Impact of fiber on growth, plasma, gastrointestinal and excreta attributes in broiler chickens and turkey poults fed corn- or wheat-based diets with or without multienzyme supplement

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ABSTRACT Effects of fiber on growth performance, gizzard attributes, ileal digesta viscosity, plasma uric acid (**PUA**) and excreta characteristics were investigated in broiler chickens (experiment 1) and turkey poults (experiment 2) fed corn or wheat-based diets with or without multienzyme supplement (**MES**). Fibrous diets were created by adding 10% corn distillers dried grains with solubles or wheat middlings in corn or wheat-based diets, respectively. The MES had main activities of xylanase and β-glucanase. A total of 960-d old Ross x Ross 708 male chicks and 720-d old male Hybrid toms were allocated to eight grain, fiber and MES combinations to give 6 replicates per combination. In each experiment, birds had free access to feed and water for 28 days. Excreta samples were collected for 3-d prior to the end and on d 28, body weight and feed intake were recorded, birds bled and subsequently necropsied for gastrointestinal samples. There was an interaction ($P \leq 0.036$) between grain, fiber and MES in broilers final body weight (**FBW**) and BW gain (**BWG**). In this context, high fiber corn diets reduced FBW and BWG and supplementation of MES improved these parameters. Broilers fed corn had a higher ($P < 0.05$) FBW (1,462 vs. 1,424 g) and BWG (1,416 vs. 1,378 g) than birds fed wheat diets. Broilers fed corn-based diets without fiber diets had a higher ileal viscosity and excreta moisture compared to birds fed wheat-based and high fiber diets. Broilers fed low fiber wheat diets without MES had higher ($P < 0.05$) PUA concentration compared to birds fed low fiber corn diets without MES. Poults fed wheat diets had a higher ($P < 0.05$) FBW (1,441 vs. 1,408 g) and BWG (1,376 vs. 1,343 g) than poults fed corn diet. The MES supplementation in corn-based diets rich in fiber increased ($P = 0.03$) gizzard weight in poults. In conclusion, there were varied growth and physiological responses in broilers and turkey suggesting the need for refining enzyme application for different poultry species.

Key words: broiler, growth performance, fiber and multienzyme, gastrointestinal ecology, turkey

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INTRODUCTION

Over the last few decades, the poultry industry has tremendously increased production and efficiency due to advancements in genetics, nutrition, and management practices (Mottet and Tempio, 2017). At the same time, feeding, a major control point of profitability has evolved and progressed both in terms of understanding digestive physiology and metabolism, and in the more precise evaluation of the quality of dietary raw materials (Kiarie and Mills, 2019). However, in the context of burgeoning human population and attendant demand for food, feed industry is now challenged by volatile commodity markets, limited availability of natural resources, climate change pressure and food-feed-biofuel competition (FAO, 2011, 2017). These emerging scenarios have put pressure on the monogastric industry to use significant quantities of alternative feedstuffs that are unacceptable for human consumption such as co-products from the milling and bio-fuel industries (Kiarie et al., 2013a; Woyengo et al., 2014; Rho et al., 2018). A characteristic of these feedstuffs is high concentration of dietary fiber, composed mainly of nonstarch polysaccharides (**NSP**) (Knudsen and Bach Knudsen, 2011; Knudsen, 2014). The fiber fractions vary

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widely among feedstuffs; however, they can be considered alike from monogastric nutrition viewpoint in that they influence voluntary feed intake, nutrient utilization, and metabolic processes.

In poultry nutrition, dietary fiber is considered as antinutritive due to its minor role in energy supply and its interference with digestive processes. For example, a large proportion of the soluble pentosans in cereal grains are of a sufficiently high molecular weight to increase viscosity of the contents of the gastrointestinal tract, resulting in a concomitant decrease in the diffusion of nutrients and, therefore, the nutritive value of the diet (Bedford and Schulze, 1998). Thus, supplemental fiber degrading enzymes are routinely supplemented in poultry diets to improve utilization of fibrous feedstuffs (Bedford and Schulze, 1998; Adeola and Cowieson, 2011; Slominski, 2011). On the other hand, it is recognized that low to moderate amounts of fiber might be beneficial for gastrointestinal development and function in young birds (Hetland et al., 2004; Mateos et al., 2012). Indeed, foundational studies more than half a century ago demonstrated that chickens have a propensity to consume a great variety of ingredients when offered free choice (Emmans, 1979). These free choice studies also showed that not only that chickens can adjust feed consumption according to caloric and nutrient needs but can voluntarily consume ingredients considered of low or non-existent nutritional value. Later research demonstrated that preference for low nutritive but structural feed material had beneficial effects on the overall utilization of feed and productivity linked to modulation of the gastrointestinal tract (Hetland and Svihus, 2001; Hetland et al., 2003b, 2005). Diets containing structural components, such as fiber, improve gizzard function by increased retention time and better grinding (Svihus, 2011; Kiarie and Mills, 2019). These mechanisms, in conjunction with better synchronization of feed flow, are thought to improve nutrient utilization (Jiménez-Moreno et al., 2009; Svihus et al., 2010).

In practical poultry nutrition, the view of fiber being “anti-nutrient” predominates, however, it appears that there could be benefits of feeding some level of fibrous feedstuffs with respect to gastrointestinal development and function. Therefore, as a general approach to enhance fibrous feedstuffs' utilization, a two-fold strategy seems plausible, mitigate negative effects of fiber with dietary enzymes and capitalize on the positive effects on gizzard function. Moreover, a better understanding of the relationship between fiber fractions and gastrointestinal development will be helpful as the industry seeks for strategies to bolster bird performance without recourse to antimicrobial growth promoters (Kiarie et al., 2013b; Kiarie and Mills, 2019; Bean-Hodgins and Kiarie, 2021). There is limited research that investigated the interactive effects of fiber and fiber degrading enzymes on gastrointestinal development in poultry. This study hypothesized that the addition of fibrous feedstuffs in the presence of fiber degrading enzyme will improve growth performance and gizzard development in both broiler chickens and turkeys. Thus, the objective was to investigate the effects of adding fibrous feedstuffs on growth performance, gizzard measurements, ileal digesta viscosity, plasma uric acid (**PUA**) and excreta characteristics in broiler chickens (Experiment 1) and turkey poults (Experiment 2) fed corn or wheat-based diets with or without multi-enzyme supplement (**MES**).

MATERIALS AND METHODS

Experimental procedures and animal use were reviewed and approved (AUP# 3521) by the University of Guelph Animal Ethics Committee. Broilers and turkeys were cared in accordance with the Canadian Code of Practice for the Care and Use of Animals for Scientific Purposes (CCAC, 2009).

Experimental Diets and Enzymes

Corn- or wheat- based (low fiber) diets were formulated with or without corn dried distillers grains with solubles (**cDDGS**) or wheat middlings (**WM**) to meet or exceed the specifications for Ross x Ross 708 broilers

Table 1. Composition of basal diets, as fed basis (experiment 1).

	Corn diets		Wheat diets	
Ingredient, %	Corn	+ DDGS	Wheat	+ Middlings
Corn	62.1	57.9		
Wheat	-	-	64.1	56.2
Corn DDGS	-	10.0	-	-
Wheat middlings, shorts	-	-	-	10.0
Soybean Meal-46%	29.8	24.2	24.3	22.3
Pork Meal−58%	3.00	3.00	3.00	3.00
Soy oil	1.07	0.87	4.17	4.05
Monocalcium phosphate	1.35	1.11	1.26	1.31
Limestone	0.61	0.76	0.81	0.77
Vitamin and trace minerals premix[1]	1.00	1.00	1.00	1.00
DL-Methionine	0.31	0.30	0.32	0.38
L-Lysine HCL	0.29	0.45	0.41	0.51
L-Threonine-	0.14	0.18	0.20	0.25
Salt	0.25	0.16	0.18	0.15
Sodium bicarbonate	0.10	0.10	0.14	0.19
Calculated Provisions				
AME, kcal/kg	3,000	3,000	3,000	3,000
Crude protein, %	21.0	21.0	21.0	21.0
Crude fat, %	3.76	3.40	5.97	6.09
Neutral detergent fiber, %	7.75	9.96	9.16	12.02
SID Lys, %	1.15	1.15	1.15	1.15
SID Met, %	0.59	0.59	0.58	0.61
SID Met + Cys, %	0.85	0.85	0.85	0.85
SID Trp, %	0.22	0.20	0.23	0.21
SID Thr, %	0.77	0.77	0.77	0.77
Calcium, %	0.92	0.92	0.92	0.92
Total phosphorous, %	0.76	0.74	0.77	0.85
Available phosphorous, %	0.46	0.46	0.46	0.46
Sodium, %	0.16	0.16	0.16	0.16
Chloride, %	0.23	0.23	0.23	0.23
Analyzed provisions				
Crude protein, %	21.0	21.5	21.4	20.2
Crude fat, %	3.07	3.83	4.34	4.84
Starch, %	40.3	37.5	40.2	38.0
Neutral detergent fiber, %	7.78	10.2	9.04	11.1

[1] Provided per kilogram of diet: trans-retinol, 2.64 mg; cholecalciferol, 83 μg; dl-α-tocopherol, 36 mg; cyanocobalamin, 12.0 mg; menadione, 3.3 mg; niacin, 50.0 mg; choline, 1,200.0 mg; folic acid, 1.0 mg; biotin, 0.22 mg; pyridoxine, 3.3 mg; thiamine, 4.0 mg; calcium pantothenic acid, 15.0 mg; riboflavin, 8.0 mg; manganese, 70.0 mg; zinc, 70.0 mg; iron, 60.0 mg; iodine, 1.0 mg; copper, 10 mg; and selenium, 0.3 mg.

Table 2. Composition of basal diets, as fed basis (experiment 2).

	Corn diets		Wheat diets	
Ingredient, %	Corn	+DDGS	Wheat	+Middlings
Corn	49.8	44.8	-	-
Wheat	-	-	53.5	45.3
Corn DDGS	-	10.0	-	-
Wheat middlings, shorts	-	-	-	10.0
Soybean meal 46%	36.3	31.4	29.3	27.6
Pork meal-58%	10.4	9.83	12.0	11.7
Soy oil	0.20	0.20	2.06	2.02
Vitamin and trace minerals premix[1]	1.00	1.00	1.00	1.00
Monocalcium phosphate	1.10	0.97	0.65	0.76
Limestone fine	0.08	0.30	-	-
L-Lysine HCL	0.51	0.65	0.64	0.72
DL-Methionine	0.42	0.41	0.44	0.49
L-Threonine	0.16	0.20	0.23	0.28
Salt	0.20	0.12	0.13	0.10
Sodium bicarbonate	0.01	0.08	0.02	0.08
L-Tryptophan	0.01	0.02	0.05	0.03
Calculated provisions				
AME, kcal/kg	2,850	2,850	2,850	2,850
Crude protein, %	27.5	27.5	27.5	27.5
Crude fat, %	3.25	3.00	4.65	4.81
Neutral detergent fiber, %	7.06	9.26	8.25	11.1
SID Lys, %	1.62	1.62	1.62	1.62
SID Met, %	0.76	0.77	0.77	0.80
SID Met + Cys, %	1.05	1.05	1.05	1.05
SID Trp, %	0.28	0.28	0.28	0.28
Sid Thr, %	0.96	0.96	0.96	0.96
Calcium, %	1.40	1.40	1.40	1.40
Total phosphorous, %	1.08	1.06	1.07	1.16
Available phosphorous, %	0.75	0.75	0.75	0.75
Sodium, %	0.16	0.16	0.16	0.16
Chloride, %	0.24	0.24	0.24	0.24
Analyzed provisions				
Crude protein, %	28.0	28.7	28.4	29.0
Crude fat, %	3.70	3.75	3.74	4.84
Starch, %	30.9	28.1	30.5	28.7
Neutral detergent fiber, %	7.87	9.03	8.90	10.4

[1] Provided per kg of diet: trans-retinol, 2.64 mg; cholecalciferol, 83 μg; dl-α-tocopherol, 36 mg; cyanocobalamin, 12.0 mg; menadione, 3.3 mg; niacin, 50.0 mg; choline, 1,200.0 mg; folic acid, 1.0 mg; biotin, 0.22 mg; pyridoxine, 3.3 mg; thiamine, 4.0 mg; calcium pantothenic acid, 15.0 mg; riboflavin, 8.0 mg; manganese, 70.0 mg; zinc, 70.0 mg; iron, 60.0 mg; iodine, 1.0 mg; copper, 10 mg; and selenium, 0.3 mg.

(Aviagen, 2019; Table 1), and Hybrid turkeys (Hybrid converter, Hendrix Genetic, Kitchener, ON, Canada; Table 2). The diets were fed without or with MES, effectively creating a 2 (corn or wheat grain) x 2 (low or high fiber) x 2 (− or + MES) factorial arrangement of 8 dietary treatments. The MES and assay procedures were provided by the Canadian Bio-Systems Inc. (Superzyme Calgary, AL, Canada). The MES supplied main activity of xylanase and β-glucanase and other minor activities including invertase, protease, cellulase, amylase, and β-mannanase. The targeted activity level for xylanase and β-glucanase was 800 U/kg and 160, U/kg of feed, respectively. The diets were prepared in a fine crumble form. The temperature of the processing condition was 60°C to 65°C and steam pressure of 30 psi.

Birds, Housing, and Experimental Procedures

The study was conducted in two independent consecutive experiments. In experiment 1, a total of 960-d old male broiler chicks (Ross x Ross 708) were allocated to 48 identical floor pens (20 birds per pen) based on body weight. Each pen had fresh wood shavings bedding, measured 200 × 213 cm and was equipped with a round pan feeder (diameter = 33.75 cm) and 5 nipple drinkers. The room temperature was set at 32°C from d 0-2, 31°C from d 3-7, 29°C from d 7-14 and 27°C from d 14 until the end of the experimental period. The lighting program was set at 24 h of light (20+ LUX) on d 0, 22 h of light (20+ LUX) on d 1, 20 h of light (20+ LUX) on d 2, 18 h of light (20+ LUX) on d 3, and 16 h of light (10−15 LUX) on d 4 onward. In experiment 2, a total of 720-d old turkey Tom poults (Hybrid Turkey) were allocated to 48 identical floor pens (15 birds per pen) based on body weight. Each pen was equipped with a feeder (similar to experiment 1) and 2 turkey drinkers. The room temperature was set at 30°C from d 0 and gradually lowered to 29°C by d 7 followed by a stepwise reduction to 25.5°C by d 21. The lighting program was set at 23 h of light (60+ LUX) on d 0, 22 h of light (60+ LUX) on d 2, 21 h of light (60+ LUX) on d 3, 20 h of light (60+ LUX) on d 4, 19 h of light (60 LUX) on d 5, 18 h of light (60 LUX) on d 6 and 16 h of light (20 LUX) on d 7 onward. The sunrise or sunset program was set at 20 minutes. The floor pens had fresh wood shavings at the start of each experiment.

In both experiments, the diets were allocated to pens in a completely randomized design to give 6 replicates per diet. Birds had free access to feed and water from d 0 to 28 ad libitum. The body weight (**BW**) and feed intake (**FI**) were recorded on d 0 and 28 for calculation of body weight gain (**BWG**) and FCR. Mortalities were recorded as they appeared for calculation of adjusted FCR. On d 25, wood shavings in half of each pen were removed and trays were placed for excreta collection from d 26 to 28. Trays were cleaned daily after each collection. Excreta samples were stored at −20°C until further processing. On d-28, 2 birds per pen were randomly selected, bled, euthanized by cervical dislocation, weighed, and necropsied for gastrointestinal measurements. Blood samples were immediately put on ice and transported to the laboratory for processing. Gizzard pH was measured (Accumet 950 pH/ion meter, Fisher Scientific Waltham, MA), then the gizzards were cleaned of digesta, and the weights were recorded. Ileal digesta was collected for viscosity measurements by squeezing out the digesta from ileal section from Meckel's diverticulum to 1 cm anterior to ileal-cecal junction. Ileal digesta samples were stored at −20°C until further processing.

Sample Processing, Physical and Chemical Analyses

The excreta samples were thawed, pooled by pen and oven dried at 60°C for 72 h to determine moisture content. The dried samples were subsequently ground, and N determination carried out using N analyzer (FP-528; Leco, Saint Joseph, MI). The ileal digesta samples were thawed, and aliquots of 5 g diluted to a volume of

