The effect of added oat hulls or sugar beet pulp to diets containing rapidly or slowly digestible protein sources on broiler growth performance from 0 to 36 days of age

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ABSTRACT The effects of formulating broiler diets that contain sources of either rapidly or slowly digestible protein and 2 different dietary fiber sources on growth performance were studied in broilers chickens from 0 to 36 d of age. A total of 1,920 one-day-old, male Ross 708 broiler chickens were randomly allocated and housed in 48 floor pens (40 birds/pen) to one of 4 dietary treatments. Birds were allotted according to a completely randomized block design using a factorial arrangement of treatments with 2 protein digestion rates (rapidly or slowly) and 2 dietary fiber sources [3% oat hulls (**OH**) or 3% sugar beet pulp (**SBP**)] from 0 to 36 d of age. All diets were formulated to be isocaloric and isonitrogenous. The pen was the experimental unit for all variables studied (12 replicates/treatment). Data were analyzed using the MIXED procedure of SAS, and the model included the main effects of the protein digestion rate, dietary fiber source, and their interaction. There were 3 experimental feeding phases; starter (from day 0–14), grower (from day 14–28), and finisher (from day 28–36). Results indicated that broilers fed diets containing sources that supplied more rapidly digestible protein had 4% greater ($P < 0.01$) ADG and improved ($P < 0.01$) the feed conversion ratio (**FCR**) by 5% throughout the experiment, most notably after the starter phase. Diets containing 3% OH increased ($P < 0.05$) the ADFI and ADG ($P < 0.05$) in the starter phase compared with broilers fed diets containing 3% SBP, without affecting the FCR. The ADG and FCR of broilers fed diets containing sources of slowly digestible protein were improved ($P < 0.05$) to the level of broilers fed rapidly digestible protein containing diets with the addition of 3% OH. It is concluded that broiler diets should be formulated to contain a high concentration of ingredients that supply rapidly digestible protein, but if this is cost-prohibitive, then 3% OH could be used to increase the ADFI and ADG and potentially protein digestion rates to reduce the FCR.

Key words: dietary fiber, growth performance, oat hull, protein digestion kinetics, sugar beet pulp

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INTRODUCTION

Broiler diets are normally formulated using apparent, standardized or true digestibility coefficients of amino acids (**AA**), and these coefficients are typically measured at the terminal ileum. However, this approach ignores the fact that AA and protein may have different rates and sites of digestion and absorption. The rate and site of protein digestion along the digestive tract have been investigated in different species including ruminant and humans (Ørskov and McDonald, 1979; Boirie et al., 1997). In broilers, there is growing evidence indicating that the site and rate of digestion of protein and absorption of AA influence broiler performance (Liu et al., 2017; Truong et al., 2017; Moss et al., 2018). In this respect, Liu et al. (2013) showed that 70% of the methionine present in sorghum-soybean meal-canola meal-based diets was digested in the proximal jejunum in broilers. In addition, Liu et al. (2015) determined apparent digestibility coefficients of protein at 4 sites of the small intestine and reported that 79% of protein was digested in the jejunum. The variation in digestion pattern across different sections of the small intestine was also reported for crude protein digestion in broilers by Gutiérrez del Álamo et al. (2009). Therefore, AA are digested to varying degrees across each section of the small intestine, although almost all investigations

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focus on ileal digestibility, and no attention is paid to jejunal digestibility coefficients. These data indicate that the kinetics of protein digestion may also need to be considered along with the static ileal digestibility coefficients, and that protein digestion rates may be used to further enhance broiler performance. It must be considered, however, that AA composition in portal circulation is a result of first-pass postabsorptive metabolism, while further metabolism and regulation alters the composition of AA in the liver and muscles.

In contrast, degradation characteristics of raw materials used in poultry diets are scarce, although this type of research is often studied in human nutrition (Dangin et al., 2001; Koopman et al., 2009). To characterize protein sources according to digestion kinetics, *in vitro* and *in vivo* protein digestibility assays have been developed to predict different ingredient protein fractions, as well as their rate and extent of digestion (Bryan et al., 2018, 2019a,b).

The type of dietary fiber in the diet affects the gastrointestinal tract (**GIT**) development and growth performance of broilers (Jiménez-Moreno et al., 2009). This is due to a number of physicochemical properties of fibrous ingredients including solubility, water-holding capacity (**WHC**), viscosity, bulk, fermentability, and ability to bind bile acids (Jiménez-Moreno et al., 2013a). In this respect, soluble dietary fiber (**SDF**) sources can increase viscosity and bulk of the digesta, which results in delayed gizzard emptying. Sugar beet pulp (**SBP**) is a source of the SDF high in pectin, a nonstarch polysaccharide with the ability to increase the viscosity of digesta within the GIT, reducing the rate of diffusion of digestive enzymes into the digesta, and consequently, reducing nutrient absorption (Jiménez-Moreno et al., 2009). On the other hand, insoluble dietary fiber (**IDF**) sources, such as oat hulls (**OH**), are known for their positive effects on the gizzard function and mucosal structure of the small intestine (González-Alvarado et al., 2008; Sacranie et al., 2012), which might improve nutrient digestibility (Hetland et al., 2004). Studies have shown that a well-developed gizzard is linked to strong muscular contractions that allow thorough grinding of the feed, helping to control the flow of the digesta from the gizzard to the small intestine, facilitating the mixing of chyme and gastric juices (Jiménez-Moreno et al., 2019). Therefore, the objective of this trial was to test the hypothesis that broilers fed diets formulated to contain ingredients which supply rapidly digestible protein (which are quickly digested and absorbed in the digestive tract) would have greater performance than those fed a diet containing sources that supply slowly digestible protein. Furthermore, the addition of OH was hypothesized to ameliorate the reduced performance of broilers fed diets containing slowly digestible protein sources.

MATERIALS AND METHODS

The present study was approved by the Trouw Nutrition animal care committee and followed recommendations of the Canadian Council of Animal Care guidelines on the care and use of farm animals in research, teaching, and testing (CCAC, 2009).

Bird Husbandry and Fiber Sources

In total, 1,920 one-day-old, male Ross 708 broiler chickens were obtained from a local hatchery and housed in the experimental facilities of Trouw Nutrition Agresearch (Burford, Ontario, Canada). After arrival, birds were weighed and randomly allocated to one of 48 floor pens (49 sq. ft./pen) with an individual feeder and nipple drinker line (4 nipples/pen). All pens had a similar average BW (39.34 ± 1.15 g) at placement. The birds were kept on a 24 h/d light program the first 3 d and 18 h/d light program from 3 to 36 d of age. The birds had *ad libitum* access to feed and water throughout the experiment. The environmental conditions of the barn were controlled automatically according to the age of the birds. The room temperature was maintained at 33°C ± 1.5°C for the first week of the experiment and then it was reduced 2°C per week until reaching 23°C. The SBP was received as 10-mm pellets, and OH were received as mash. The dietary fiber sources were ground with a hammer mill and sieved with a 2.5-mm screen before being included in their respective experimental diets. The calculated and analyzed composition and the physicochemical properties of the dietary fiber sources are shown in Table 1.

Table 1. Calculated and analyzed chemical composition (%, as-fed basis, unless otherwise indicated) and the physicochemical properties of the dietary fiber sources.

Item (%, as fed basis, unless otherwise indicated)	Oats hulls	Sugar beet pulp
Calculated composition		
Dry matter	90.7	93.4
Total ash	4.3	4.8
Crude protein	5.1	9.2
Starch	18.1	-
Ether extract	1.4	0.8
Crude fiber	25.9	19.9
Neutral detergent fiber	57.9	46.8
Acid detergent fiber	29.3	24.0
Analyzed composition[1]		
Dry matter	92.6	91.1
Gross energy (Kcal/kg)	979.2	926.7
Total ash	4.0	5.8
Crude protein	3.9	9.6
Starch	9.2	1.0
Crude fiber	23.2	17.5
Neutral detergent fiber	61.9	48.5
Acid detergent fiber	32.4	21.3
Acid detergent lignin	5.4	3.0
Total dietary fiber	71.3	59.0
Insoluble dietary fiber	70.6	47.4
Soluble dietary fiber	0.7	11.6
Physicochemical properties		
GMD[2]±GSD[3]	760 ± 1.9	630 ± 2.1
WHC[4]±SD	4.6 ± 0.75	9.8 ± 0.21
SWC[5]±SD	2.4 ± 0.40	5.3 ± 0.78

[1] Analyzed in duplicate.
[2] GMD = geometric mean diameter (μm).
[3] GSD = log normal geometric SD.
[4] WHC = water-holding capacity (mL/g DM).
[5] SWC = swelling water capacity (mL/g DM).

Experimental Design, Experimental Diets, and Measurements

Four dietary treatments were arranged in a randomized complete block design using a 2 × 2 factorial arrangement with 2 protein digestion rates (rapidly or slowly) and 2 sources of dietary fiber (3% OH or SBP) from day 0 to 36 of age. There were 12 blocks in the house, and these were distributed throughout the house to ensure equal treatment spacing from the exhaust fans on the southside of the house and the air inlet vent on the north side of the house. Five blocks were closest to the air inlet vent, 3 blocks were in the middle, 3 blocks were closest to the exhaust fans, and 1 block was equally split between the middle and closest to the exhaust fans. The experimental unit was the pen with 40 birds per pen, and each experimental treatment was replicated 12 times. There were 3 experimental feeding phases: starter (from day 0–14), grower (from day 14–28), and finisher (from day 28–36). Starter diets were fed as a crumble, whereas grower and finisher diets were fed as pellets (3 mm). According to the literature (Truong et al., 2017; Bryan et al., 2019a; Jaworski et al., 2019), soybean meal and wheat were considered as rapidly digestible protein sources, whereas soy protein concentrate, rapeseed meal, corn gluten meal, and corn were considered as slowly digestible protein sources. The SDF source was SBP, whereas the IDF source was OH. All diets were formulated to be isocaloric and isonitrogenous and were formulated to meet or exceed requirements for digestible AA and phosphorus, vitamins, and minerals (CVB Feed Table, 2016). Exogenous phytase and xylanase were added to all experimental diets.

Birds were weighed by pen, and feed intake was measured by pen on days 0, 8, 14, 22, 28, and 36 d of the experiment. Mortalities were recorded daily. The ADG, ADFI, and feed conversion ratio (**FCR**) were calculated from these data by week and cumulatively. Mortality was not included in the calculation of the FCR.

Laboratory Analyses

Representative samples of the dietary fiber sources and experimental diets were ground in a laboratory mill (Retsch model Z-I; Retsch GmbH, Stuttgart, Germany) equipped with a 1-mm screen. Samples were analyzed for moisture by oven-drying (method 930.15), total ash by muffle furnace (method 942.05), and nitrogen by Dumas (method 968.06) using a Leco analyzer (model FP-528; Leco Corp., St. Joseph, MI) as indicated by the AOAC International (2000). Ether extract in raw materials and in experimental diets was determined (method 920.39) according to AOAC International (2005). Acid detergent fiber and neutral detergent fiber were determined using Ankom Technology methods 12 and 13, respectively (Ankom^{2000} Fiber Analyzer, Ankom Technology, Macedon, NY), and acid detergent lignin was analyzed as the acid detergent fiber residue remaining after a 72-h soak in 72% H_2SO_4. Insoluble dietary fiber and SDF were analyzed in all samples according to method 991.43 (AOAC International, 2007) using the Ankom^{TDF} Dietary Fiber Analyzer (Ankom Technology). The total dietary fiber (**TDF**) was determined as the sum of the analyzed IDF and SDF. The geometric mean diameter and geometric SD of the fiber sources were determined in 100-g samples using a shaker (Retsch GmbH) provided with 8 sieves ranging in mesh from 5,000 to 40 μm, as described by the ASAE (1995). The in vitro WHC was measured as indicated by González-Alvarado et al. (2008). Briefly, 2 subsamples (1.0 g DM) of each dietary fiber source were left to soak for 20 h in an excess of distilled water (100 mL). Samples were filtered on a fritted glass crucible (porosity 2). The wet sample was weighed after letting the water drain for 10 min, and the WHC, expressed as milliliters per gram DM, was calculated as the amount of water retained. In addition, the swelling water capacity (**SWC**) was determined as indicated by Jiménez-Moreno et al. (2009a). Briefly, 2 subsamples (2.0 g of DM) of the dietary fiber source were hydrated in 10 mL of distilled water in a calibrated cylinder (25 mL) at room temperature. Samples were dispersed by gentle stirring for 5 min and left undisturbed at room temperature for 22 to 24 h. After equilibration, the bed volume was recorded and expressed as milliliters per gram DM of the original sample.

Statistical Analyses

Normality of residuals were determined using the UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC). Outliers were determined using the BOXPLOT procedure of SAS (SAS Inst. Inc., Cary, NC) and the influence statement in conjunction with Cook's D. Three outliers were from 1 pen of birds fed the diet containing rapidly digestible protein and OH (ADG day 15 to 22 = 75.5 g/d; FCR day 15 to 22 = 1.163 g/g; FCR day 22 to 28 = 1.702 g/g), 2 outliers were from 1 pen of birds fed the same diet (ADFI day 8 to 15 = 46.0 g/d; FCR day 8 to 15 = 1.320 g/d), 2 outliers were from 1 pen of birds fed the diet containing rapidly digestible protein and SBP (ADFI day 8 to 15 = 42.0 g/d; FCR day 8 to 15 = 1.163 g/g), and 1 outlier was from 1 pen of birds fed the diet containing slowly digestible protein and SBP (FCR day 8 to 15 = 1.501 g/g). Growth performance was analyzed as a 2 × 2 factorial arrangement of treatments, and the model included the main effects of protein digestion rate (rapidly vs. slowly), dietary fiber source (3% OH or SBP), and their interaction using an ANOVA in the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The block was considered a random effect. The pen was the experimental unit. For all outcomes, a *P*-value ≤ 0.05 was used to determine significance among dietary treatments, and a *P*-value > 0.05, but <0.10, was considered a trend.

RESULTS

The analyzed chemical composition and physical characteristics of the dietary fiber sources are shown in Table 1. Oat hulls contained 71.3, 70.6, and 0.7% TDF, IDF, and SDF, respectively, whereas SBP contained 59.0, 47.4, and 11.6% of TDF, IDF, and SDF, respectively. The geometric mean diameter was greater for OH than for SBP (760 vs. 630 µm, respectively). The WHC and SWC of SBP were twice as high compared with those of OH. The calculated and determined analysis of the experimental diets are shown in Tables 2 and 3. The analyzed CP in the rapidly digestible protein plus OH diet was 25.4%, and this was greater compared with the 21.5% CP that was calculated. We suspect this to be an analytical error because the NIR result was 20.5% CP. Nonetheless, this could have impacted the observed performance results during the starter phase. Overall mortality was low (2.4%) and not affected by treatment ($P > 0.05$; data not shown).

During the starter phase (day 0 to 14 of age), broilers fed diets that contained slowly digestible protein sources had a greater ADFI (36.7 vs. 34.8 g/d; $P < 0.05$) and an inferior FCR (1.34 vs. 1.30 g/g; $P < 0.05$) than birds fed diets that contained rapidly digestible protein sources (especially from day 8 to 14 of age), however, the ADG was not different (Table 4). In addition, from day 0 to 14 of age, broilers fed OH resulted in a greater ADFI (36.6 vs. 34.9 g/d; $P < 0.05$) and ADG (27.5 vs. 26.5 g/d; $P < 0.05$), but the positive effect of 3% OH inclusion was not reflected in the FCR. There was an interaction between the protein digestion rate and dietary fiber source indicating that the ADFI and ADG were improved ($P < 0.05$) when broilers were fed 3% OH in the diet that contained slowly digestible protein sources (Table 4). During the grower phase (day 14 to 28 of age), the ADFI was not affected by either the protein digestion rate or dietary fiber source. However, broilers fed diets that contained rapidly digestible protein sources had a greater ADG (77.5 vs. 74.0 g/d; $P < 0.05$) and an improved FCR (1.42 vs. 1.48 g/g; $P < 0.05$) than broilers fed diets that contained slowly digestible protein sources (Table 5). In the finisher phase (from day 28–36 of age), a similar pattern as in the grower phase was observed. Broilers fed diets that contained rapidly digestible protein sources had a greater ADG (84.0 vs. 80.3 g/d; $P < 0.05$) and an improved FCR (1.79 vs. 1.87 g/g; $P < 0.05$) relative to broilers fed diets that contained slowly digestible protein sources (Table 6). There was an interaction between the protein digestion rate and dietary fiber source, which indicated that the ADG was less and FCR was inferior ($P < 0.05$) when broilers were fed 3% SBP in the diet that contained slowly digestible protein sources. Overall (day 0–36), broilers fed diets that contained rapidly digestible protein sources had a greater ADG (57.6 vs. 55.5 g/d; $P < 0.05$) and improved FCR (1.51 vs. 1.58 g/g; $P < 0.05$) compared with broilers fed diets that contained slowly digestible protein sources (Table 6). In addition, there was an interaction between the protein digestion rate and dietary fiber source, which indicated that broiler ADG was less ($P < 0.05$) when

Table 2. Experimental diets (%, as-fed basis, unless otherwise indicated) during the 3 feeding phases (day 0–36 of age).

	Starter (Day 0–14 of age)				Grower (Day 14–28 of age)				Finisher (Day 28–36 of age)			
Protein digestion rate	Rapidly		Slowly		Rapidly		Slowly		Rapidly		Slowly	
Dietary fiber source	OH[1]	SBP[2]	OH	SBP	OH	SBP	OH	SBP	OH	SBP	OH	SBP
Ingredient, %												
Corn	20.55	32.93	44.15	39.29	24.78	12.37	27.61	30.43	19.79	22.19	50.79	51.24
Wheat	31.45	20.00	10.00	16.03	31.85	45.36	30.61	27.91	40.81	38.56	10.00	10.00
Soybean meal, dehulled 48% CP	34.09	36.49	20.74	19.12	32.65	29.68	17.46	17.61	29.21	29.26	18.41	18.00
Rapeseed meal	2.30		7.50	7.50			7.50	7.50			7.50	7.50
Soy protein concentrate			5.00	5.00			5.00	5.00			4.17	4.28
Corn gluten meal	0.23		2.88	3.42		1.86	1.45	1.39				
Oats hulls	3.00		3.00		3.00		3.00		3.00		3.00	
Sugar beet pulp		3.00		3.00		3.00		3.00		3.00		3.00
Soybean oil	5.00	4.21	3.35	3.25	4.99	5.00	4.66	4.52	4.90	4.76	3.92	3.81
Dicalcium phosphate	1.05	1.08	1.04	1.04	0.47	0.46	0.41	0.42	0.20	0.20	0.18	0.18
Calcium carbonate	1.00	0.97	0.98	0.94	1.02	0.99	0.98	0.93	0.88	0.84	0.81	0.77
Sodium bicarbonate	0.24	0.22	0.30	0.30	0.19	0.20	0.25	0.24	0.19	0.18	0.23	0.22
Salt	0.18	0.18	0.14	0.13	0.19	0.17	0.15	0.15	0.19	0.19	0.17	0.16
DL-methionine 99%	0.27	0.28	0.22	0.22	0.24	0.22	0.21	0.21	0.22	0.22	0.20	0.20
L-Lysine HCl 98%	0.20	0.17	0.27	0.31	0.17	0.23	0.25	0.25	0.16	0.16	0.19	0.19
L-Threonine min. 98%	0.05	0.04	0.03	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.03	0.03
Nonstarch polysaccharide enzyme[3]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Phytase	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin and mineral premix[4]	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35

[1] Oat hulls.

[2] Sugar beet pulp.

[3] Commercially available enzyme that provided 500 units of endo-1,4-beta-xylanase.

[4] Provided the following (per kilogram of diet): 10,000-IU vitamin A (trans-retinyl acetate), 2,500-IU vitamin D3 (cholecalciferol), 50-IU vitamin E (all-rac-tocopherol-acetate), 2.0-mg vitamin B1 (thiamine-mononitrate), 6-mg vitamin B2 (riboflavin), 40-mg niacin, 490-mg vitamin B4 choline cl 70%, 4.0-mg vitamin B6 (pyridoxine HCl), 25-mcg vitamin B12 (cyanocobalamin), 2.0-mg vitamin K3 (bisulfate menadione complex), 10-mg pantothenic acid (d-Ca pantothenate), 1.0-mg folic acid, 150-mcg d-biotin, 0.25 mg Se (Na2SeO3),1.0-mg I, 15-mg Cu (CuSO4·5H2O), 67.7-mg Fe ($FeSO_4 \cdot 7H_2O$), 90-mg Mn ($MnSO_4$·H2O), 80-mg Zn (ZnO), (supplied by Trouw Nutrition, St. Mary's Ontario Canada), 500-mg Salinomycin sodium 12%.

Table 3. Calculated and analyzed (%, as-fed basis, unless otherwise indicated) nutrient and energy concentration of experimental diets during the 3 feeding phases (day 0–36 of age).

	Starter (Day 0–14 of age)				Grower (Day 14–28 of age)				Finisher (Day 28–36 of age)			
Protein digestion rate	Rapidly		Slowly		Rapidly		Slowly		Rapidly		Slowly	
Dietary fiber source	OH[1]	SBP[2]	OH	SBP	OH	SBP	OH	SBP	OH	SBP	OH	SBP
Calculated analysis												
Dry matter	87.65	87.32	87.32	87.29	87.42	87.53	87.48	87.35	87.34	87.23	86.95	86.86
Total ash	5.63	5.80	5.37	5.49	4.84	4.91	4.61	4.76	4.30	4.46	4.16	4.31
Crude protein	21.50	21.50	21.50	21.50	20.12	20.50	19.90	20.00	19.00	19.11	18.50	18.55
Ether extract	6.62	6.03	5.42	5.24	6.66	6.47	6.43	6.33	6.48	6.38	6.07	5.96
Starch	30.54	31.12	33.31	33.71	33.20	33.52	34.91	34.86	35.35	35.32	36.94	37.02
AMEn (kcal/kg)	2,700	2,700	2,700	2,700	2,775	2,775	2,775	2,775	2,800	2,800	2,800	2,800
Crude fiber	3.42	2.57	3.74	3.19	3.17	2.65	3.85	3.26	3.19	2.61	3.69	3.12
Total dietary fiber	18.85	17.58	18.68	17.93	18.26	17.50	18.95	18.17	18.24	17.47	18.61	17.86
Determined analysis												
Dry matter	87.40	87.30	87.30	88.30	87.70	88.40	88.60	88.00	87.80	88.00	87.70	87.90
Total ash	4.72	4.76	4.95	4.65	4.80	4.90	5.10	5.20	3.90	4.22	4.28	4.13
Crude protein	25.40	21.60	22.20	20.60	20.90	21.20	20.20	19.80	18.60	20.10	19.80	19.50
Crude Fat	6.65	5.71	2.67	4.82	6.20	6.90	6.80	6.70	5.77	6.54	6.16	6.15
Starch	30.70	32.20	35.50	35.20	35.50	32.50	36.50	35.60	37.10	34.20	34.50	35.00
Crude fiber	3.12	2.81	3.09	3.19	3.30	3.30	3.80	3.70	3.70	3.14	3.94	3.51
Total dietary fiber	17.70	16.90	16.10	17.01	15.62	15.83	16.40	15.33	15.54	16.95	18.90	18.40
Soluble dietary fiber	1.90	1.90	1.90	1.90	1.40	1.80	1.30	1.70	1.60	1.60	1.60	1.90
Insoluble dietary	15.80	15.10	15.10	14.22	14.43	13.84	15.05	13.60	15.30	13.80	17.43	16.64

[1] Oat hulls.
[2] Sugar beet pulp.

broilers were fed diets that contained slowly digestible protein sources supplemented with 3% SBP (Table 6).

DISCUSSION

Effect of Using Rapidly or Slowly Digestible Protein Sources in Broiler Diets

Results indicated that formulating diets to contain rapidly digestible protein sources increased the broiler ADG and improved FCR. However, economics of using rapidly digestible protein sources in diets must be considered as these ingredients can typically be more costly.

Therefore, we hypothesized that the addition of OH to diets containing less-expensive slowly digestible protein sources could ameliorate the loss in performance that results from including slowly digestible protein sources in broiler diets. Indeed, in grower and finisher phases, there was an interaction between the protein digestion rate and dietary fiber source indicating that the ADFI and ADG was improved when broilers were fed with 3% OH in the diets that contained slowly digestible protein sources. These results confirm the hypothesis that the

Table 4. Influence of protein digestion rates and dietary fiber sources on growth performance of broilers from day 0 to 14 of age.

	Rapidly digested protein		Slowly digested protein			*P*-values		
Item	SBP[1]	OH[2]	SBP[1]	OH[2]	SEM[3]	Protein	Dietary fiber	Protein × dietary fiber
Initial BW[4]	39.2	39.6	39.3	39.3	0.341	0.546	0.189	0.281
Day 0 to 8								
BW day 8	171.0^{b}	172.0^{b}	168.0^{b}	180.0^{a}	2.33	0.302	0.003	0.011
ADFI[5]	20.6	21.4	20.9	22.3	0.406	0.132	0.007	0.395
ADG[6]	16.4^{b}	16.5^{b}	16.1^{b}	17.4^{a}	0.281	0.240	0.005	0.018
FCR[7]	1.26	1.30	1.30	1.28	0.016	0.426	0.580	0.081
Day 8 to 14								
BW day 14	443.0^{b}	448.0^{b}	438.0^{b}	467.0^{a}	5.01	0.065	0.006	0.009
ADFI	51.2^{b}	52.0^{b}	52.1^{b}	56.5^{a}	0.570	<0.001	<0.001	0.001
ADG	38.7^{b}	39.3^{b}	38.3^{b}	40.8^{a}	0.514	0.099	<0.001	0.005
FCR	1.32^{b}	1.32^{b}	1.36^{b}	1.38^{a}	0.008	<0.001	0.014	0.008
Day 0 to 14								
ADFI	34.5^{b}	35.2^{b}	35.4^{b}	38.0^{a}	0.460	0.001	0.003	0.082
ADG	26.7^{b}	26.8^{b}	26.4^{b}	28.2^{a}	0.414	0.113	0.007	0.010
FCR	1.29^{b}	1.31^{b}	1.34^{a}	1.35^{a}	0.070	0.001	0.356	0.662

[a,b] Means not sharing the same superscript letter across each row differ at $P \leq 0.05$ based on the interactive effect.
[1] Sugar beet pulp.
[2] Oat hull.
[3] SEM (n = 12).
[4] BW, g.
[5] ADFI, g/d.
[6] ADG, g/d.
[7] Feed conversion ratio, g/g.

Table 5. Influence of protein digestion rates and dietary fiber sources on growth performance of broilers from day 14 to 28 of age.

