composition, egg quality, laying hen, egg production

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INTRODUCTION

As a byproduct from the almond industry, almond hulls account for around 54% of total almond tree fruit production by weight at 2 billion kg during 2018/2019 crop year (Almond Board of California, 2019). Almond hulls have been traditionally used as a feed ingredient in ruminant ration to partially replace alfalfa (Reed and Brown, 1988; Rad et al., 2016), however, the increasing production of almonds has led hulls become a surplus on the market. At the meantime, using alternative feed ingredients in the poultry diet has recently gained more attentions as a consequence of competing for ingredients with biofuel production. Alternative feed ingredients are commonly agricultural byproducts with a high fiber content.

Dietary fiber has been considered as a nutrient diluent in monogastric animals and sometimes regarded as an antinutritional factor (Rougière and Carré, 2010). However, recent studies have revealed some potential benefits from dietary fiber intake, but not restricted to, stimulating gastrointestinal tract development, modulating gut microbiota balance, and increasing short-chain fatty acid production (Jiménez-Moreno et al., 2016; Montoya et al., 2016). The beneficial effect from dietary fiber is related to the fiber source, and insoluble fiber is reported more preferable to improve performance and nutrient digestibility than soluble fiber (Jiménez-Moreno et al., 2009; Chen et al., 2020).

Previous studies have demonstrated that insoluble fibers (hemicellulose, cellulose, and lignin) and fermentable sugars (glucose, fructose, and sucrose) are the major components present in almond hulls (Offeman et al., 2014; Holtman et al., 2015). Sugars presented in almond hulls are reported from 25 to 37%, making it a potential energy source in poultry diet (Sequeira and Lew, 1970; Holtman et al., 2015). The almond hulls are also rich in polyphenols and pigments as antioxidants since they are the pulp of the almond fruit (Esfahlan et al., 2010). The polyphenols extracted from hulls are not only reported

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to have a higher antioxidant activity than vitamin E but also effectively protect DNA from radical-induced scission and chelating metal ions (Takeoka and Dao, 2003; Wijeratne et al., 2006). Additional antioxidants in diet such as vitamin E have been reported to positively influence the egg quality and laying hen performance (Kirunda et al., 2001; Jiang et al., 2013). However, there is little literature on the effect of plant origin antioxidants on laying hen performance and egg quality.

The plant origin antioxidants and pigments, particularly for carotenoids, have been known to deposit into egg yolk (Scott et al., 1968). Thus, laying hens fed with a diet containing almond hulls could have a potential beneficial effect on egg quality. Previous studies on hens fed with high-fiber diets while met the nutrient requirements showed no effects on egg production and quality (Deaton et al., 1977; Roberts et al., 2007; Azizi and Moradi, 2017). Hens are also known more tolerant to the high-fiber diet compared to fast growing broilers (Walugembe et al., 2014).

Thus, we hypothesized that almond hulls could be used in the laying hen diet at higher levels. The nutrient matrix value could be found in our previous report (Wang et al., 2021) showing that broilers fed a diet containing prime or California type hulls at 9% had a similar body weight gain compared to those fed the corn soybean meal control diet. The prime hulls and California type hulls used in the present study have a nitrogen corrected true metabolizable energy (**TMEn**) at 1,624 and 1,514 kcal/kg, respectively. The objective of the present experiment was to evaluate the effect of 2 almond hulls varieties as 2 independent ingredients on laying hen performance, egg production and quality, nutrient digestibility, and body composition.

MATERIALS AND METHODS

The experimental protocol was reviewed and approved by the University of Georgia Institutional Animal Care and Use Committee (A2020 06-007).

Experimental Procedure

The experimental birds were selected from the main laying hen stock in the Poultry Research Center at University of Georgia. A total of 100 Hy-Line W36 laying hens at 23 wk of age were selected and randomly allocated to 5 dietary treatments with 5 replicates and 4 birds each. Hens were individually allocated in metabolic cages (dimension: length × width × height, 47 × 33.5 × 39 cm) in an environmental controlled room with the lighting schedule set at a cycle of 16 h light and 8 h dark. Four consecutive cages in a row were regarded as a replicate. There was 1 wk as an adaptive period by feeding a corn and soybean meal-based control diet prior to an 8 wk period of the main trial. Egg production, body weight, and feed intake of laying hens were measured during the adaptation period to confirm no statistical difference in performance among treatments.

Diets were formulated to meet or exceed the recommendations for Hy-Line W36 hens in the Hy-Line W36 Commercial Hens Management Guide (2016). Five dietary treatments consisted of control diet based on corn and soybean meal; T2 and T3 were formulated to contain 7.5 and 15% of prime hulls in the diet, respectively; and T4 and T5 contained 7.5 and 15% of California type hulls in the diet, respectively. Additional soybean was used in diet containing almond hulls to assure all that 5 experimental diets were isonitrogenous and isocaloric. Formulations and nutrient contents of diets are presented in Table 1. Five treatment diets were individually mixed in a horizontal mixer (Davis Double Ribbon Mixer, Bonner Springs, KS) for 12 min. Chromium dioxide (0.3%) was used as an indigestible marker for determining apparent total tract digestibility of crude protein and nitrogen corrected apparent metabolizable energy (**AMEn**). All 5 treatments feed were sent out to Agricultural and Environmental Services Laboratories in University of Georgia for Ca, total P, and proximate analysis (dry matter, crude protein, ethanol extract, crude fiber, ash, and nitrogen free extract) following the method as indicated by AOAC International (1990). Feed and water were provided ad libitum throughout the experimental period. Hens were checked twice a day for general health and mortality. Egg production was recorded daily. Egg quality, feed intake, and body weight were measured at 28 and 32 wk of age. At 32 wk of age, 2 birds from each replicate were euthanized by cervical dislocation for determining body composition using dual energy X-ray absorptiometry with small animal software (GE Healthcare, Chicago, IL). Feces were collected and pooled within each replicate to determine the apparent total tract nutrient digestibility was measured at 32 wk of age.

Hen Performance and Egg Quality Assessment

Daily egg production was recorded. Feed conversion ratio was calculated as feed consumption per dozen of eggs. Eggs produced over 2 consecutive days (around 40 eggs per treatment) were collected at the end of 28 and 32 wk of age for egg quality measurements following the methods previously described from our lab, including egg weight, specific gravity, Haugh unit, yolk weight, shell weight, and shell thickness (Castro et al., 2019). Briefly, eggs were individually weighed using a precision scale (Ohaus Defender 3000, Parsippany, NJ). The specific gravity of eggs was determined using saline solutions as described by Hamilton (1982). Haugh unit was measured using a Haugh unit device (Ames Haugh Uni Micrometer S-8400, Ames, Waltham, MA).

Egg yolk was separated and weighed. At 32 wk of age, the egg yolk color was analyzed using a portable colorimeter (CR-400 Chroma Meter, Ramey, NJ). Egg shell was washed and dried at 55°C for 24 h to determine the weight. Albumen weight was calculated as egg weight minus yolk and shell weight. The shell thickness was

Table 1. Diet formulation and calculated nutrients (as fed basis).

Item	Control	Prime		California type			
		7.5%	15%	7.5%	15%		
Ingredients (%)						Calculated nutrients (%)	
Corn	47.32	36.39	25.45	36.23	25.00	ME[1], kcal/kg	2850
SBM[1] 48%	31.95	32.88	33.81	32.86	33.80	Crude protein	19.05
DCP[1]	2.39	2.41	2.43	2.42	2.45	L-Lys	1.06
Soybean oil	5.29	7.83	10.37	7.99	10.73	DL-Met	0.60
Limestone	5.69	5.65	5.62	5.66	5.63	TSAA[1]	0.91
Oyster shell	5.69	5.65	5.62	5.66	5.63	L-Thr	0.79
Salt	0.47	0.44	0.44	0.46	0.44	Ca	4.94
DL-Met	0.30	0.31	0.33	0.32	0.34	Nonphytate P	0.58
L-Thr	0.08	0.09	0.10	0.09	0.12		
Almond hulls	0	7.5	15	7.5	15		
Cr_2O_3	0.30	0.30	0.30	0.30	0.30		
Sand	0.20	0.20	0.20	0.20	0.27		
Premix[2]	0.33	0.33	0.33	0.33	0.33		
Analyzed nutrients (%)							
GE[1], kcal/kg	3985	4002	4073	4015	4112		
Crude protein	18.81	20.08	19.56	19.56	19.13		
Crude fiber	1.64	2.48	3.52	3.74	5.55		
Ca	4.89	4.94	4.97	4.84	4.99		
Total P	0.74	0.77	0.78	0.77	0.75		

[1]DCP, dicalcium phosphate; GE, gross energy; ME, metabolizable energy; SBM, soybean meal; TSAA, total sulfur amino acids.
[2]Provided per kg of premix: Vitamin A, 2,204,586 IU; Vitamin D_3, 200,000 ICU; Vitamin E, 2,000 IU; Vitamin B12, 2 mg; Biotin, 20 mg; Menadione, 200 mg; Thiamine, 400 mg; Riboflavin, 800 mg; D-pantothenic acid, 2,000 mg; Vitamin B6, 400 mg; Niacin, 8,000 mg; Folic acid, 100 mg; Choline, 34,720 mg; Ca, 0.72 g; Mn, 3.04 g; Zn, 2.43 g; Mg, 0.61 g; Fe, 0.59 g; Cu, 22.68 g; I, 22.68 g; Se, 9.07 g.

measured in 3 different parts of the equatorial region using a gauge (Ames eggshell Thickness Measure Model 25M-5, Ames, Waltham, MA) and taking the average of 3 measurements.

Apparent Total Tract Nutrient Digestibility

Excreta samples were collected from each bird using a metal tray placed below each metabolic cage during 24-h period at 32 wk of age. The samples from each hen were collected over 2 consecutive 12-h periods, pooled together, and dried in a forced air oven at 88°C over 24 h. Excreta samples were ground using a coffee grinder (Kitchen Aid, Benton Harbor, MI). Determination of the chromium concentration in feed and excreta followed the method described by Adhikari et al. (2020). The total tract crude protein digestibility and AMEn were calculated using the following Equation 1. Nitrogen contents in feed and excreta were determined using the LECO system as indicated by AOAC International (2000). Gross energy values in feed and excreta were determined using the bomb calorimeter (IKA C1 Compact Bomb Calorimeter, IKA-Werke., Staufen, Germany).

Nutrient digestibility was calculated using following equation:

$$\text{Nutrientdigestibility} = [1 - (Ci/Co) \times (No/Ni)] \times 100 \quad (1)$$

Where: Ci is the concentration of chromium in the diet; Co is the concentration of chromium in the ileal digesta or feces; Ni is the concentration of the nutrient in the diet; No is the concentration of the nutrient in the ileal digesta or feces; all values were expressed as a percentage of dry matter. AMEn was calculated as using the nitrogen correction factor as 8.22 kcal/g (Sibbald and Slinger, 1963).

Statistical Analysis

Data of egg production, egg quality, nutrient digestibility, body weight (initial body weight was used as a cofactor), and body composition from the prime and California type hulls compared with control were analyzed separately via one-way ANOVA for a completely randomized design using the GLM procedure of SAS 9.4. The initial body weight was used as a cofactor for body weight at wk 28 and 32. Significant differences among the treatments were determined using Tukey's honestly significant difference test. Data were considered significantly different at $P < 0.05$.

RESULTS

Almond Hull and Hen Performance

From the previous report of our lab, the nutrient matrix values of both prime and California type hulls are shown in Table 2 (Wang et al., 2021). No mortality was found during the 8 wk experimental period, and hens in all dietary treatments were able to maintain egg laying rates over 90% (Table 3). During 24 to 32 wk of age, the diets containing prime hulls at both levels had no effects on body weight gain, feed intake, feed conversion ratio, and egg laying rate, whereas the diet containing California hulls at 7.5% decreased ($P \leq 0.001$) final body weight and body weight gain compared to the control, but had no effects on other performance parameters.

Table 2. Nutrient matrix values of almond hulls (air-dry basis, Wang et al., 2021).

Item	Energy (kcal/kg)			Proximate analysis and sugar profile (%)						
	GE	AMEn		CP	DM	EE	Ash	CF	NFE	Sugar
Prime	3,699	1,624		4.80	85.50	1.62	8.54	13.11	57.43	18.14
CA	4,003	1,514		5.01	88.11	1.87	5.98	26.35	48.90	15.89
				Mineral content (ppm)						
	Ca	P	K	Na	Mg	Mn	Fe	Al	Zn	Cu
Prime	2,700	900	36,300	10	0.12	8	173	17	8	6
CA	2,300	800	27,600	10	0.09	9	137	6	6	6
				Indispensable amino acid content (%)						
	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val
Prime	0.13	0.07	0.12	0.20	0.15	0.04	0.13	0.13	<0.02	0.17
CA	0.12	0.07	0.10	0.17	0.14	0.03	0.12	0.11	<0.02	0.15

Abbreviations: CA, California type hulls; CF, crude fiber; CP, crude protein; DM, dry matter; EE, ether extract; GE, gross energy; NFE, nitrogen-free extract; Sugar, fermentable sugar

Table 3. Effect of almond hulls on the performance of laying hens during 24 to 32 wk of age.

Item	Control	7.5%	15%	SEM	*P* value
Prime hull					
Initial BW (g/bird)	1449	1376	1398	10.56	0.176
Final BW (g/bird)	1677	1583	1579	29.03	0.098
BWG (g/bird)	228	207	180	19.64	0.336
FI (g/bird/d)	110	106	112	1.874	0.107
FCR (g/dozen eggs)	1412	1366	1443	24.57	0.145
Egg laying rate (%)	93.9	93.3	93.5	0.603	0.825
California type hull					
Initial BW (g/bird)	1449	1423	1442	28.67	0.831
Final BW (g/bird)	1677^{a}	1465^{b}	1640^{a}	27.71	0.001
BWG (g/bird)	228^{a}	42^{b}	198^{a}	17.19	<0.001
FI (g/bird/d)	110	107	108	1.345	0.193
FCR (g/dozen eggs)	1412	1363	1380	16.92	0.160
Egg laying rate (%)	93.9	94.1	93.7	0.494	0.834

Abbreviations: BW, body weight; BWG, body weight gain; FCR, feed conversion ratio; FI, feed intake; SEM, standard error of the mean with n = 5.
^{a,b}Means within a row with no common superscripts differ significantly ($P < 0.05$).

Table 4. Effect of almond hull on the apparent total tract digestibility of nutrients of laying hens at 32 wk of age.

Items	Control	7.5%	15%	SEM	*P* value
Prime hull					
DM (%)	65.11	65.87	66.36	0.955	0.136
AMEn (kcal/kg)	2958^{b}	3169^{a}	3104^{ab}	34.36	0.022
N digestibility (%)	58.59^{b}	65.92^{a}	62.69^{ab}	1.156	0.020
California hull					
DM (%)	65.11	65.18	66.50	0.907	0.124
AMEn (kcal/kg)	2958^{b}	3233^{a}	3296^{a}	43.83	<0.001
N digestibility (%)	58.59^{b}	63.47^{a}	65.07^{a}	1.064	0.020

Abbreviations: AMEn, nitrogen corrected apparent metabolizable energy; DM, dry matter; SEM, standard error of the mean with n = 5.
^{a,b}Means within a row with no common superscripts differ significantly ($P < 0.05$).

Almond Hull and Nutrient Digestibility

Feeding 7.5% of prime hulls resulted in higher AMEn ($P = 0.022$) and nitrogen digestibility ($P = 0.020$) compared to the control (Table 4). Feeding California type hulls at 7.5 or 15% showed higher AMEn ($P < 0.001$) and nitrogen digestibility ($P = 0.020$) compared to the control.

Almond Hull and Egg Quality

Both prime and California type hulls had no effects on egg weight, egg specific gravity, Haugh unit, yolk weight, shell weight, shell thickness, and albumen weight (Tables 4 and 5). For yolk color, in contrast with the control, the lightness was not affected by prime and California type hulls, but prime hulls at 15% decreased values of a (greener, $P = 0.009$) and b (less yellow, $P < 0.001$), and California type hulls at 15% reduced b ($P = 0.001$).

Almond Hull and Body Composition

The hens fed prime hulls at both levels had lower body fat weight ($P = 0.005$) and body fat percentage

Table 5. Effect of prime hull on the egg quality of Hy-Line laying hens at 28 and 32 wk of age.

Item	Control	Prime hulls		SEM	*P* value
		7.5%	15%		
28 wk of age					
Egg weight (g/egg)	57.78	56.78	58.44	0.808	0.311
Egg specific gravity	1.094	1.092	1.093	0.001	0.520
Haugh unit	101.5	101.9	101.2	0.795	0.864
Yolk weight (g/egg)	13.75	13.98	14.35	0.311	0.349
Shell weight (g/egg)	5.994	5.804	6.038	0.102	0.165
Albumen weight (g/egg)	37.96	36.69	38.05	0.625	0.268
Shell thickness (mm)	0.41	0.40	0.40	0.002	0.117
32 wk of age					
Egg weight (g/egg)	58.76	59.05	59.33	0.785	0.884
Egg specific gravity	1.093	1.095	1.093	0.001	0.160
Haugh unit	105.8	105.6	106.8	1.191	0.767
Yolk weight (g/egg)	14.97	14.19	14.70	0.449	0.491
Shell weight (g/egg)	5.925	5.966	5.866	0.061	0.570
Albumen weight (g/egg)	25.68	22.77	19.90	3.326	0.540
Shell thickness (mm)	0.40	0.41	0.39	0.007	0.371
Yolk color					
Lightness	54.63	53.73	54.60	0.857	0.842
a	-1.01[b]	-1.19[b]	-1.93[a]	0.236	0.009
b	31.72[a]	31.23[a]	26.14[b]	0.629	<0.001

Abbreviations: SEM, standard error of the mean with n = 5; a, difference in red and green (+ = redder, − = greener); b, difference in yellow and blue (+ = yellower, − = bluer).

[a,b]Means within a row with no common superscripts differ significantly ($P < 0.05$).

($P = 0.014$) compared to the control, whereas the lean weight remained uninfluenced (Table 7). The similar pattern was seen on the hens fed California type hulls had lower body fat weight ($P = 0.016$) and percentage ($P = 0.017$) compared to control birds. In addition, hens fed diet containing 7.5% California type hulls had lower ($P = 0.025$) lean weight compared to control birds, but not for those fed at 15%.

