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Effects of Low Level Water-soluble Pentosans, Alkaline-extractable Pentosans, and Xylanase on the Growth and Development of Broiler Chicks

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ABSTRACT: This study investigated the effects of low levels of water-soluble pentosans (WSP), alkaline-extractable pentosans (AEP), and xylanase on the growth and organ development of broiler chicks. Three hundred and fifty 1-d-old female broiler chicks were randomly allocated into seven experimental groups of five pen replicates, with ten chicks per replicate. The control group consumed a corn-soybean meal-based diet. Six dietary treatment groups consumed the basal diet supplemented with one of the following: WSP at 50 mg/kg (WSP50) or 100 mg/kg (WSP100); AEP at 50 mg/kg (AEP50) or 100 mg/kg (AEP100); or xylanase at 3 mg/kg (Xase3) or 6 mg/kg (Xase6). Data including the body weight, digestive organ weights, gut length, rectal digesta viscosity, and gut microflora and pH were collected on d 5, 10, and 15. When compared to the control group, WSP50 promoted body weight gain and organ growth throughout the study, calculated as 3-d averages ($p<0.05$). WSP100 increased weight gain and enhanced organ development (proventriculus, gizzard, and gut) on d 10 ($p<0.05$), but the 3-d averages were not different from the control group except for the weight of gizzard. Both Xase3 and Xase6 increased the 3-d average weight gain and the growth of the gizzard ($p<0.05$). WSP50 increased the digesta viscosity compared to Xase3 on d 10 and 15 ($p<0.05$). WSP50, Xase3, and Xase6 increased the concentration of *Lactobacillus* in the rectum when compared to the control group ($p<0.05$), but only Xase3 lowered the digesta pH in the ileum and cecum on d 10 and 15. AEP had minimal influence on the growth and organ development of broilers. The results showed that low levels of WSP, AEP, and xylanase had different effects and underlying mechanisms on the growth and organ development of broiler chicks. WSP50 could increase the growth performance of broilers fed a corn-soybean meal-based diet. (**Key Words:** Pentosan, Xylanase, Broiler, Organ, Growth)

INTRODUCTION

Pentosans, also known as arabinoxylans, are the main components of the non-starch polysaccharides in grains. They are also important polysaccharide components in the cell walls of grains. Pentosans are used as thickeners and humectants in additives for beverages, condiments, dairy products, candy, and other foods (Izydorczyk et al., 1995). As dietary fibers, pentosans play important roles in increasing intestinal motility (Shinnick et al., 1991; Topping, 2007; François et al., 2012), reducing blood sugar (Lu et al., 2000a,b), lowering blood pressure (Anderson et al., 1994; Topping, 2007), improving immunity (Ghoneum et al., 2000; Hee-Jeong et al., 2012), and preventing colon cancer (Reddy et al., 2000). Pentosan polysulfide sodium is also effective in treating urethritis (Duthie et al., 2012). Based on their solubility, pentosans are classified as water-soluble pentosans (WSP) and water insoluble pentosans (WIP). The majority of WIP can be extracted with alkaline solutions, and are referred to as alkaline-extractable pentosans (AEP). It is not fully understood whether the functions of WSP are the same as those of AEP or pentosan mixtures.

In the feed industry, non-starch polysaccharides, such as pentosans and β-glucan, are often considered anti-nutritive factors in animal diets, especially in diets that are wheat-based. Based on data from early studies, it has been widely accepted that high viscous non-starch polysaccharides in wheat diets increase digesta viscosity and reduce the digestion and absorption of nutrients (Antoniou et al., 1981;

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Choct et al., 1990). Accordingly, xylanase or a combination of enzymes is often added to wheat feed to reduce the anti-nutritive effect of non-starch polysaccharide pentosans (Boguhn et al., 2007; Kalmendal et al., 2012). However, recent studies have reported that pentosans did not affect nutrient digestion and absorption, but displayed the beneficial effects of prebiotics (Kabel et al., 2002; Courtin et al., 2008; Broekaert et al., 2011; Maki et al., 2012). Pentosans are big molecules with complicated spatial structures. It is not yet clear how their physiological functions and anti-nutritive effects are related to their structures and dosage. In a previous study (Choct et al., 1990) in which the anti-nutritive effect of wheat pentosans was reported, the minimal levels of WSP and WIP added to a sorghum based diet were 4.8 g/kg dry matter (DM) and 3.5 g/kg DM, respectively. Some oligosaccharides, such as β-glucan and mannan oligosaccharide, have exhibited physiological functions at low levels (Shashidhara et al., 2003; Sohail et al., 2010; Gu et al., 2011). The present study investigated the effects of low levels of WSP and AEP supplementation (50 and 100 mg/kg diet), and xylanase supplementation (3 and 6 mg/kg diet) on the growth and organ development of broiler chicks fed a corn-soybean meal-based diet.

MATERIALS AND METHODS

Preparation of WSP and AEP

Wheat bran was provided by the Flour Factory of Shangdong Farm Equipment Inc. (Jinan, Shangdong, China). WSP and AEP were first extracted using thermostable α-amylase (Wuxi Syder Bio-products Co., Ltd, Jiangsu, China) as described by Xue-Ling et al. (2008). Thereafter, the pentosan and protein content of the extract were analyzed using the phlogoglucinol reaction. The amounts of pentosans and crude protein in WSP were 78.2% and 10.4%, respectively, and the amounts in AEP were 74.6% and 11.2%, respectively. Xylanase was purchased from Jienuo Enzyme Co., Ltd. (Zaozhuang, Shandong, China), and the activity level of xylanase was 95819 units (U). One U of xylanase activity is defined as the amount of enzyme required to produce 1 μmol of xylose in one minute upon hydrolysis of xylan at pH 5.0 and 50°C.

Experimental birds and treatment diets

Three hundred and fifty 1-d-old Ivy female broiler chicks were obtained from a local hatchery and randomly allocated to one of the seven experimental groups. Each group consisted of 5 pen replicates with 10 birds per pen. The basal diet consisted of corn-soybean meal and its composition is shown in Table 1. The WSP and AEP concentrations in the basal diet were measured to be 1.55 g/kg DM and 4.82 g/kg DM based on actual tests. The control group consumed the basal diet only. Six dietary treatment groups consumed the basal diet supplemented with one of the following: i) 50 mg/kg WSP (WSP50), ii) 100 mg/kg WSP (WSP100), iii) 50 mg/kg AEP (AEP50), iv) 100 mg/kg AEP (AEP100), v) 3 mg/kg xylanase (Xase3), or vi) 6 mg/kg xylanase (Xase6). Each group was raised in a correspondingly single cage with 50 chicks per cage. The initial brooding temperature was 34°C, and the temperature was gradually lowered 2°C each week. The ambient temperature, ventilation, and light were the same for each group. Feed and water were provided *ad libitum*. Standardized feeding and maintenance procedures were followed throughout the study. This study protocol was reviewed and approved by the Animal Welfare Committee of Shandong Academy of Agricultural Sciences.

Table 1. Composition of corn-soybean basal diet

Ingredients (%)	Proportion
Corn meal	65
Extruded soybean meal	30.0
Peanut meal	0.9
Fish meal	1.0
Met	0.05
Lys	0.05
Premix[1]	3.0
Nutrient level	Content (calculated)
Metabolizable energy(MJ/kg)	2.85
Crude protein (%)	19.5
Crude fiber (%)	2.6
Lys (%)	1.0
Met+cys (%)	0.74
Ca (%)	0.98
Available phosphorus (%)	0.41

[1] Supplied per kilogram of diet: Fe, 100 mg; Zn, 58 mg; Mn, 30 mg; Cu, 16 mg, iodine, 0.35 mg; Se, 6 mg, vitamin A, 18,000 IU; vitamin D_3, 3,600 IU; vitamin E, 10.8 IU; vitamin K, 1.6 mg; vitamin B_1, 2.5 mg; vitamin B_2, 13.5 mg; vitamin B_6, 4.2 mg; vitamin B_{12}, 0.02 mg; niacin, 73.3 mg; pantothenic acid, 18.4 mg; folic acid, 1.2 mg; choline, 920 mg.

Assessment of growth, organ development, and gut digesta viscosity

On d 5, 10, and 15, 10 chicks from each experimental unit were randomly selected after overnight fasting and killed by cervical dislocation. The body weight, and weights of the bursa, proventriculus, and gizzard were obtained. The length of the entire gut tract was measured. An additional 5 chicks from each experimental unit were killed and dissected to collect the rectal digesta aseptically. The digesta was then used to assess the concentrations of *Lactobacillus*, *Streptococcus*, and *E. coli* by plate counting. The digesta in the cecum, ileum, and rectum were gently removed and diluted at 1:30 (by weight) for pH measurement. The viscosity was determined in a Brookfield DV-II rotational viscometer (Brookfield), with a shear force

Table 2. Effects of pentosan and xylanase on growth and organ development of broiler chicks

	Days	Control	WSP50	WSP100	AEP50	AEP100	Xase3	Xase6	p
Body weight (g)	5	54.32±4.64	56.65±6.43	52.58±5.63	54.08±1.64	54.34±4.70	55.20±5.40	55.13±3.38	0.0513
	10	79.98±8.35^{a}	89.67±7.16^{b}	87.04±5.47^{b}	88.95±6.20^{b}	86.66±7.96^{ab}	89.38±7.16^{b}	93.17±6.94^{b}	0.0194
	15	114.81±7.09^{a}	120.21±10.56^{b}	113.00±10.96^{a}	112.59±8.82^{a}	115.03±12.02^{a}	121.2±10.03^{b}	117.04±14.98^{ab}	0.0458
Average		83.04±30.36^{a}	88.84±31.78^{b}	86.21±33.21^{ab}	86.54±29.33^{ab}	85.34±30.37^{ab}	88.59±33.01^{b}	88.43±31.21^{b}	0.0223
Bursa of fabricius (g)	5	0.13±0.05^{a}	0.16±0.05^{b}	0.12±0.04^{a}	0.14±0.02^{a}	0.15±0.02^{ab}	0.15±0.02^{ab}	0.18±0.05^{b}	0.0445
	10	0.33±0.05^{a}	0.40±0.06^{b}	0.35±0.06^{a}	0.38±0.09^{ab}	0.36±0.06^{ab}	0.42±0.14^{b}	0.37±0.11^{ab}	0.0316
	15	0.58±0.12^{a}	0.67±0.17^{b}	0.60±0.15^{ab}	0.62±0.18^{ab}	0.59±0.10^{a}	0.58±0.13^{a}	0.63±0.16^{ab}	0.0461
Average		0.25±0.23^{a}	0.41±0.25^{b}	0.36±0.24^{ab}	0.36±0.25^{ab}	0.37±0.22^{ab}	0.38±0.21^{ab}	0.39±0.22^{b}	0.0381
Proventriculus (g)	5	0.78±0.15	0.75±0.15	0.77±0.11	0. 78±0.07	0.78±0.11	0.72±0.10	0.78±0.08	0.0564
	10	0.91±0.13^{a}	1.13±0.15^{b}	1.08±0.07^{b}	1.02±0.08^{ab}	1.06±0.12^{ab}	1.07±0.09^{ab}	1.05±0.13^{ab}	0.0264
	15	1.21±0.13^{ab}	1.21±0.15^{ab}	1.18±0.11^{a}	1.27±0.15^{ab}	1.22±0.15^{ab}	1.29±0.14^{b}	1.26±0.21^{ab}	0.0479
Average		0.97±0.22^{a}	1.03±0.25^{b}	1.01±0.21^{ab}	1.02±0.25^{ab}	1.02±0.22^{ab}	1.03±0.29^{ab}	1.03±0.24^{ab}	0.0416
Gizzard (g)	5	3.30±0.67	3.27±0.77	3.16±0.40	3. 45±0.22	3.34±0.32	3.22±0.35	3.37±0.66	0.0691
	10	3.94±0.44^{a}	4.25±0.27^{ab}	4.32±0.25^{b}	4.37±0.29^{b}	4.23±0.36^{ab}	4.39±0.50^{b}	4.43±0.41^{b}	0.0192
	15	5.00±0.52^{a}	5.41±0.50^{b}	5.32±0.43^{ab}	5.15±0.52^{ab}	5.10±0.34^{ab}	5.17±0.40^{ab}	4.93±0.67^{a}	0.0002
Average		4.08±0.86^{a}	4.31±1.07^{b}	4.27±1.08^{b}	4.32±0.85^{b}	4.22±0.88^{b}	4.26±0.98^{b}	4.24±0.80^{b}	0.0406
Gut (cm)	5	50.71±4.79^{a}	55.50±5.78^{b}	54.17±6.22^{ab}	56.00±6.25^{b}	54.58±4.14^{ab}	51.40±3.23^{a}	55.12±3.29^{b}	0.0317
	10	67.10±6.42^{a}	71.88±5.27^{b}	71.11±3.26^{b}	70.61±5.30^{ab}	72.20±4.64^{b}	68.75±2.98^{ab}	66.52±6.40^{a}	0.0295
	15	78.50±4.58^{a}	78.13±3.97^{b}	74.02±3.36^{a}	74.80±3.17^{a}	75.30±3.54^{ab}	77.60±3.66^{ab}	78.01±5.39^{b}	0.0248
Average		65.44±13.97^{a}	68.50±11.69^{b}	66.50±10.79^{ab}	67.14±9.87^{ab}	67.36±11.18^{ab}	65.92±13.33^{ab}	66.58±11.49^{ab}	0.0287

^{ab} Means bearing different superscripts in a row differ significantly ($p<0.05$); n = 10.

of 93.0 N and the spindle at 100 rpm at a temperature of 37°C.

Statistical analysis

Data are presented as means±SEMs. All microbiological concentrations were subjected to base-10 logarithmic transformation before analysis. Data were analyzed with SPSS13.0 software (SPSS Inc., Chicago, IL, USA) with a 1+2×2 factorial arrangement using orthogonal contrasts. Two-way analysis of variance (ANOVA) was used to analyze the means, and the Student-Newman-Keuls test was used to detect differences among means. Statistical significance was defined as $p<0.05$.

RESULTS

Results of the dietary treatments on chick growth and organ development are presented in Table 2. From d 5 to 15, the body weight, and weights of the bursa, proventriculus, gizzard, and gut length increased gradually in both the control and the dietary treatment groups. When compared to the control group, the 3-d averages of the body weight, and the weights of the bursa of Fabricius, proventriculus, and gizzard, and gut length in the WSP50 group were all higher than in the control group ($p<0.05$), and there were no significant differences between the 3-d averages in the WSP100, AEP50, and AEP100 groups compared to the control group. The 3-d averages of the body weight, and the weights of the bursa of Fabricius and gizzard in the Xase6 group were higher than those in the control group ($p<0.05$) and showed no significant difference with those in the WSP50 group. No significant difference in growth or organ development was observed among the groups treated with WSP, AEP, and xylanase when analyzing the 3-d averages. WSP100 increased weight gain and enhanced organ development (proventriculus, gizzard, and gut) on d 10 ($p<0.05$). There was no interaction between the type of pentosan (WSP and AEP) and the dosage of pentosan (50 and 100 mg/kg) on the body weight, and the weights of the bursa of Fabricius, proventriculus, and gizzard, and gut length ($p>0.05$).

Table 3 shows the effect of dietary treatments on digesta viscosity. In comparison to the control group, addition of WSP50, WSP100, AEP50 and AEP100 to the diet slightly increased the digesta viscosity in the ileum, cecum, and rectum from d 5 to 15, but no significant differences in digesta viscosities were found between the WSP and AEP groups and the control group. To some extent, the inclusion of xylanase in the diet decreased intestinal digesta viscosities. Addition of Xase3 and Xase6 to the diet slightly lowered the digesta viscosity of the ileum, cecum, and rectum from d 5 to 15, but no significant differences in digesta viscosities were found between the Xase3 and Xase6 groups and the control group. The Xase3 group had significantly lower digesta viscosities at ileum when compared to the AEP50 and AEP100 groups from d 5 to 15 ($p<0.05$). There was no interaction between the type of pentosan (WSP and AEP) and the dosage of pentosan (50 and 100 mg/kg) on the digesta viscosity of the ileum, cecum, and rectum ($p>0.05$).

Table 3. Effects of pentosan and xylanase on digesta viscosity in the gut (Pa·s)

	Days	Control	WSP50	WSP100	AEP50	AEP100	Xase3	Xase6	p
Ileum	5	2.04±0.21^{ab}	2.14±0.16^{ab}	2.23±0.10^{b}	2.26±0.17^{b}	2.29±0.14^{b}	2.01±0.17^{a}	1.96±0.13^{a}	0.0317
	10	1.92±0.14^{ab}	1.96±0.13^{ab}	1.99±0.13^{ab}	2.15±0.09^{b}	2.14±0.09^{b}	1.89±0.09^{a}	1.88±0.11^{a}	0.0019
	15	1.83±0.06^{ab}	1.93±0.08^{b}	1.91±0.04^{b}	1.96±0.05^{b}	2.02±0.06^{b}	1.73±0.07^{a}	1.82±0.05^{ab}	0.0005
Cecum	5	2.24±0.12^{ab}	2.35±0.13^{b}	2.33±0.16^{b}	2.43±0.15^{b}	2.51±0.16^{b}	2.27±0.13^{a}	2.21±0.13^{a}	0.0364
	10	2.19±0.14^{ab}	2.20±0.13^{ab}	2.23±0.07^{ab}	2.25±0.15^{ab}	2.28±0.13^{b}	2.15±0.11^{ab}	2.06±0.10^{b}	0.0283
	15	2.06±0.10^{ab}	2.11±0.12^{b}	2.11±0.09^{b}	2.12±0.14^{b}	2.07±0.14^{ab}	1.89±0.12^{a}	1.93±0.08^{ab}	0.0001
Rectum	5	2.08±0.16^{ab}	2.16±0.09^{b}	2.18±0.11^{b}	2.26±0.08^{b}	2.27±0.20^{b}	2.06±0.09^{ab}	1.98±0.10^{a}	0.0073
	10	1.95±0.13^{ab}	2.04±0.14^{b}	2.04±0.10^{b}	2.07±0.12^{b}	2.08±0.08^{b}	1.87±0.14^{ab}	1.83±0.13^{a}	0.0009
	15	1.95±0.13^{ab}	2.04±0.14^{b}	2.04±0.10^{b}	1.98±0.12^{b}	2.02±0.06^{b}	1.79±0.06^{ab}	1.75±0.14^{a}	0.0001

^{ab} Means bearing different superscripts in a row differ significantly ($p<0.05$); n = 5.

Table 4 shows the effects of the dietary treatments on the concentrations of bacterial strains in the rectum. The *Lactobacillus* concentrations in the WSP50, Xase3, and Xase6 groups were significantly increased compared with the control group ($p<0.05$) and were slightly higher than in the WSP100, AEP50, and AEP100 groups. However, the WSP50 group had the lowest levels of *Streptococcus* and *E. coli* among all of the groups. There was no interaction between the type of pentosan (WSP and AEP) and the dosage of pentosan (50 and 100 mg/kg) on the *Lactobacillus*, *Streptococcus*, and *E. coli* concentrations.

The results concerning the effects of WSP, AEP, and xylanase on the pH of the gut digesta are presented in Table 5. The pH levels throughout the gut in all of the dietary treatment groups were slightly lower than that of the control group, with significant differences detected between the Xase3 and control groups in the ileum and cecum on d 10 and 15 ($p<0.05$). There was no interaction between the type of pentosan (WSP and AEP) and the dosage of pentosan (50 and 100 mg/kg) on the pH of the ileum, cecum, and rectum.

DISCUSSION

Dietary fiber, known as "crude fiber", was overlooked

Table 4. Effects of pentosans and xylanase on the microflora in the gut (Log10 cfu/g)

	Days	Control	WSP50	WSP100	AEP50	AEP100	Xase3	Xase6	p
Lactobacillus	5	4.38±0.16^{a}	4.61±0.16^{b}	4.47±0.17^{b}	4.46±0.16^{b}	4.53±0.15^{b}	4.47±0.17^{b}	4.49±0.12^{b}	0.0078
	10	4.54±0.16^{a}	4.73±0.15^{b}	4.66±0.16^{ab}	4.70±0.16^{b}	4.62±0.17^{ab}	4.77±0.15^{b}	4.78±0.15^{b}	0.0286
	15	4.85±0.15^{a}	5.01±0.15^{b}	5.02±0.16^{b}	5.11±0.16^{b}	5.06±0.17^{b}	5.22±0.15^{b}	5.25±0.15^{b}	0.0291
Streptococcus	5	3.84±0.16^{a}	3.64±0.17^{b}	3.73±0.14^{ab}	3.76±0.14^{ab}	3.73±0.14^{ab}	3.87±0.15^{a}	3.78±0.15^{a}	0.0462
	10	4.30±0.16	4.28±0.16	4.65±0.15	4.52±0.15	4.60±0.15	4.76±0.15	4.62±0.15	0.0513
	15	4.78±0.16	4.50±0.16	4.89±0.15	5.01±0.15	5.06±0.16	5.18±0.15	5.08±0.14	0.0549
E. coli	5	3.86±0.15^{ab}	3.56±0.14^{a}	3.86±0.14^{ab}	3.73±0.14^{ab}	3.96±0.14^{b}	4.26±0.15^{b}	4.33±0.14^{b}	0.0371
	10	4.89±0.14^{ab}	4.63±0.14^{a}	5.05±0.15^{b}	4.79±0.14^{ab}	5.05±0.14^{b}	4.88±0.16^{ab}	4.72±0.16^{ab}	0.0388
	15	5.34±0.15	5.09±0.15	5.30±0.16	5.23±0.16	5.50±0.15	5.54±0.15	5.49±0.15	0.0601

^{ab} Means bearing different superscripts in a row differ significantly ($p<0.05$); n = 5.

Table 5. Effects of pentosans and xylanase on the chime pH in the gut

	Days	Control	WSP50	WSP100	AEP50	AEP100	Xase3	Xase6	p
Ileum	5	7.08±0.05	6.94±0.06	6.99±0.03	6.92±0.02	6.98±0.06	6.78±0.07	6.90±0.06	0.0537
	10	6.91±0.06^{a}	6.81±0.08^{ab}	6.78±0.13^{ab}	6.90±0.06^{a}	6.76±0.03^{ab}	6.63±0.05^{b}	6.82±0.04^{ab}	0.0446
	15	6.84±0.06^{a}	6.76±0.06^{ab}	6.69±0.05^{ab}	6.80±0.08^{a}	6.68±0.04^{ab}	6.61±0.03^{b}	6.68±0.03^{ab}	0.0467
Cecum	5	6.92±0.14^{ab}	6.91±0.08^{ab}	6.98±0.07^{a}	6.95±0.05^{a}	6.80±0.06^{ab}	6.70±0.04^{b}	6.86±0.09^{ab}	0.0403
	10	6.88±0.08^{a}	6.75±0.09^{ab}	6.80±0.13^{ab}	6.79±0.14^{ab}	6.71±0.07^{b}	6.66±0.05^{b}	6.73±0.06^{ab}	0.0384
	15	6.80±0.09^{a}	6.72±0.05^{ab}	6.74±0.04^{ab}	6.73±0.02^{ab}	6.55±0.07^{ab}	6.47±0.08^{b}	6.61±0.08^{ab}	0.0399
Rectum	5	7.13±0.06	7.10±0.02	7.11±0.09	7.08±0.02	6.92±0.02	6.99±0.09	6.92±0.10	0.0528
	10	7.08±0.16	6.91±0.09	6.97±0.12	6.99±0.16	6.67±0.03	6.84±0.12	6.85±0.09	0.0591
	15	6.86±0.15^{a}	6.87±0.07^{a}	6.83±0.05^{a}	6.84±0.07^{a}	6.65±0.03^{b}	6.77±0.10^{ab}	6.81±0.06^{b}	0.0472

^{ab} Means bearing different superscripts in a row differ significantly ($p<0.05$); n = 5.

until the 1970s. Today, dietary fiber is considered "the seventh largest nutrient for humans", and its importance is increasingly being recognized. Many studies have revealed that low dietary fiber intake is associated with a variety of human diseases, such as colon cancer and diabetes. Dietary fibers are often supplemented as prebiotics in modern society (Park et al., 2007).

Typically, dietary fiber decreases intestinal transit time, adds bulk to the stool, and promotes colonic fermentation in humans. There have been relatively few reports on the physiological functions and appropriate dosage of pentosans as dietary fiber. The limited data available are mostly on the anti-nutritive effect of pentosans in the animal feed industry. In this study, we found that WSP supplementation at 50 mg/kg diet promoted weight gain and organ development of broiler chicks fed corn-soybean meal-based diets, suggesting that pentosans may act as physiological enhancers and promote the growth of broiler chicks. Our finding is consistent with that of Courtin et al. (2008). In their study, supplementing 0.5% rice bran arabinoxylan to a wheat-based diet and 0.25% rice bran arabinoxylan to a corn-based diet improved the food conversion rate, and this beneficial effect was attributed to the prebiotic properties of arabinoxylan. Our result differs from that of Choct et al. (1990) who reported an anti-nutritive effect of pentosans. The discrepancy may due to the different levels of WSP and AEP in the test diets. A minimum of 4.8 g/kg DM WSP or 3.5 g/kg DM WIP was added to sorghum-casein hydrochloride based diets in the study by Choct et al. (1990). In the present study, a corn-soybean meal-based diet was used and the maximal level of WSP and AEP supplementation was 100 mg/kg. It is possible that pentosans function as prebiotics at 50 and 100 mg/kg supplementation in this study but as an anti-nutritive factor when supplemented at higher levels. Furthermore, the varying effects may be partially due to the different types of basal diets (sorghum-casein vs corn-soybean). In another study (Choct et al., 1992), dietary supplementation of AEP at 35 g/kg diet increased digesta viscosity in the ileum by twofold and depressed broiler performance. In the present study, inclusion of AEP at 100 mg/kg in the diet had no influence on the viscosity of the intestinal digesta and growth performance. The large difference between including 35 g/kg and 100 mg/kg of AEP in the diet may explain the conflicting results in digesta viscosity and growth performance observed in the two independent studies. Digesta viscosity is known to have an anti-nutritional effect (Choct et al., 1990). No data are available regarding to the range of changes in digesta viscosity following the inclusion of AEP in the diet of broiler chicks.

We found that dietary supplementation of 50 mg/kg WSP promoted the growth performance and organ development of broiler chicks in the present study. In contrast, supplementation of 100 mg/kg WSP, and 50 mg/kg or 100 mg/kg AEP had little or no effect. These findings suggest that WSP and AEP differ in their function and effective dosages. Studies comparing the functional effects of low levels of WSP and AEP are limited. Furthermore, the different basal diets and various levels of fiber contained in the basal diets are often confounding factors when evaluating the effect of WSP or AEP *per se*. Jiménez-Moreno et al. (2010) demonstrated that the addition of 30 g/kg oat hull improved gizzard weight and growth performance in young chicks fed low-fiber diets (15.4 g/kg). It is estimated that the low-fiber diet in their study with 20 and 30 g/kg oat hull supplementation (Mateos et al., 2012) contained a total of 94 and 141 mg/kg WSP and 2,044 and 3,066 mg/kg pentosans based on the data of Hashimoto et al. (1987). In the present study, the exogenous WSP was 50 and 100 mg/kg and the dietary fiber was 26.0 g/kg. The WSP levels in the two studies were at comparable levels, but the other dietary fiber compositions were different; therefore, the beneficial effects of prebiotic function in the study by Jiménez-Moreno et al. (2010) may not be simply due to the WSP in the oat hull. Similarly, the function and effective dosage of AEP could also be affected by the type of basal diet and other dietary fiber components in different studies (González-Alvarado et al., 2008; Jiménez-Moreno et al., 2010; Mateos et al., 2012; Rochell et al., 2012). To our knowledge, this is the first report that directly compares the effects of WSP and AEP supplementation on animal growth performance at practical levels.

The differences in the physiological responses and functions of WSP and AEP may be partially explained by the structural diversities of the arabinoxylans. Damen et al. (2011) showed that the prebiotic effects and enteric fermentation of arabinoxylans are structure-dependent. It has also been reported that intestinal flora are highly selective for the structures of pentosans (Moura et al., 2008). As a result of this selectivity, pentosans of various structures display different prebiotic effects and enteric fermentation capacities (Moura et al., 2008; Van Craeyveld et al., 2008). The observation in this study that only WSP50 increased the concentration of *Lactobacillus* in the rectum may be explained by this selectivity.

Numerous studies have reported the effects of xylanase on the growth performance of broiler chicks. The reduction of digesta viscosity by xylanase has been proposed as the underlying mechanism for the improvements in digestion and growth performance (Redgwell et al., 2001; Murphy et al., 2009). However, this theory is still under intensive debate. Dusel et al. (1998) suggested that xylanase enhances the performance of broiler chicks by improving the digestibility of dietary starch and fat, and the reduction in digesta viscosity may be the result of improved digestibility. Mathlouthi et al. (2002) speculated that xylanase improves

animal growth performance by modifying the conjugated bile acids in the intestinal content. Bao et al. (2010) reported that xylanase can hydrolyze non-starch polysaccharides and generate more phenolic resin, which act as anti-oxidants and clear the free radicals in the gut. In the present study, supplementation of xylanase reduced the digesta viscosity in the rectum of broiler chicks when compared to AEP supplementation. This result is supported by data from an *in vitro* study conducted by Rumpaqaporn et al. (2012) in which alkali-extractable arabinoxylan solution showed higher viscosity than xylanase-hydrolyzate. Although the decrease in digesta viscosity with xylanase supplementation was not significant in the present study when compared to the control group, the reduction could have a positive influence on food digestion and nutrient absorption. The lack of a significant change in digesta viscosity with WSP and AEP supplementation is likely due to the low dosages in the present study. The influence of these low dosages of WSP and AEP on the microflora concentration could be minimal as well. We only observed an increase in the *Lactobacillus* concentration in the rectum with 50 mg/kg WSP supplementation.

Inclusion of xylanase in the diet, particularly at the 3 mg/kg level, increased the concentration of *Lactobacillus* in the rectum and lowered the pH in the ileum on d 10 and 15 ($p<0.05$). WSP and AEP are the products of the hydrolysis of α-amylase and the breakdown of the α-1, 4-glycosidic bond, whereas xylanase hydrolyzes the β-1, 4-glycosidic bond of polysaccharides. Therefore, xylanase activity will generate products different from WSP and AEP. Apparently, products generated from xylanase activity are substrates for *Lactobacillus*. As a result, xylanase promoted microflora proliferation and fermentation, reduced gut pH, and enhanced food digestion and absorption.

CONCLUSION

Supplementation of WSP and xylanase in a corn-soybean meal-based diet improved the growth performance of broiler chicks, with supplementation of WSP at 50 mg/kg diet being the most efficient in promoting organ development. