An Evaluation of Endo-β-D-mannanase (Hemicell) Effects on Broiler Performance and Energy Use in Diets Varying in β-Mannan Content[1]

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ABSTRACT Two experiments were conducted to evaluate the effects of a commercial endo-β-D-mannanase (Hemicell) on overall performance, ME_n, net energy for gain, and some serum parameters of broilers fed diets varying in β-mannan level (experiment 1) and to evaluate effects of enzyme level on the same variables in broilers fed diet high in β-mannan (experiment 2). As a semipurified β-mannan source, guar gum was used to alter the dietary β-mannan level. In experiment 1, guar gum was added at 0, 0.5, 1, and 2% in a corn-soy-based starter diet with (0.05%) and without endo-β-D-mannanase supplementation in a 4 × 2 factorial design. Enzyme supplementation improved ($P < 0.01$) feed efficiency at control and each guar gum inclusion level, whereas 2% guar gum supplementation reduced ($P < 0.01$) BW and increased ($P < 0.01$) 14-d feed:gain ratio. Enzyme supplementation also increased dietary ME_n and net energy gain.

In experiment 2, endo-β-D-mannanase was added at 0, 0.5, 1, and 1.5% in a corn-soy-based starter diet containing 1% guar gum. Increasing endo-β-D-mannanase supplementation did not affect ($P > 0.10$) final BW but improved 14-d feed:gain ratio at all inclusion levels. As in the first experiment, ME improved ($P < 0.05$) with increasing enzyme inclusion. Dietary endo-β-D-mannanase inclusion significantly reduced water:feed ratio and total dry fecal output ($P < 0.01$). Taken together, the results of these 2 experiments indicate that endo-β-D-mannanase supplementation may improve the utilization of nutrients in diets containing β-mannan.

(*Key words*: broiler, guar gum, enzyme supplementation, metabolizable energy, net energy)

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INTRODUCTION

The identification and alleviation of factors inhibiting nutrient utilization are necessary for successful poultry production. Among potential factors reducing nutrient bioavailability are the nonstarch polysaccharides (NSP). Nonstarch polysaccharides are complex high molecular weight carbohydrates found in the structure of plant cell walls (Annison and Choct, 1991; Classen and Bedford, 1991; Bedford and Classen, 1993; Choct, 2002). The NSP include various fiber types such as lignin, β-glucans, arabinoxylans (pentosans), uronic acid, galactose, and mannose in poultry feedstuffs (Aman and Graham, 1990). The β-glucans are predominantly found in barley and oats, whereas the arabinoxylans are found in wheat, rye, and triticale at higher rates (Classen and Bedford, 1991). Both fiber types, however, occur at some lower concentrations in most feedstuffs. Certain protein concentrates, especially palm kernel meal, copra meal, and guar meal, are among the feedstuffs rich in glucomannans and galactomannans (Carré, 2002).

Among NSP, mannans occur in the forms of glucomannans, galactomannans, glucogalactomannans, and glucuronomannans in plant cell walls (Aman and Graham, 1990). In β-mannan, repeating D-mannose units with β-1,4 bonds and D-galactose units are attached in a 2:3 ratio (Ward and Fodge, 1996; Carré, 2002). Several studies have demonstrated the negative effects of dietary β-mannan found in palm kernel meal, copra meal, guar gum, and guar meal (Ray et al., 1982; Teves et al., 1988; Furuse and Mabayo, 1996).

Enzyme supplementation of poultry rations has been widely reviewed and well documented to improve efficiency of converting feedstuffs into broiler tissue (Annison and Choct, 1991; Campbell and Bedford, 1992; Bedford and Morgan, 1996; Marquardt et al., 1996; Choct, 2001). Reported benefits include improved weight gain, feed:gain ratio, and ME as well as reduced excreta and P output, water intake, digesta viscosity, and gastrointes-

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Abbreviation Key: GIT = gastrointestinal tract; NEG = net energy for gain; NSP = nonstarch polysaccharides.

tinal tract (GIT) size (Friesen et al., 1992; Brenes et al., 1993; Annison et al., 1995; Marquardt et al., 1996). Copra and guar meals, feedstuffs rich in β-mannan, have also been reported to increase utilization with bacterial mannanase treatment (Verma and McNab, 1982; Patel and McGinnis, 1985; Teves et al., 1988).

Guar (*Cyamopsis tetragonoloba*) is an annual legume that is widely grown in countries such as India and Pakistan (Patel and McGinnis, 1985). Its endosperm is a rich source of a galactomannan polysaccharide, guar gum (Vohra and Kratzer, 1964a; Couch et al., 1967). Guar gum has long been known to depress growth when fed to chicks (Vohra and Kratzer, 1964b; Ray et al., 1982). Studies with guar gum, classified as a soluble dietary fiber, have demonstrated that increased digesta viscosity in GIT is associated with a delay in gastric emptying (Holt et al., 1979) and reduced nutrient utilization (Jenkins et al., 1978; Taylor, 1979; Blackburn and Johnson, 1981). Jorgensen et al. (1996) observed a significant increase in the length and weight of the GIT of broiler chickens fed rations containing high levels of NSP. Addition of soluble NSP to broiler diets significantly elevated fermentation in small intestine and depolymerization of the NSP almost completely overcame this problem (Choct et al., 1996).

Chemical structure of β-mannan in soy and in guar gum are almost identical (Whistler and Saarnio, 1957; Ward and Fodge, 1996), which provides a potential means of elevating β-mannan in practical diets. This study sought to investigate the efficacy of endo-β-D-mannanase supplementation level in broiler diets varying in β-mannan (as guar gum) level on broiler growth rate, feed:gain ratio, water:feed ratio, ME_n, net energy for gain (NEG), and some serum metabolites. The inclusion of guar gum in corn-soy-based diet was intended to mimic inclusion of feed ingredients high in β-mannan, including poor quality soybean meal, palm kernel meal, and copra meal (D. Fodge, unpublished data).

MATERIALS AND METHODS

General Procedures

Two experiments were conducted to evaluate efficacy and inclusion level effects of endo-β-D-mannanase (Hemicell[3]) in broiler diets varying in β-mannan content. Because of its high β-mannan content, guar gum was used as a semipurified β-mannan source. In both experiments, 1-d-old Cobb × Cobb male chicks were obtained from a commercial hatchery, wing banded, individually weighed, and randomly assigned to metabolic chambers.

TABLE 1. Composition of starter basal diet

Ingredients and composition	Starter diet, %
Ground corn	60.04
Soybean meal	29.00
Pro-pak[1]	5.05
Vegetable fat	3.15
Dicalcium phosphate	1.20
Calcium carbonate	0.81
Salt	0.38
Methionine	0.13
Vitamin premix[2]	0.05
Mineral mix[3]	0.05
Choline chloride	0.05
Lasalosid	0.05
Copper sulfate (250,000 mg/kg)	0.03
Selenium premix (6,000 mg/kg)	0.0015
Calculated analysis	
ME, kcal/kg	3,150
CP (%)	22.67
Methionine (%)	0.54
Lysine (%)	1.25
Calcium (%)	0.95
Total phosphorus (%)	0.72

[1]Pro-pak is a marine and animal protein product that contains 60% CP and is a registered trade mark of H. J Baker & Bro., Inc., Little Rock, AR.

[2]Supplied per kilogram of diet: vitamin A, 38,500 IU; vitamin D_3, 11,000 IU; vitamin E, 55 IU; vitamin B_{12}, 0.066 mg; riboflavin, 33 mg; niacin, 165 mg; D-pantothenic acid, 55 mg; menadione, 11 mg; folic acid, 3.3 mg; pyridoxine, 13.75 mg; thiamin, 6.66 mg; D-biotin, 0.28 mg.

[3]Supplied per kilogram of diet: manganese, 120 mg; zinc, 100 mg; copper, 10 mg; iodine, 2.5 mg; calcium, 135 mg.