100 mL with distilled water and centrifuged at 2,500 g x 15 min at 41°C. The dilution was necessary because the samples were small, and the equipment required a minimum liquid volume of 100 mL. The supernatant was withdrawn, and the viscosity (expressed in centipoise) was measured (Brookfield LVDV-I Prime digital viscometer with a LV 61 spindle, Brookfield Engineering Labs, Stoughton, UK) at 100 rpm. Blood samples were centrifuged at 2,500 g x 15 min at 4°C and the supernatant (plasma) transferred to a 2 mL microcentrifuge tube and analyzed at the Animal Health Laboratory (University of Guelph, Guelph, Canada) for plasma uric acid concentration (**PUA**) by photometric method. The short-chain fatty acid (**SCFA**) concentration was analyzed as described by Mohammadigheisar et al. (2019).The cecal digesta was thawed and approximately 0.1 g of the digesta was suspended in 1mL 0.005 H_2SO_4 (1:10, wt/vol) and vigorously vortexed in a microcentrifuge tube. The samples were then centrifuged at 11,000 x g for 15 min. After centrifuging, 400 μL of the supernatant was then transferred into a high-pressure liquid chromatography (**HPLC**) vial and 400 μL of 0.005 N H_2SO_4 buffer was added. The digesta fluid was then assayed for short-chain fatty acid (**SCFA**) concentration by using HPLC (Hewlett Packard 1100, Germany) with Rezex ROA-Organic Acid LC column, 300 × 7.8 mm from Phenomenex and Refractive Index detector at 40°C (Agilent 1260 Infinity RID from Agilent Technologies, Germany). A total of 20 μL of the resulting sample was injected into the column with a column temperature of 60°C and mobile phase of 0.005 N H_2SO_4 buffer at 0.5 mL/min isocratic for 35 min. The detector was heated to 40°C. Xylanase activity in diets was assayed using Xylazyme AX tablets (Megazyme International Ltd., Bray, Ireland). One unit of xylanase was defined as the quantity of the enzyme that liberated 1 μmoL of xylose equivalent per min. Endo 1,4- β-glucanase was assayed using Azo Barley Glucan as a substrate. One unit of β-glucanase was defined as the amount of enzyme that produces one micromole of glucose reducing per min.

Calculations and Statistical Analysis

The gizzard weight was expressed as a percentage of bodyweight. The data for each experiment was analyzed independently as completely randomized design using GLM procedures of SAS (SAS Inst. Inc., Cary, NC). The model included the main effects of grain (wheat, corn), fiber (low, high), MES (yes, no) and associated interactions as fixed factors. Tukey method was used for Lsmeans separation when interaction effects and t-test was used for the main effects. An alpha level of $P \leq 0.05$ was used to determine statistical significance.

RESULTS

The analyzed xylanase and β-glucanase activities were 112 and 45, 75 and 67, 480 and 200, 601 and 239, 167 and 38, 147 and 60, 944 and 250, 1,027 and 240 U/kg of feed for the corn, corn + cDDGS, corn + MES, corn + cDDGS + MES, wheat, wheat + WM, wheat + MES and wheat + WM + MES diets, respectively in experiment 1. The corresponding values for experiment 2 were 147 and 23, 78 and 57, 679 and 245, 675 and 200, 114 and 25, 70 and 35, 895 and 216, 1,095 and 205 U/kg, respectively.

Experiment 1

There was no interaction ($P > 0.10$) between grain, fiber and MES on FI and FCR (Table 3). An interaction ($P \leq 0.04$) between grain, fiber and MES was such that the addition of fiber to corn-based diets reduced final body weight (**FBW**) and BWG but addition of MES improved these parameters (Table 3). Additionally, broilers fed corn diet with fiber and MES had higher FBW and BWG than broilers fed wheat diet with fiber and MES. Overall, broilers fed corn-based diets tended to eat more feed (1,915 vs. 1,860 g, $P = 0.07$) and were heavier (1,462 vs. 1,424 g, $P = 0.02$) than birds fed wheat-based diets. Fiber tended to reduce FBW ($P = 0.08$) and BWG ($P = 0.09$). There was no interaction ($P > 0.10$) between grain, fiber and MES on the gizzard weight, gizzard pH and ileal digesta viscosity (Table 3). The main effect of grain was such that birds fed corn diets had lower ($P = 0.01$) gizzard pH and higher ($P = 0.04$) ileal digesta viscosity than birds fed wheat diets. Birds fed high fiber diet had a lower ($P = 0.01$) ileal digesta viscosity than birds fed low fiber diets. There was an interaction ($P = 0.05$) between grain, fiber and MES on concentration of PUA, such that birds fed low fiber wheat-based diet without MES had a higher (389 vs. 307 μmol/L) PUA compared with birds fed low fiber corn-based diet without MES (Table 3).

There was an interaction ($P \leq 0.03$) between grain, fiber and MES on ceca digesta concentration of lactic and propionic acid (Table 4). In this context, birds fed corn + cDDGS with MES had higher ceca digesta lactic acid than birds fed same diet without MES. Whereas for propionic acid, birds fed wheat + WM exhibited higher lactic acid concentration than birds fed corn diet with cDDGS or MES. There was no interaction ($P > 0.10$) between grain, fiber and MES on excreta moisture and N contents in broiler chickens (Table 4). Birds fed corn-based diets had higher ($P = 0.003$) excreta moisture contents compared with birds fed wheat-based diets. Additionally, broilers fed low fiber diets had a higher excreta moisture (78.4 vs. 77.7%, $P = 0.004$) and N (27.7 vs. 25.1%, $P = 0.002$) compared with birds fed high fiber diets (Table 4).

Experiment 2

There was no interaction ($P > 0.10$) between grain, fiber and MES on BWG, FBW, FI, and FCR (Table 5). However, a tendency ($P = 0.09$) for interaction between

Table 3. Effects of adding fibrous ingredients in a corn or wheat diet without or with multi enzymes on growth performance, gizzard attributes, ileal digesta viscosity and concentration of plasma uric acid in broiler chickens (experiment 1).