DISCUSSION

Almond hulls contain a high amount of fibers similar to other byproducts such as sugar beet pulp, soy hulls or coffee husks. To date, there is little knowledge on effect of almond hulls on laying hen performance and egg quality. Hens are more tolerant to dietary fibers, and diets containing 3.12 to 3.88% of crude fiber mainly from sugar beet pulp linearly increased feed intake and egg production of hens during 25 to 33 wk of age (Selim and Hussein, 2020). In the present study, hens fed 7.5 to 15% of almond hulls in the diet, equivalent to 2.48 or 5.55% of crude fiber, had no negative effects on egg production, which was in agreement with previous studies that the egg production was not influenced by the high fiber inclusion rate (Vargas and Naber, 1984; Courtney Jones et al., 2013).

In contrast with the control, hens responded differently to the diet containing prime or California type hulls at 7.5% on body weight, which could be due to the higher fiber content of California type hulls (26%) compared to prime hulls (13%). Similar results were found in literature that fibers from soy hulls or coffee husks (higher content of pectin) reduced the hen body weight, but did not influence egg production (Sousa et al., 2019). The final body weight, fat weight and lean weight reduction for layers feeding diets with 7.5% California type hulls could be a sign of potential negative effect, because the layer body weight is less than the recommended curve from Hy-Line W-36 Commercial Layer Management Guide (2016) at 32wk (1.50−1.54 kg). In addition, the lean weight reduction for layers feeding 7.5% California type hulls is another sign of potential negative effect. However, the reduction of bodyweight and lean weight was alleviated when California type hulls content increased to 15%. A plausible explanation is that as inclusion of almond hulls in the diet was increased, the oil content was increased as well to make diets isocaloric; higher oil content in 15% California type hulls alleviated the negative effects of high almond hull inclusion in hen diets. Because extra oil in the feed is known to increase the growth and nutrient utilization, the beneficial effect from oil outweighs the negative effect from California type hulls. Thus, there was a recovery on layer body weight and lean weight in hens fed 15% California type hulls. The dietary fibers in almond hulls are a mixture of soluble and insoluble fibers including pectin, hemicellulose, cellulose, and lignin (Holtman et al., 2015), which may be the greatest contributor for the body weight change. Vegetable oils are commonly used in laying hen diet to balance the dietary energy level when supplementary ingredients contained a high fiber content, however, in practice, farmers need to further integrate these from aspects of economics, health, and environment.

Meanwhile, the AMEn and N digestibility were increased for the hens fed diets containing 7.5% of prime and California type hulls, however, there was no difference in apparent digestibility of dry matter when a higher fiber content was included in the diet, and the dietary high oil may be a major contributor on the benefits of body weight

Table 6. Effect of California type hull on the egg quality of Hy-Line laying hens at 28 and 32 wk of age.

Item	Control	California type hulls		SEM	*P* value
		7.5%	15%		
28 wk of age					
Egg weight (g/egg)	57.78	57.16	58.22	0.758	0.629
Egg specific gravity	1.094	1.0933	1.093	0.001	0.962
Haugh unit	10.48	10.14	10.01	0.229	0.377
Yolk weight (g/egg)	101.5	100.3	99.48	0.909	0.345
Shell weight (g/egg)	13.75	14.13	13.98	0.326	0.727
Albumen weight (g/egg)	5.994	5.894	5.914	0.059	0.554
Shell thickness (mm)	37.96	37.17	38.02	0.642	0.601
32 wk of age					
Egg weight (g/egg)	58.76	57.92	60.28	0.882	0.236
Egg specific gravity	1.093	1.091	1.093	0.001	0.168
Haugh unit	105.8	105.4	106.6	1.306	0.825
Yolk weight (g/egg)	14.97	14.61	14.88	0.386	0.815
Shell weight (g/egg)	5.925	5.856	6.000	0.097	0.649
Albumen weight (g/egg)	25.68	20.11	20.20	3.318	0.481
Shell thickness (mm)	0.40	0.39	0.40	0.005	0.809
Yolk color					
Lightness	54.63	54.57	54.73	0.421	0.969
a	-1.01	-1.52	-1.56	0.226	0.256
b	31.72[a]	30.58[a]	27.52[b]	0.602	0.001

Abbreviations: SEM, standard error of the mean with n = 5; a, difference in red and green (+ = redder, − = greener); b, difference in yellow and blue (+ = yellower, − = bluer).

[a,b]Means within a row with no common superscripts differ significantly ($P < 0.05$).

Table 7. Effect of almond hull on the body composition of Hy-Line hens at 32 wk of age.

Item	Control	7.5%	15%	SEM	*P* value
Prime hull					
Fat (%)	38.5[a]	32.3[b]	29.6[b]	1.497	0.005
Fat (g)	589[a]	458[b]	408[b]	0.079	0.014
Lean (g)	934	964	959	0.091	0.858
BMD (g/cm^2)	0.237	0.234	0.221	0.008	0.395
BMC (g)	44.5	44.1	38.6	2.256	0.160
Bone Area (cm^2)	188	188	174	4.924	0.156
California type hull					
Fat (%)	38.5[a]	33.4[b]	31.4[b]	1.497	0.016
Fat (g)	589[a]	396[b]	461[b]	0.079	0.017
Lean (g)	934[a]	786[b]	1000[a]	0.091	0.025
BMD (g/cm^2)	0.237	0.221	0.223	0.008	0.172
BMC (g)	44.5	35.9	39.2	2.256	0.109
Bone Area (cm^2)	188	162	175	4.924	0.068

Abbreviations: BMC, body mineral content; BMD, body mineral density; SEM, standard error of the mean with n = 5.

[a,b]Means within a row with no common superscripts differ significantly ($P < 0.05$).

and nutrient digestibility on the hens fed diets including almond hulls. Increasing the oil content in the diet slows down the passage rate of feed in digestive tract, thus it improves the nutrient digestion and absorption of birds (Ravindran et al., 2016). In the present study, the increase on apparent nutrient digestibility when layers were fed 7.5% of both almond hulls could be mainly contributed by the soybean oil increase in the diet. However, as the prime hull inclusion increased to 15%, the positive effect on AMEn and N digestibility was diminished. An explanation for the current result is that the antinutritional effect from fibers in prime hulls outweighs the beneficial effect of soybean oil, since the fibers from prime hulls are rich in hemicellulose as an antinutrient factor (Tahir et al., 2008). Meantime, layers fed diet containing 15% of California type hulls showed a higher apparent nutrient digestibility compared to the control group. The different results between feeding 15% of prime and California type hulls could be due to the fiber difference. Fibers in California type hulls are mainly lignins and cellulose from shells with less impact on nutrient digestibility. However, it was previously reported hens fed a high fiber isocaloric diet (balanced using corn oil at 7.5%) showed no difference in the apparent dry matter and energy digestibility during a 14-d trial compared to wheat and soybean meal control diet (Courtney Jones et al., 2013). The different results on DM and metabolizable energy digestibility from the present study may be due to the feeding period, environments, and breeds. Additionally, almond hulls contain some nutraceuticals with erectogenic, antihypertensive, antidiabetic, antioxidative properties (Adefegha et al., 2017), however, the contribution from those active compounds on the metabolism, digestion, and performance of hens needs further study.

Egg weight, Haugh unit, and shell weight were not affected by prime and California type hulls added at the

2 levels, but yolk color was influenced by increasing on greenness and decreasing on yellowness as the increasing doses of almond hulls. Egg yolk color is influenced by the deposition of dietary pigments such as beta-carotene, riboflavin and zeaxanthin (Damron et al., 1984). Almond hulls are dried almond fruit flesh containing a high amount of chlorophyll and carotenoid contents (Murathan et al., 2020). A plausible explanation of the egg yolk color difference observed here between 15% almond hull inclusion rate and control group is the pigments from almond fruit and a reduction of corn in the diets. However, further studies are necessary for determining the specific pigments in almond hulls affecting the egg yolk color. Additionally, it is possible that the fat-soluble polyphenols and other active compounds are deposited into egg yolks together with pigments in almond hulls. The active compounds in hulls were reported to have health benefits through inhibiting lipid oxidation, providing pigmentation, and antimicrobial activity (Bolling, 2017). However, more studies are needed to investigate the effect of polyphenols in almond hulls in eggs.

Both prime and California type hulls used in the present study reduced body fat compared to the control, which was mainly attributed to dietary fiber. There is limited research on dietary fiber alternating laying hens body composition, however, dietary fiber has been associated with human body weight loss, particularly in body fat weight loss (Howarth et al., 2001). The mechanisms by which dietary fiber regulates body composition are mediated through a complex interplay of multiple factors (Kaczmarczyk et al., 2012). Carbohydrate metabolism is influenced by dietary fiber intake, which is involved in the release of insulin related hormones (Raninen et al., 2011). Moreover, dietary fiber is also known to shifting the gut microbiota away from obesity-associated microbiome (Guigoz et al., 2002). Nonetheless, the current experiment supports that high fiber diet reduces body fat weight and percentage. However, a longer time trial is needed to investigate whether the body fat weight loss is beneficial for the health and egg mass of hens during late stage of egg production since body fat deposition is a main negative factor for laying hens.

In conclusion, the present study demonstrates that both prime and California type hulls can be fed to laying hens at dietary inclusion up to 15% without negative effects on egg production and egg quality. Additionally, the AMEn and nitrogen digestibility are positively affected by the inclusion of almond hulls and increasing soybean oil content. Body fat and egg yolk yellow color are reduced when a high amount of almond hull is used in the diet. Further study is required on how polyphenols in almond hulls affect the eggs antioxidants.

DISCLOSURES

There is no conflict interest.

REFERENCES

Adefegha, S. A., G. Oboh, S. I. Oyeleye, and I. Ejakpovi. 2017. Erectogenic, antihypertensive, antidiabetic, anti-oxidative properties and phenolic compositions of Almond fruit (*Terminalia catappa* L.) Parts (Hull and Drupe)−in vitro. J. Food Biochem. 41:e12309.

Adhikari, R., D. White, J. House, and W. K. Kim. 2020. Effects of additional dosage of vitamin D3, vitamin D2, and 25-hydroxyvitamin D3 on calcium and phosphorus utilization, egg quality and bone mineralization in laying hens. Poult. Sci. 99:364–373.

Almond Board of California. 2019. Almond Almanac. Almond Board of California, Sacramento CA.

AOAC International. 1990. Official Methods of Analysis. 15th ed. Off. Anal. Chem., Washington, DC.

AOAC International. 2000. Official Methods of Analysis. 17th ed. AOAC Int., Gaithersburg, MD.

Azizi, P., and S. Moradi. 2017. Effect of source and particle size of dietary fiber on performance and egg quality in commercial laying hens. Anim. Prod. Res. 6:4.

Bolling, B. W. 2017. Almond polyphenols: methods of analysis, contribution to food quality, and health promotion. Compr. Rev. Food Sci. Food Saf. 16:346–368.

Castro, F., H. Kim, Y. Hong, and W. K. Kim. 2019. The effect of total sulfur amino acid levels on growth performance, egg quality, and bone metabolism in laying hens subjected to high environmental temperature. Poult. Sci. 98:4982–4993.

Chen, T., D. Chen, G. Tian, P. Zheng, X. Mao, J. Yu, J. He, Z. Huang, Y. Luo, J. Luo, and B. Yu. 2020. Effects of soluble and insoluble dietary fiber supplementation on growth performance, nutrient digestibility, intestinal microbe and barrier function in weaning piglet. Anim. Feed Sci. Tech. 260:114335.

Courtney Jones, S. K., A. J. Cowieson, S. A. Williamson, and A. J. Munn. 2013. No effect of short-term exposure to high-fibre diets on the gastrointestinal morphology of hens (*Gallus gallus domesticus*): body reserves are used to manage energy deficits in favour of phenotypic plasticity. J. Anim. Physiol. Anim. Nutr. 97:868–877.

Damron, B. L., S. R. Goodson, R. H. Harms, D. M. Janky, and H. R. Wilson. 1984. Beta-carotene supplementation of Laying Hen Diets. Br. Poult. Sci. 25:349–352.

Deaton, J., L. Kubena, F. Reece, and B. Lott. 1977. Effect of dietary fibre on the performance of laying hens. Br. Poult. Sci. 18:711–714.

Esfahlan, A. J., R. Jamei, and R. J. Esfahlan. 2010. The importance of almond (*Prunus amygdalus* L.) and its by-products. Food Chem 120:349–360.

Guigoz, Y., F. Rochat, G. Perruisseau-Carrier, I. Rochat, and E. J. Schiffrin. 2002. Effects of oligosaccharide on the faecal flora and non-specific immune system in elderly people. Nutr. Res. 22:13–25.

Hamilton, R. 1982. Methods and factors that affect the measurement of egg shell quality. Poult. Sci. 61:2022–2039.

Ravindran, V., P. Tancharoenrat, F. Zaefarian, and G. Ravindran. 2016. Fats in poultry nutrition: digestive physiology and factors influencing their utilisation. Anim. Feed Sci. Tech. 213:1–21.

Holtman, K. M., R. D. Offeman, D. Franqui-Villanueva, A. K. Bayati, and W. J. Orts. 2015. Countercurrent extraction of soluble sugars from almond hulls and assessment of the bioenergy potential. J. Agric. Food Chem. 63:2490–2498.

Howarth, N. C., E. Saltzman, and S. B. Roberts. 2001. Dietary fiber and weight regulation. Nutr. Rev. 59:129–139.

Jiang, W., L. Zhang, and A. Shan. 2013. The effect of vitamin E on laying performance and egg quality in laying hens fed corn dried distillers grains with solubles. Poult. Sci. 92:2956–2964.

Jiménez-Moreno, E., A. de Coca-Sinova, J. González-Alvarado, and G. Mateos. 2016. Inclusion of insoluble fiber sources in mash or pellet diets for young broilers. 1. Effects on growth performance and water intake. Poult. Sci. 95:41–52.

Jiménez-Moreno, E., J. González-Alvarado, A. de Coca-Sinova, R. Lázaro, and G. Mateos. 2009. Effects of source of fibre on the development and pH of the gastrointestinal tract of broilers. Anim. Feed Sci. Tech. 154:93–101.

Kaczmarczyk, M. M., M. J. Miller, and G. G. Freund. 2012. The health benefits of dietary fiber: beyond the usual suspects of type 2 diabetes mellitus, cardiovascular disease and colon cancer. Metabolism 61:1058–1066.

Kirunda, D. F., S. E. Scheideler, and S. R. McKee. 2001. The efficacy of vitamin E (DL-α-tocopheryl acetate) supplementation in hen diets to alleviate egg quality deterioration associated with high temperature exposure. Poult. Sci. 80:1378–1383.
Montoya, C. A., S. J. Henare, S. M. Rutherfurd, and P. J. Moughan. 2016. Potential misinterpretation of the nutritional value of dietary fiber: correcting fiber digestibility values for nondietary gut-interfering material. Nutr. Rev. 74:517–533.
Murathan, Z. T., A. Kaya, N. Erbil, M. Arslan, E. Dıraz, and S. Karaman. 2020. Comparison of bioactive components, antimicrobial and antimutagenic features of organically and conventionally grown almond hulls. Erwerbs-Obstbau 62:463–472.
Offeman, R. D., K. M. Holtman, K. M. Covello, and W. J. Orts. 2014. Almond hulls as a biofuels feedstock: variations in carbohydrates by variety and location in California. Ind. Crops. Prod. 54:109–114.
Rad, M. I., Y. Rouzbehan, and J. Rezaei. 2016. Effect of dietary replacement of alfalfa with urea-treated almond hulls on intake, growth, digestibility, microbial nitrogen, nitrogen retention, ruminal fermentation, and blood parameters in fattening lambs. J. Anim. Sci. 94:349–358.
Raninen, K., J. Lappi, H. Mykkänen, and K. Poutanen. 2011. Dietary fiber type reflects physiological functionality: comparison of grain fiber, inulin, and polydextrose. Nutr. Rev. 69:9–21.
Reed, B. A., and D. L. Brown. 1988. Almond hulls in diets for lactating goats: effects on yield and composition of milk, feed intake, and digestibility. J. Dairy Sci. 71:530–533.
Roberts, S. A., H. Xin, B. J. Kerr, J. R. Russell, and K. Bregendahl. 2007. Effects of dietary fiber and reduced crude protein on nitrogen balance and egg production in laying hens1. Poult. Sci. 86:1716–1725.
Rougière, N., and B. Carré. 2010. Comparison of gastrointestinal transit times between chickens from D+ and D− genetic lines selected for divergent digestion efficiency. Anim 4:1861–1872.
Scott, M. L., I. Ascarelli, and G. Olson. 1968. Studies of egg yolk pigmentation. Poult. Sci. 47:863–872.
Selim, S., and E. Hussein. 2020. Production performance, egg quality, blood biochemical constituents, egg yolk lipid profile and lipid peroxidation of laying hens fed sugar beet pulp. Food Chem 310:125864.
Sequeira, R. M., and R. B. Lew. 1970. Carbohydrate composition of almond hulls. J. Agric. Food Chem. 18:950–951.
Sibbald, I., and S. Slinger. 1963. A biological assay for metabolizable energy in poultry feed ingredients together with findings which demonstrate some of the problems associated with the evaluation of fats. Poult. Sci. 42:313–325.
Sousa, L. S.d., T. S. M. Carvalho, F. A. Nogueira, M. M. Saldanha, D. P. Vaz, A. G. Bertechini, N. C. Baião, and L. Lara. 2019. Fiber source and xylanase on performance, egg quality, and gastrointestinal tract of laying hens. R. Bras. Zootec. 48:e20170286.
Tahir, M., F. Saleh, A. Ohtsuka, and K. Hayashi. 2008. An effective combination of carbohydrases that enables reduction of dietary protein in broilers: importance of hemicellulase. Poult. Sci. 87:713–718.
Takeoka, G. R., and L. T. Dao. 2003. Antioxidant constituents of almond [*Prunus dulcis* (Mill.) D.A. Webb] hulls. J. Agric. Food Chem. 51496–51501.
Vargas, R. E., and E. C. Naber. 1984. Relationship between dietary fiber and nutrient density and its effect on energy balance, egg yolk cholesterol and hen performance. J. Nutr. 114:645–652.
Walugembe, M., M. Rothschild, and M. Persia. 2014. Effects of high fiber ingredients on the performance, metabolizable energy and fiber digestibility of broiler and hen chicks. Anim. Feed Sci. Tech. 188:46–52.
Wang, J., A. K. Singh, F. Kong, and W. K. Kim. 2021. Effect of almond hulls as an alternative ingredient on broiler performance, nutrient digestibility, and cecal microbiota diversity. Poult. Sci. 100:100853.
Wijeratne, S. S., R. Amarowicz, and F. Shahidi. 2006. Antioxidant activity of almonds and their by-products in food model systems. J. Am. Oil Chem. Soc. 83:223.