Feed samples were collected for analysis of enzyme activity.[4]

Metabolic chamber facilities and procedures utilized for bird rearing and indirect calorimetry measurements have been documented elsewhere (Belay and Teeter, 1993). Briefly, the system utilizes the differential concentrations of incoming and outgoing O_2 and CO_2 to calculate bird O_2 consumption and CO_2 production. The equation developed by Brouwer (1965) was subsequently used to calculate bird heat production from CO_2 production and O_2 consumption measurements.

In all cases, chicks were reared according to the breeder recommendations (Cobb × Cobb) with ad libitum access to feed (Table 1) and water. The chambers were monitored 4 times daily for mortality and general conditions. Chick BW, feed consumption, and water consumption measurements were recorded on d 7 and 14. Both trials were terminated on d 14 when chicks were individually weighed, and blood samples were collected via venipuncture (from 2 birds per chamber selected at random in experiment 1, and 4 such birds per chamber in experiment 2). Samples were measured for hematocrit values by microcentrifugation. Serum concentrations of inorganic P, Ca, glucose, and triglycerides were determined.[5] Serum variables were measured using a Cobas Mira[6] wet chemistry analyzer.

Excreta from chamber-housed birds were quantitatively collected and stored in plastic bags at –20°C until analysis. Samples were dried at 55°C, ground to a fine powder, and analyzed for C and N[7] and for gross energy

[3]Hemicell is a registered trademark of ChemGen Corp., Gaithersburg, MD. Dried *Bacillus lentus* fermentation solubles with 158 million units/kg minimum enzyme activity. Recommended usage rate is 0.05% of feed.

[4]ChemGen Corp., Gaithersburg, MD.

[5]Kit numbers 44031, 44033, 47382, and 44120, respectively. Hoffman-LaRoche, Nutley, NJ.

[6]Roche Diagnostics Systems, Inc., Montclair, NJ.

[7]Model CN-2000, LECO, Inc., St. Joseph, MI.

via a bomb calorimeter.[8] Apparent metabolizable energy was corrected to zero N balance (Titus et al., 1959). The NEG was determined by subtracting measured heat production from the determined ME_n.

Experiment 1. This experiment was conducted to examine the effects of 4 dietary inclusion levels of guar gum, each with and without enzyme supplementation, on broiler performance; water consumption; serum Ca, P, glucose, and triglycerides; dietary ME_n and NEG; and total fecal output. The study used 144 1-d-old chicks, which were randomly assigned to 8 dietary treatments in a 4×2 factorial treatment arrangement in a randomized block design. Each metabolic chamber had 4 birds throughout the study. Four guar gum levels (0, 0.5, 1, and 2%) and 2 enzyme levels (0 and 0.05%) were used. Due to limitations in the number of metabolic chambers (36 total), treatments with 0 and 1% guar gum inclusion levels had 5 replications, but treatments with 0.5 and 2% guar gum inclusion levels had 4 replications.

Experiment 2. This experiment was conducted to examine the effects of 4 dietary enzyme supplementation levels on broiler performance; water consumption; serum Ca, P, glucose, and triglycerides; dietary ME_n and NE; and total fecal output. This study used 216 1-d-old chicks randomly assigned to 4 dietary enzyme levels (0, 0.05, 0.1, and 0.15%) included in a starter ration (Table 1) containing 1% guar gum in a completely randomized block design. Each treatment was replicated with 6 metabolic chambers containing 9 birds each.

Data Analysis

The data were analyzed using the general linear models procedure of SAS software (SAS, 1991), which is robust enough to allow for the moderately imbalanced data from these experiments. The model included guar gum and enzyme as main effects. The interaction between main effects was included in the model. Mean separation was accomplished using least significant difference (Steel and Torrie, 1960). Unless otherwise stated, significance level was set at $P < 0.05$. Carbon dioxide production and O_2 consumption were regressed against elapsed time with equations for each individual chamber being integrated to compute CO_2 production and O_2 consumption for the time period.

RESULTS

Experiment 1

Enzyme activities for diets containing 0, 0.5, 1, and 2% guar gum supplemented with enzyme were 152.7, 127.7, 145.9, 141.5 million units per ton, respectively. These values were within the expected range.

Experiment 1 results for BW, water:feed ratios, and feed:gain ratios are presented in Table 2. A significant enzyme × guar gum interaction was detected for 1- and 2-wk BW and overall water:feed and feed:gain ratios. Feed conversion and BW were severely reduced by the dietary inclusion level of 2% guar gum as early as 1 wk of age. During wk 1, addition of dietary enzyme generally improved feed conversion at each guar gum level, including negative control. The BW at 2 wk of age was restored to control values by enzyme for all treatments except 2% guar gum. As the guar gum level was increased, the BW decreased. The 2% guar gum level depressed 2-wk BW to a greater extent than all other enzyme-free treatments. Further, the 2-wk enzyme fortification improved ($P < 0.05$) the feed conversion at every guar gum inclusion level including the negative control. Feed conversion was similar for the control and the 1% guar gum with Hemicell treatments. Only 2% guar gum inclusion with enzyme had a feed conversion poorer ($P < 0.05$) than the control. Guar gum inclusion generally increased water:feed ratio.

Effects of guar gum and enzyme supplementation on ME_n, NEG, and total N and dry fecal output data in experiment 1 are presented in Table 3. As with performance data, there was a dramatic decrease in ME_n with 2% guar gum levels. At the 1 and 2% guar gum levels, enzyme supplementation increased ($P < 0.05$) ME_n of the diet. Increasing guar gum level in the diet increased total excreted N and total dry fecal output with the highest increase occurring at the 2% guar gum level.

In the current study, neither guar gum nor enzyme supplementation had an impact on hematocrit levels or on serum glucose, triglyceride, Ca, and P levels (data not shown).

Experiment 2

Determined enzyme activities (million units per ton) for 0, 0.05, 0.1, and 0.15% enzyme supplementation levels were 1.4, 145.9, 225.8, and 349.8, respectively. These values were within the expected range.

Experiment 2 results for BW and water:feed ratio are presented in Table 4. Increasing dietary endo-β-mannanase supplementation did not have an impact on final BW of these broiler chicks; however, a significant improvement in overall feed utilization was observed with increasing enzyme level from 0 to 0.15%. Overall enzyme effect on feed conversion was quadratic and its efficiency gradually declined as enzyme level increased, plateauing at 0.1% enzyme. Dietary enzyme supplementation reduced water:feed ratio, and water:feed ratio was the lowest with the highest enzyme concentration.

Effects of guar gum and enzyme supplementation on ME_n, NEG, and total nitrogen and dry fecal output data in experiment 2 are presented in Table 5. Regardless of its level, enzyme supplementation significantly improved ME_n as compared with the negative control group. As reported for experiment 1, dietary endo-β-D-mannanase supplementation reduced both total N excreted and dry fecal output. The decrease in both total N excreted and

[8]Parr Co., Moline, IL.

TABLE 2. Effects of guar gum and endo-β-D-mannanase (Hemicell) supplementation on the growth, performance, and water:feed ratio of broiler chicks during experiment 1

Treatment		Week 1 BW[1] (g)	Week 1 Water:feed (g:g)	Week 1 Feed:gain (g:g)	Week 2 BW (g)	Week 2 Water:feed (g:g)	Week 2 Feed:gain (g:g)	Overall Water:feed (g:g)	Overall Feed:gain (g:g)
Enzyme, %									
0		168.6	2.899	1.071	368.2	2.437^{a}	1.365	2.585	1.251
0.05		170.4	2.852	1.045	382.6	2.361^{b}	1.307	2.517	1.208
Guar gum, %									
0		178.6	2.673	1.019	392.5	2.347^{a}	1.261	2.449	1.166
0.5		174.9	2.755	1.021	381.2	2.385^{a}	1.271	2.507	1.172
1		170.8	3.031	1.032	383.1	2.478^{b}	1.306	2.657	1.202
2		153.8	3.043	1.160	344.8	2.386^{a}	1.506	2.591	1.377
Guar gum, %	Endo-β-D-mannanase, %								
0	0	182.6^{a}	2.588^{d}	1.032^{cde}	394.8^{a}	2.374	1.282^{d}	2.446^{c}	1.182^{d}
0	0.05	174.5^{bc}	2.759^{c}	1.006^{f}	390.2^{a}	2.319	1.239^{e}	2.453^{c}	1.149^{e}
0.5	0	170.2^{c}	2.904^{b}	1.041^{c}	366.2^{bc}	2.481	1.294^{d}	2.617^{ab}	1.193^{d}
0.5	0.05	179.5^{ab}	2.606^{d}	1.002^{f}	396.2^{a}	2.287	1.247^{e}	2.398^{c}	1.150^{e}
1	0	169.9^{c}	3.068^{a}	1.037^{cde}	376.2^{b}	2.519	1.319^{c}	2.700^{a}	1.211^{c}
1	0.05	171.7^{c}	2.993^{ab}	1.028^{de}	390.0^{a}	2.437	1.293^{d}	2.615^{ab}	1.193^{d}
2	0	151.7^{d}	3.035^{ab}	1.173^{a}	335.7^{d}	2.372	1.565^{a}	2.579^{b}	1.417^{a}
2	0.05	155.9^{d}	3.050^{a}	1.146^{b}	354.0^{c}	2.398	1.448^{b}	2.602^{ab}	1.337^{b}
SEM		1.77	0.051	0.004	4.43	0.037	0.006	0.036	0.004
Source of variation		Probability							
Enzyme		0.5973	0.4949	0.0001	0.0002	0.0060	0.0001	0.0182	0.0001
Guar gum		0.0001	0.0001	0.0001	0.0001	0.0025	0.0001	0.0001	0.0001
Enzyme × guar gum		0.0002	0.0002	0.0202	0.0014	0.0612	0.0001	0.0064	0.0001

[a–e]Means in a column with no common superscript differ ($P < 0.05$).

[1]Initial chick BW for enzyme (0 and 0.05%) and guar gum (0, 0.5, 1, and 2%) levels were 40.8, 41.0, 41.3, 40.7, 40.8 and 40.8 g, respectively.

dry fecal output as compared with the levels in the control groups was significant.

Enzyme supplementation did not affect hematocrit values but numerical increases in serum glucose, triglycerides, Ca, and P were observed with enzyme supplementation (data not shown).

DISCUSSION

As expected, dietary guar gum inclusion reduced broiler BW, and the decrease in BW was severe especially at 2% guar gum level. Similar results have been reported previously with 2% guar gum (Vohra and Kratzer, 1964a;

TABLE 3. Effects of guar gum and endo-β-D-mannanase (Hemicell) supplementation on ME_n, net energy for gain (NEG), and total N and fecal output during experiment 1

Treatment		ME_n (kcal/kg)	NEG (kcal/kg)	Total N excreted (g)	Dry fecal output (g)
Enzyme,%					
0		2,995	1,298^{b}	18.90	377.5
0.05		3,061	1,366^{a}	18.07	356.5
Guar gum, %					
0		3,160	1,390^{a}	15.28^{c}	319.5^{b}
0.5		3,136	1,410^{a}	15.99^{bc}	323.2^{b}
1		3,062	1,338^{a}	17.46^{b}	350.7^{b}
2		2,752	1,193^{b}	25.22^{a}	474.5^{a}
Guar gum, %	Endo-β-D-mannanase, %				
0	0	3,177^{a}	1,403	15.36	323.7
0	0.05	3,144^{ab}	1,377	15.20	315.3
0.5	0	3,107^{b}	1,372	15.63	320.5
0.5	0.05	3,166^{ab}	1,448	16.34	325.8
1	0	3,018^{c}	1,304	18.23	359.0
1	0.05	3,106^{b}	1,373	16.70	342.4
2	0	2,678^{e}	1,116	26.39	506.8
2	0.05	2,827^{d}	1,269	24.05	442.2
SEM		22.36	35.28	1.04	19.88
Source of variation		Probability			
Enzyme		0.0030	0.0421	0.3397	0.2462
Guar gum		0.0001	0.0001	0.0001	0.0001
Enzyme × guar gum		0.0089	0.1731	0.5685	0.4944

[a–e]Means in a column with common superscript do not differ ($P < 0.05$).

TABLE 4. Effects of guar gum and endo-β-D-mannanase (Hemicell) supplementation on the growth, performance, and water:feed ratio of broiler chicks during experiment 2[1]

Treatment		Week 1			Week 2			Overall	
Guar gum (%)	Endo-β-D-mannanase (%)	BW[1] (g)	Water:feed (g:g)	Feed:gain (g:g)	BW (g)	Water:feed (g:g)	Feed:gain (g:g)	Water:feed (g:g)	Feed:gain (g:g)
1	0	171.3^{bc}	3.046^{a}	1.074^{a}	346.5	2.753^{a}	1.533^{a}	2.853^{a}	1.336^{a}
1	0.05	171.5^{b}	2.987^{ab}	1.049^{c}	346.9	2.632^{c}	1.495^{b}	2.752^{b}	1.304^{b}
1	0.1	176.0^{a}	3.045^{a}	1.036^{d}	348.1	2.699^{b}	1.493^{b}	2.821^{a}	1.291^{c}
1	0.15	168.8^{c}	2.947^{b}	1.056^{b}	345.5	2.523^{d}	1.454^{c}	2.664^{c}	1.286^{c}
SEM		0.86	0.025	0.0014	1.43	0.017	0.004	0.018	0.002
Source of variation		Probability							
Enzyme		0.0001	0.0187	0.0001	NS	0.0001	0.0001	0.0001	0.0001

[a–d]Means in a column with common superscript do not differ significantly ($P < 0.05$).

[1]Mean initial weights for enzyme levels (0, 0.05, 0.1, and 0.15%) were 40.9, 41.1, 41.1, and 40.3 g, respectively.

Ray et al., 1982). Results from the current study demonstrated a positive response to dietary enzyme addition; hence, BW was restored to control values for all chicks fed guar gum except the 2% guar gum in experiment 1. Although enzyme supplementation improved BW at the 2% guar gum level, the negative effect was too large to be corrected by enzyme addition. Dietary enzyme supplementation did not have an impact on broiler BW when different enzyme levels were added in a corn-soy-based diet with 1% guar gum in experiment 2.

A significant improvement in feed utilization with dietary enzyme supplementation in both experiments is an indicator of better utilization of nutrients as previously reported in other studies (Ray et al., 1982; Verma and McNab, 1982; Patel and McGinnis, 1985; Takahashi et al., 1994, Ellis et al., 1995; Furuse and Mabayo, 1996). In our study, improved feed conversion was observed in experiment 1, in which a single enzyme level was applied to diets with 4 levels of guar gum, and in experiment 2, in which different enzyme levels were applied to a diet containing 1% guar gum. This was also true for the guar gum-free negative control. Gluco- and galactomannans are cell wall components of legumes (Reid, 1985), and galactomannan is also found in soybean hulls in small quantities (Whistler and Saarnio, 1957; Dierick, 1989; Ward and Fodge, 1996). Current findings indicate that dietary endo-β-D-mannanase supplementation also improves nutrient utilization of typical corn-soy-based diets low in β-mannan as well as mannan-rich dietary ingredients such as guar, palm kernel, and copra-meal which may be used in poultry diets (D. Fodge, unpublished data). Other studies using turkeys (Odetallah et al., 2002) and swine (Pettey et al., 1999) also indicate that enzyme supplementation has the potential to reduce the cost of production. Replacing 48% CP soybean meal with 44% CP soybean meal in turkey diets had negative impacts on body weight and feed conversion of market-age turkeys, and these were the ones that benefited most from dietary enzyme supplementation (Odetallah et al., 2002). In another study, Jackson et al. (1999) reported an increase in egg weight at early stages of production and an increase in egg production by delaying the postpeak decline in laying hens. In this study, experiment 2 revealed the fact that diets with higher β-mannan content require higher enzyme levels. However, to keep dietary enzyme supplementation cost effective, optimum enzyme level needs to be determined for the varying β-mannan levels.

Water consumption per unit feed consumption was increased with increasing dietary guar gum (experiment 1), whereas enzyme supplementation tended to reduce water consumption per unit feed consumed (experiment 2). The viscous nature of guar gum is a factor contributing to the reduction of absorption and utilization of nutrients. This occurs by slowing the gastric emptying, impairing the mixing of substrate with digestive enzymes, and reducing the rate of contact of nutrients with the absorptive

TABLE 5. Effects of guar gum and endo-β-D-mannanase (Hemicell) supplementation on ME_n, net energy for gain (NEG), and total N and fecal output during experiment 2

Treatment					
Guar gum (%)	Endo-β-D-mannanase (%)	ME_n (kcal/kg)	NEG (kcal/kg)	Total N excreted (g)	Dry fecal output (g)
1	0	2,971^{b}	1,247	44.11^{a}	855.6^{a}
1	0.05	3,057^{a}	1,299	35.99^{b}	754.3^{b}
1	0.1	3,067^{a}	1,255	35.03^{b}	726.3^{b}
1	0.15	3,061^{a}	1,263	33.32^{b}	703.5^{b}
SEM		12.00	24.75	1.34	22.17
Source of variation		Probability			
Enzyme		0.0005	0.5182	0.0011	0.0041

[a,b]Means in a column with common superscript do not differ significantly ($P < 0.05$).

epithelium (Read, 1986). Therefore, birds need to drink more water to maintain proper mixing of digestive enzymes with substrates and to overcome the negative effects of this viscous product. One can assume that dietary enzyme probably eased the problem by partially degrading β-mannan and reducing water consumption.

In general, dietary ME_n was reduced by increasing levels of guar gum, which can be totally or partially corrected by enzyme supplementation. The dramatic decrease in ME_n with 2% guar gum level suggests that both dietary enzyme and β-mannan levels should be monitored when diets high in β-mannan are fed to broilers. Dietary NEG values had trends similar to those of ME_n. In experiment 1, 2% guar gum level significantly reduced NEG whereas enzyme supplementation improved NEG. In experiment 2, however, the positive impact of enzyme was not significant. This is presumably due to the increased heat production in these birds caused by improved nutrient absorption and utilization. A significant reduction in total N excretion and dry fecal output supports this theory. Additionally, NSP have an impact on gastrointestinal tract viscosity and digestion and absorption of nutrients (Ikegami et al., 1990; Salih et al., 1991; Almirall et al., 1995; Annison et al., 1995). Partially hydrolyzed guar gum has less detrimental effects compared with intact guar gum (Takahashi et al., 1994; Furuse and Mabayo, 1996). Viscous polysaccharides also cause physiological and morphological changes to the digestive system in various species (Brown et al., 1979; Cassidy et al., 1981; Jacobs, 1983; Morgan et al., 1985; Jorgensen et al., 1996). The GIT size has been reported to contribute to the basal metabolic rate; therefore, any reductions in GIT size and viscosity could reduce bird heat production and improve net energy of the diet. In the current report, however, there was no apparent improvement in NEG attributable to enzyme supplementation. Diets containing high levels of NSP significantly increase the length and weight of the gastrointestinal tract (Jorgensen et al.,1996), enlarge digestive organs, increase secretion of digestive enzymes, and depress apparent ileal protein digestibility (Ikegami et al., 1990). Guar gum forms viscous solutions in the GIT that delay the absorption of other nutrients such as glucose (Blackburn and Johnson, 1981) and fat (Higham and Read, 1992). Guar gum also decreases the absorption and use of protein (Poksay and Schneeman, 1983). In the current study, dietary endo-β-D-mannanase supplementation significantly or numerically reduced N and dry fecal output in both experiments.

This study clearly demonstrated the advantages of endo-β-D-mannanase supplementation in broiler diets containing β-mannan. Therefore, dietary enzyme supplementation should be considered as an alternative solution for producers, particularly when high quality plant-origin protein sources are either in limited quantity or too expensive.

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