	Rapidly digested protein		Slowly digested protein			*P*-values		
Item	SBP[1]	OH[2]	SBP	OH	SEM[3]	Protein	Dietary fiber	Protein × dietary fiber
Day 14 to 22								
BW[4] day 22	897^{a,b}	913^{a}	862^{b}	902^{a,b}	8.91	0.001	0.001	0.072
ADFI[5]	88.4	90.1	88.6	91.5	0.839	0.243	0.002	0.317
ADG[6]	64.5	65.3	60.2	61.2	0.868	0.001	0.196	0.834
FCR[7]	1.37	1.39	1.47	1.50	0.010	0.001	0.063	0.711
Day 22 to 28								
BW day 28	1,464^{a}	1,454^{a,b}	1,406^{b}	1,448^{a,b}	14.82	0.017	0.214	0.052
ADFI	135^{b}	134^{b}	135^{b}	140^{a}	1.52	0.118	0.156	0.037
ADG	93.0^{a}	91.9^{a}	88.1^{b}	91.0^{b}	1.40	0.045	0.520	0.152
FCR	1.46^{b}	1.45^{b}	1.53^{a}	1.54^{a}	0.014	0.001	0.834	0.499
Day 14 to 28								
ADFI	149	151	147	153	1.48	0.130	0.256	0.127
ADG	77.8^{a}	77.3^{a}	73.8^{b}	74.3^{b}	1.38	0.003	0.946	0.535
FCR	1.42^{b}	1.42^{b}	1.45^{a}	1.52^{a}	0.025	0.001	0.164	0.360

[a,b] Means not sharing the same superscript letter across each row differ at $P \leq 0.05$ based on the interactive effect.
[1] Sugar beet pulp.
[2] Oat hull.
[3] SEM (n = 12).
[4] BW, g.
[5] ADFI, g/d.
[6] ADG, g/d.
[7] Feed conversion ratio, g/g.

addition of OH to diets containing slowly digestible protein sources would ameliorate the reduced performance. The supplementation of 3% OH to diets that contained slowly digestible protein sources potentially increased the passage rate and improved the GIT development and, thereby, improved protein digestion rates to similar levels as the diets which contained rapidly digestible protein sources. In this respect, Hetland and Svihus (2001) reported an increased passage rate of digesta with inclusion of OH and hypothesized that a rapid feed passage would decrease time for microbial fermentation in the small intestine and, thus, less protein will be fermented resulting in improved GIT development and health. The positive results of including rapidly digestible protein sources in broiler diets are in agreement with most data published. In this respect, Jaworski et al. (2019) studied the influence of 3 different levels of protein digestion rate (low, medium, and high) and reported that broilers fed diets with high concentrations of rapidly digested protein had 12% heavier BW than broilers fed diets containing a low level of rapidly digestible protein. In addition, Liu et al. (2017) reported that the feed conversion efficiency might be improved by inclusion of rapidly digestible protein sources. Furthermore, Truong et al. (2017) offered broiler chickens 2 diets containing different rates of protein digestion (rapidly vs. slowly) and reported that the rapidly digestible protein diet had significantly higher apparent digestibility coefficients of AA in the distal jejunum and distal ileum. The beneficial effect observed in birds fed diets containing rapidly digestible protein may also be due to these sources being rapidly absorbed in the proximal small intestine, suggesting that there was less undigested protein in the ileal digesta. In this respect, Goldberg and Guggenheim (1962) compared the digestion of AA and their appearance in portal circulation in rats offered

Table 6. Influence of protein digestion rates and dietary fiber sources on growth performance of broilers from day 28 to 36 of age.

	Rapidly digested protein		Slowly digested protein			*P*-values		
Item	SBP[1]	OH[2]	SBP[1]	OH[2]	SEM[3]	Protein	Dietary fiber	Protein × dietary fiber
Day 28 to 36								
BW[4] day 36	2,142^{a}	2,145^{a}	2,026^{b}	2,133^{a}	18.49	0.005	0.038	0.001
ADFI[5]	149	151	147	153	1.48	0.797	0.079	0.330
ADG[6]	85.0^{a}	83.0^{a}	77.5^{b}	83.1^{a,b}	1.38	0.006	0.228	0.041
FCR[7]	1.76^{b}	1.83^{b}	1.91^{a}	1.84^{a,b}	0.025	<0.001	0.568	0.002
Overall, day 0–36								
ADFI	86.7	87.7	86.3	89.8	0.889	0.147	0.068	0.153
ADG	57.8^{a}	57.4^{a}	54.2^{b}	56.8^{a,b}	0.625	0.002	0.226	0.032
FCR	1.50^{b}	1.52^{b}	1.59^{a}	1.58^{a}	0.008	<0.001	0.388	0.235

[a,b] Means not sharing the same superscript letter across each row differ at $P \leq 0.05$ based on the interactive effect.
[1] Sugar beet pulp.
[2] Oat hull.
[3] SEM (n = 12).
[4] BW, g.
[5] ADFI, g/d.
[6] ADG, g/d.
[7] Feed conversion ratio, g/g.

either casein, as a rapidly digestible protein source, or soy flour, as a slowly digestible protein source. The authors reported that a greater proportion of lysine was absorbed and entered the portal circulation from casein, the more rapidly digested protein source.

Effect of Type of Dietary Fiber in the Diet

From day 0 to 14 of age, broilers fed diets containing 3% SBP had a reduced ADFI compared with broilers fed diets containing 3% OH. In addition, in finisher and the overall period, broilers fed diets containing 3% SBP tended to have reduced ADFI. These results are in disagreement with the data of Jimenez-Moreno et al. (2013b) and Rogel et al. (1987). In the studies of Jimenez-Moreno et al. (2013b), broilers were fed with increased levels of OH (2.5, 5.0, and 7.5%), and the authors did not find any improvement on the ADFI. In addition, Rogel et al. (1987) reported similar ADFI in broilers fed 40 or 60 g OH/kg diet to broilers fed the control diet. The discrepancy between our study and previous reports is most likely because we compared 2 different sources of dietary fiber at similar concentrations of the TDF, whereas others compared the same source of dietary fiber, but at increased inclusion rates (i.e., increased concentrations of TDF). The increased addition of OH (or any other fiber source) would typically limit the ADFI because the TDF would be increased in the diets, whereas in our study, the TDF was similar among experimental treatments. Therefore, it actually appears that an increased SDF from SBP reduced broiler ADFI, rather than OH improving the ADFI.

In contrast, Gonzalez-Alvarado et al. (2010) reported improvements in the ADFI from day 1 to 42 of age in broilers fed with 3% OH compared with broilers fed with 3% SBP, in agreement of the results obtained in the current experiment. In addition, Hetland and Svihus (2001) determined that broilers fed with 40 g OH/kg diet increased the ADFI from day 7 to 21 of age. In this respect, Montagne et al. (2003) reported that an increase in IDF increased the rate of passage of digesta through the distal part of the GIT that in turn might result in a greater feed intake. On the other hand, the reduction of the ADFI in broilers fed 3% SBP was expected. The pectin content in SBP is characterized by its high WHC and SWC (Serena and Bach Knudsen, 2007; Gonzalez-Alvarado et al., 2010), and in this study, it was twice as much as OH. A wetter and bulkier digesta caused by inclusion of SBP in the diet could result in an increase in gut fill, and delayed emptying of the GIT, reducing feed intake. On the other hand, in the current experiment, from day 0 to 14 of age, broilers fed with 3% OH had improved ADG compared with broilers fed with 3% SBP. In this respect, Gonzalez-Alvarado et al. (2010) also reported improvements in ADG when broilers were fed with 3% OH compared with broilers fed a diet containing 3% SBP or a control diet from day 25 to 42 of age and for the entire experimental period. The increase of ADG detected in broilers fed with OH might account for the differences in the ADFI observed between broilers fed OH and SBP. Finally, broilers fed with 3% OH improved energy efficiency (g BW gain/Kcal AMEn ingested) compared with broilers fed with 3% SBP. The difference in energy efficiency between diets could be attributed to differences in their physicochemical characteristics that might affect gut motility, microbiota growth, and voluntary feed intake of the birds. In addition, the ether extract and oil content in the diets of the current experiments were higher in OH diets than SBP diets. In this respect, Hetland et al. (2003) reported that the inclusion of 100 g OH/kg diet increased bile acids' concentration in the chime, which in turn, could improve lipid digestibility in young broilers. Further research would be required to validate the relative interaction effects on nutrient digestibility throughout the digestive tract to confirm these hypotheses.

In conclusion, broilers fed diets containing rapidly digestible protein sources had an increased ADG and improved FCR throughout the experiment, but most notably after the starter phase. Inclusion of IDF such as OH improved the ADFI and ADG in the starter phase compared with SBP, an SDF source. However, this was not reflected in an improvement on the FCR. The ADG and FCR of broilers fed diets that contained slowly digestible protein sources could be improved to the level of broilers fed diets containing rapidly digestible protein sources by adding 3% OH. These results confirm the hypothesis that the addition of OH to diets that contain slowly digestible protein sources would ameliorate the reduced performance of broilers fed slowly digestible protein diets. It is concluded that broiler diets should be formulated to contain a high concentration of rapidly digestible protein sources, but if this is cost-prohibitive, then 3% OH or potentially other IDF sources can be used to increase the ADFI and ADG and potentially protein digestion rates to reduce the FCR.

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