Item			Growth performance					Gizzard			
			IBW, g/bird	FBW, g/bird	BWG, g/bird	FI, g/bird	FCR[2]	Empty weight, g/kg BW	Digesta pH	Viscosity, cP	PUA, μmol/L
Grain	Fiber	Enzyme[1]									
Corn	Low	-	46.3	1,495^{a}	1,448^{a}	1,977	1.346	18.1	2.6	5.77	307.2^{b}
	High	-	45.8	1,425^{bc}	1,379^{bc}	1,874	1.359	18.6	2.7	5.52	343.4^{ab}
	Low	+	46.0	1,457^{abc}	1,410^{abc}	1,901	1.348	17.2	2.8	5.68	376.5^{ab}
	High	+	46.0	1,473^{ab}	1,427^{ab}	1,910	1.360	17.0	2.9	4.95	335.7^{ab}
Wheat	Low	-	46.0	1,428^{bc}	1,382^{bc}	1,853	1.368	15.4	2.9	5.38	389.2^{a}
	High	-	45.8	1,423^{bc}	1,377^{bc}	1,789	1.297	17.4	3.3	4.50	336.0^{ab}
	Low	+	46.3	1,448^{abc}	1,401^{abc}	1,891	1.367	16.5	3.1	5.45	335.7^{ab}
	High	+	46.0	1,399^{c}	1,353^{c}	1,909	1.374	17.3	2.9	4.28	364.0^{ab}
	SEM		0.15	0.26	21.2	41.8	0.022	0.93	0.16	0.38	27.51
Main effect of Grain											
Corn				1,462^{a}	1,416^{a}	1,915	1.353	17.7	2.7^{b}	5.48^{a}	340.6
Wheat				1,424^{b}	1,378^{b}	1,860	1.351	16.6	3.1^{a}	4.90^{b}	356.2
Main effect of Fiber											
Low				1,457	1,410	1,905	1.357	16.8	2.9	5.57^{a}	352.1
High				1,430	1,384	1,870	1.347	17.6	2.9	4.81^{b}	344.8
Main effect of Enzyme											
-				1,443	1,396	1,873	1.342	17.4	2.9	5.29	343.9
+				1,444	1,398	1,903	1.362	17.0	2.9	5.09	353.0
SEM				10.6	10.6	20.9	0.011	0.46	0.08	0.19	13.8
Probabilities											
Grain				0.016	0.016	0.070	0.908	0.107	0.010	0.036	0.430
Fiber				0.083	0.085	0.245	0.526	0.223	0.505	0.007	0.707
Enzyme				0.919	0.934	0.322	0.212	0.563	0.798	0.456	0.645
Grain x Fiber				0.993	0.996	0.682	0.159	0.363	0.926	0.321	0.796
Grain x Enzyme				0.811	0.800	0.102	0.246	0.190	0.355	0.640	0.270
Fiber x Enzyme				0.480	0.482	0.110	0.232	0.514	0.237	0.475	0.955
Grain x Fiber x Enzyme				0.035	0.036	0.802	0.206	0.872	0.198	0.852	0.049

[1] Supplied main activity of xylanase and β-glucanase and other minor activities including invertase, protease, cellulase, amylase and mannanase. The targeted activity level of xylanase and β-glucanase were 800 and160, U/kg of feed, respectively.

[2] Corrected for mortality.

[a-c] Within a factor of analyses, response criteria with means with different superscripts are significantly different, $P < 0.05$.

grain, fiber, and MES was observed for FI such that poults fed wheat diet with MES tended to eat more feed than poults fed wheat diet without MES. The main effect ($P = 0.03$) of grain on FBW and BWG in poults showed that birds fed wheat-based had a greater FBW (1,441 vs. 1,408) and BWG (1,376 vs. 1,343) than birds fed corn-based diets. There was no interaction ($P > 0.10$) between grain, fiber and MES on the gizzard weight, gizzard pH and ileal digesta viscosity (Table 5). However, there was an interaction ($P = 0.03$) between grain and enzyme on gizzard weight (Table 5). In this context, poults fed a corn diet with MES had heavier gizzard (26.7 g/kg BW) than poults fed corn diets without MES (23.7 g/kg BW) and wheat diets without (22.8 g/kg BW) or with (21.9 g/kg BW) MES. In general, poults fed corn-based diets had higher ($P = 0.001$) gizzard weight compared with poults fed wheat-based diets. Fiber tended to increase ($P = 0.09$) gizzard weight in poults. Additionally, feeding fiber increased ($P = 0.04$) the gizzard pH relative low fiber (Table 5). Ileal digesta viscosity and concentration of PUA was not affected ($P > 0.10$) by treatments (Table 5).

Diets had no effects ($P > 0.10$) on ceca digesta concentration of SCFA (Table 6). There was no interaction ($P > 0.10$) between grain, fiber and MES on excreta moisture and N contents (Table 6). However, excreta N content was affected by grain interaction with enzyme ($P = 0.003$), and fiber ($P = 0.04$). Inclusion of fiber reduced excreta N content in corn diets; the excreta N contents for low and high fiber corn diets were 33.8 and 30.6%, and respective values in wheat diets were 30.1 and 29.7%. Similarly, MES increased excreta N content in corn diets, with values for corn diets without and with MES being 30.5 and 34.2%, and respective values in wheat diets were 30.1 and 29.3%. Generally, poults fed corn diets exhibited higher ($P = 0.01$) excreta N than poults fed wheat-based diets.

DISCUSSION

Broiler chickens fed corn diets had greater growth compared to those fed wheat diets. In contrast, poults grew better when fed wheat diets than corn diets. It is generally accepted that corn-based diets have a superior nutritive value relative to diets based on small grains such as wheat and barley linked to higher concentration of anti-nutritive soluble fiber (Slominski, 2011). However, it has also been demonstrated that the nutritional value of corn is variable and linked to the chemical composition profile (Cowieson, 2005; Leung and Kiarie, 2020). However, since the corn used in the present study was from the same source (feed mill), it is postulated that physiological differences between broilers and turkeys could have played a part. There are very few comparative studies between broilers and turkeys in

Table 4. Effects of adding fibrous ingredients in a corn or wheat diet without or with multi enzymes on ceca digesta concentration of short chain fatty acids and litter attributes in broiler chickens (experiment 1).

Item			Short chain fatty acids, μmol/g					Litter attributes, %	
			Lactic	Acetic	Propionic	Iso-Butyric	Butyric	Moisture	Nitrogen
Grain	Fiber	Enzyme[1]							
Corn	Low	-	24.2^{ab}	87.2	7.42^{ab}	9.11	20.9	79.0	28.6
	High	-	21.3^{b}	91.8	6.88^{b}	9.47	17.9	77.8	25.9
	Low	+	22.3^{ab}	88.1	6.93^{b}	8.67	17.5	78.5	27.2
	High	+	26.4^{a}	87.3	8.47^{ab}	10.5	21.4	78.2	26.0
Wheat	Low	-	21.8^{ab}	91.4	7.47^{ab}	8.02	18.7	78.0	26.8
	High	-	25.5^{ab}	91.6	8.96^{a}	9.06	21.9	77.5	24.9
	Low	+	25.6^{ab}	92.3	7.92^{ab}	9.13	20.6	77.9	28.3
	High	+	24.2^{ab}	82.6	7.48^{ab}	8.06	18.8	77.5	23.7
	SEM		1.78	3.62	0.63	0.73	2.36	0.28	1.1
Main effect of Grain									
Corn			23.6	88.6	7.43	9.44	19.4	78.4^{a}	26.9
Wheat			24.3	89.5	7.96	8.61	20.0	77.7^{b}	25.9
Main effect of Fiber									
Low			23.5	89.8	7.43	8.78	19.4	78.4^{a}	27.7^{a}
High			24.4	88.3	7.95	9.27	20.0	77.7^{b}	25.1^{b}
Main effect of Enzyme									
-			23.2	90.5	7.68	8.91	19.8	78.1	26.5
+			24.6	87.6	7.70	9.13	19.6	78.0	26.3
SEM			0.88	1.56	0.31	0.37	1.18	0.14	0.57
Probabilities									
Grain			0.581	0.716	0.240	0.121	0.744	0.003	0.215
Fiber			0.489	0.584	0.253	0.353	0.725	0.004	0.002
Enzyme			0.257	0.259	0.965	0.677	0.879	0.848	0.782
Grain x Fiber			0.839	0.197	0.975	0.255	0.927	0.382	0.449
Grain x Enzyme			0.883	0.661	0.238	0.886	0.827	0.925	0.539
Fiber x Enzyme			0.714	0.145	0.937	0.693	0.778	0.233	0.708
Grain x Fiber x Enzyme			0.020	0.668	0.0304	0.079	0.082	0.326	0.207

[1] Supplied main activity of xylanase and β-glucanase and other minor activities including invertase, protease, cellulase, amylase and mannanase. The targeted activity level of xylanase and β-glucanase were 800 and 160, U/kg of feed, respectively.

Corrected for mortality

[a, b] Within a factor of analyses, response criteria with means with different superscripts are significantly different, $P < 0.05$.

Table 5. Effects of adding fibrous ingredients in a corn or wheat diet without or with multi enzymes on growth performance gizzard attributes, ileal digesta viscosity and plasma uric acid in turkey poults (experiment 2).

Item			Growth performance					Gizzard			
			IBW, g/bird	FBW, g/bird	BWG, g/bird	FI, g/bird	FCR[2]	Empty weight, g/kg BW	Digesta pH	Viscosity, cP	PUA, μmol/L
Grain	Fiber	Enzyme[1]									
Corn	Low	-	65.7	1,447	1,381	1,765	1.278	22.5	2.3	4.95	308.0
	High	-	65.5	1,400	1,335	1,621	1.206	24.8	2.5	5.50	275.7
	Low	+	65.8	1,392	1,326	1,606	1.223	25.9	2.6	5.35	281.5
	High	+	65.7	1,395	1,329	1,721	1.294	27.6	2.5	4.85	262.2
Wheat	Low	-	65.7	1,452	1,386	1,480	1.071	22.1	2.3	5.10	247.8
	High	-	65.7	1,443	1,374	1,600	1.273	23.0	2.8	4.70	261.5
	Low	+	66.2	1,440	1,377	1,746	1.167	21.5	2.3	5.15	268.7
	High	+	65.5	1,431	1,366	1,616	1.185	22.3	2.9	4.50	254.5
	SEM		0.35	20.6	20.6	103.9	0.081	1.14	0.19	0.29	30.01
Main effect of Grain											
Corn				$1,408^{b}$	$1,343^{b}$	1,678	1.251	25.2^{a}	2.5	5.16	281.8
Wheat				$1,441^{a}$	$1,376^{a}$	1,611	1.174	22.2^{b}	2.6	4.86	258.1
Main effect of Fiber											
Low				1,432	1,367	1,617	1.185	23.0	2.4^{b}	5.13	276.5
High				1,417	1,352	1,672	1.240	24.4	2.7^{a}	4.89	263.5
Main effect of Enzyme											
-				1,435	1,370	1,649	1.207	23.1	2.5	5.06	273.3
+				1,414	1,348	1,640	1.217	24.3	2.6	4.96	266.7
SEM				10.2	10.2	51.9	0.04	0.57	0.10	0.14	15.0
Probabilities											
Grain				0.029	0.028	0.362	0.187	0.001	0.473	0.152	0.272
Fiber				0.307	0.305	0.451	0.342	0.090	0.044	0.230	0.543
Enzyme				0.115	0.147	0.897	0.862	0.142	0.583	0.629	0.551
Grain x Fiber				0.655	0.653	0.252	0.343	0.482	0.066	0.188	0.760
Grain x Enzyme				0.523	0.521	0.951	0.917	0.028	0.751	0.904	0.530
Fiber x Enzyme				0.387	0.382	0.976	0.858	0.801	0.542	0.121	0.862
Grain x Fiber x Enzyme				0.400	0.400	0.090	0.160	0.890	0.575	0.336	0.634

[1] Supplied main activity of xylanase and β-glucanase and other minor activities including invertase, protease, cellulase, amylase and mannanase. The targeted activity level of xylanase and β-glucanase were 800 and 160, U/kg of feed, respectively.

[2] Corrected for mortality.

[a, b] Within a factor of analyses, response criteria with means with different superscripts are significantly different, $P < 0.05$.

Table 6. Effects of adding fibrous ingredients in a corn or wheat diet without or with multi enzymes on ceca digesta concentration of short chain fatty acids and litter attributes in turkey poults (experiment 2).

Item			Short chain fatty acids, μmol/g					Litter attributes, %	
			Lactic	Acetic	Propionic	Iso-butyric	Butyric	Moisture	Nitrogen
Grain	Fiber	Enzyme[1]							
Corn	Low	-	38.3	54.1	12.4	11.9	25.4	76.1	30.7
	High	-	54.4	57.0	10.0	10.8	25.2	77.8	29.6
	Low	+	44.4	60.2	17.4	10.8	25.8	78.4	37.0
	High	+	46.3	59.8	11.4	10.2	24.6	77.4	31.6
Wheat	Low	-	44.3	57.9	10.5	11.3	25.9	77.7	30.4
	High	-	42.9	60.1	13.3	11.9	28.5	77.8	30.6
	Low	+	43.0	52.2	12.9	10.8	24.7	77.8	29.0
	High	+	54.2	63.4	13.2	10.9	25.9	77.5	29.6
	SEM		4.93	4.66	3.35	1.33	2.13	0.85	1.20
Main effect of Grain									
Corn			45.8	57.8	12.8	10.9	25.3	77.4	32.2[a]
Wheat			46.1	58.4	12.5	11.2	26.3	77.7	29.9[b]
Main effect of Fiber									
Low			42.5	56.1	13.3	11.2	25.4	77.5	31.8
High			49.5	60.1	12.0	10.9	26.1	77.6	30.4
Main effect of Enzyme									
-			45.0	57.3	11.6	11.5	26.3	77.3	30.3
+			47.0	59.9	13.7	10.7	25.3	77.8	31.8
SEM			2.46	2.33	1.68	0.67	1.06	0.43	0.60
Probabilities									
Grain			0.940	0.850	0.890	0.749	0.509	0.651	0.010
Fiber			0.053	0.235	0.587	0.779	0.679	0.808	0.106
Enzyme			0.576	0.618	0.370	0.401	0.512	0.466	0.086
Grain x Fiber			0.568	0.411	0.229	0.524	0.391	0.729	0.038
Grain x Enzyme			0.403	0.397	0.668	0.987	0.533	0.361	0.003
Fiber x Enzyme			0.906	0.675	0.532	0.990	0.686	0.230	0.249
Grain x Fiber x Enzyme			0.061	0.358	0.906	0.793	0.961	0.337	0.187

[1] Supplied main activity of xylanase and β-glucanase and other minor activities including invertase, protease, cellulase, amylase and mannanase. The targeted activity level of xylanase and β-glucanase were 800 and160, U/kg of feed, respectively.

Corrected for mortality.

[a, b] Within a factor of analyses, response criteria with means with different superscripts are significantly different, $P < 0.05$.

terms of feedstuffs' utilization. Although the diets were formulated to have similar nutrient specifications for each bird type, comparatively the wheat diets had a higher concentration of fiber than corn diets. Feeding a diet containing 8 vs. 2.5 % crude fiber reduced growth in broiler chicks while poults growth was unaffected (Hollister, 1991). It was opined that turkey poults might be able to achieve normal growth on high fiber diets due to their digestive capacity. Diets containing up to 6% crude fiber were shown to enhance growth performance in turkeys older than 6 weeks of age and crude fiber of 9% did not have deleterious effects on growth (Leeson et al., 1997; Sklan et al., 2003). However, the same study showed growth performance was poorer in turkeys below 4 weeks of age when fed 9% crude fiber relative to 3% crude fiber suggesting that young birds are more sensitive to fiber due to their immature gastrointestinal tract. Kiarie et al. (2017) suggested that insoluble NSP can have negative effects on growth performance in younger broilers relative to older broilers. Insoluble NSP can hinder growth performance by increasing gut transit time and motility, while hindering the ability of endogenous enzymes to digest their respective substrates (Bedford and Schulze, 1998; Slominski, 2011). Furthermore, wheat is one of the most variable cereal grains, as the chemical and physical composition fluctuates (Gutierrez Del Alamo et al., 2008), and can be attributed to the time of year, growing location, moisture conditions, variety as well as many other factors (Amerah et al., 2009). Many studies have shown that the growth performance of birds fed wheat-based diets can vary depending on the type of wheat used, particularly the level of NSP (Amerah, 2015). Although, the insoluble and soluble components of the diets were not analyzed in the current study, the data suggested that the wheat used could have had low-NSP concentration compared to other studies. This can be further backed up by the lower gizzard weights in turkeys fed wheat-based diets as it is well established that dietary NSP increases gizzard weight (Hetland and Svihus, 2001; Hetland et al., 2003a; Amerah et al., 2009; Sanchez et al., 2019).

Addition of the cDDGS to corn-based diets reduced FBW and BWG in broilers but MES improved these parameters. This was expected as fiber degrading enzymes has been shown to increase growth performance in broilers fed corn-based diets formulated with cDDGS (Kiarie et al., 2014). In the wheat-based diets, the FBW and BWG was surprisingly reduced with the addition of MES and WM. This was not expected as various studies outlined the beneficial effects of supplemental fiber degrading enzymes in wheat-based diets in poultry (Bedford and Schulze, 1998; Adeola and Cowieson, 2011; Slominski, 2011; Kiarie et al., 2013b). It is plausible wheat component could have had an inhibitory effect on MES through xylanase inhibitors in the endosperm (Amerah, 2015). Poultry ingest dietary fiber from two main sources, feed, as well as the ingestion of fibrous litter material when made available (Kalmendal et al., 2013). Fiber is often referred to as a diluent in the diet with no nutritional benefits, sometimes even considered to be an antinutritional factor due to negative impacts on nutrient digestibility, production, and voluntary feed intake (Angkanaporn et al., 1994; Mateos et al., 2012; Walugembe et al., 2014; Kiarie et al., 2017). However, several studies have shown that the inclusion of coarse particles and fiber in a diet can improve gizzard size and activity and increase retention time in the proximal gastrointestinal tract (Hetland et al., 2003a; Svihus, 2011). As a result, the gizzard pH will decrease principally due to increased HCl production in the proventriculus via increased gastric reflux (Svihus, 2011, 2014; Classen et al., 2016; Kheravii et al., 2018). In the current study, the gizzard pH was lower in broilers fed corn-based diets compared to wheat-based diets. This suggested an increase in gizzard activity. Additionally, poults fed high fiber diets had a higher gizzard pH, despite having a higher fiber concentration. We cannot ascertain the logic behind these observations but could be attributed to the particle size differences between the diets. The particle size was not determined in the current study.

It is established that high soluble NSP contents in wheat increases intestinal viscosity resulting in poorer nutrient utilization and growth performance in broilers (Bedford and Schulze, 1998). However, the present data showed the opposite as the ileal viscosity of broilers fed wheat-based diets and high fiber diets was lower than birds fed corn-based and low fiber diets. This can be attributed to the previously indicated argument that, the wheat used in the present study could have been of a low soluble NSP-fraction variety. It is hard to explain the increased ileal viscosity associated with low fiber diets, without further analyzing the particle size and fiber fraction of the diets. An increase in ileal viscosity is known to cause an increased litter moisture and wet droppings in poultry (Choct and Annison, 1992; Choct, 2009). Evidence of this can be seen in the present data, as broilers fed corn-based diets and low fiber diets had higher excreta moisture than broilers fed wheat-based diets and high fiber diets, respectively.

The digestibility of nutrients can be reduced due the complex structural arrangement of dietary NSP (de Vries et al., 2012). Thus, the inclusion of insoluble fiber in poultry diets must be small enough to prevent these effects. The present data showed that the broilers fed wheat-based diets without WM inclusion and MES supplementation had higher PUA than birds fed corn-based diets without cDDGS and MES supplementation. Birds are unable to store excess amino acids; therefore, they are excreted as uric acid (Roberts et al., 2007). As a result, PUA concentration can be used as an indicator for amino acid balance. It is assumed that a reduction in protein digestibility can cause amino acid imbalance, limiting the nitrogen available for synthesis of non-essential amino acids (NEAA). Thus, essential amino acids are converted into NEAA, causing an increase in PUA (Casartelli et al., 2005). Typically, the nitrogen present in poultry manure consists mostly of uric acid, amino acids and bacterial protein, mainly from undigested nitrogen and endogenous nitrogen (Sittiya et al., 2020). Additionally, ammonia is also emitted from the manure due to microbial decomposition of the nitrogenous compounds, but primarily from uric acid (Li et al., 2008). Studies have shown that the addition of fiber in poultry diets reduce ammonia emissions from the manure of laying hens (Roberts et al., 2007) and pigs (Canh et al., 1997; Shriver et al., 2003). Thus, excreta nitrogen was determined in the present study. There was no interaction effect between grain, fiber and MES in both species on excreta nitrogen. However, in broilers, the high fiber diets reduced excreta nitrogen compared to the low fiber diets. In contrast, wheat diets reduced excreta nitrogen in poults, compared to corn diets.

Dietary fiber is fermented in the ceca by the resident microbes, producing SCFA, ammonia, carbon dioxide and methane. However, the fermentation capacity of these resident microbes in chickens and turkeys are much less compared to other non-ruminant animals, such as pigs (Józefiak et al., 2004). Despite this, SCFA play a key role as an energy source and regulates the microbial environment in the ceca (Fleming and Gill, 1997; Józefiak et al., 2004; Leung et al., 2018). Lactic, acetic, propionic, and butyric acids can promote the proliferation of beneficial bacteria while creating an unfavorable environment for pathogenic bacteria (Józefiak et al., 2004; Kiarie et al., 2013b, Kheravii et al., 2018). Futhermore, addition of exogenous enzymes to poultry diets can also further influence the cecal SCFA concentrations (Józefiak et al., 2004; Kiarie et al 2013b; Kiarie et al., 2014). The present data shows that broilers fed corn diets with cDDGS and supplemented with MES had higher cecal lactic acid concentrations compared to birds fed the same diet but without MES. This could explain improvement of BWG seen in birds fed corn + cDDGS diet with MES. Broilers fed wheat diets with WM but without MES had a higher cecal propionic acid concentration compared to birds fed corn diets with cDDGS or MES. This was in agreement with previous studies in which fiber and xylanase supplementation increased concentration of SCFA in the ceca (Choct et al., 1999; Kheravii et al., 2018). Additionally, it is important to understand that the majority of the SCFA produced in the hindgut are absorbed and at a rapid rate, which may result in variability in SCFA concentrations determined on samples collected via serial slaughter (González-Ortiz et al., 2020).

There were varied diet responses seen on growth, gizzard weight and pH in both species. High fiber and wheat-based diets reduced ileal digesta viscosity and excreta moisture in broiler chickens. Increased plasma uric acid in broilers fed wheat diets without fiber or MES suggested altered amino acids metabolism. Supplemental MES had varied responses in both species suggesting the need to refine activities and dosing for different poultry species.

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DISCLOSURES

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. R.P. is an employee of Canadian Biosystems Inc.

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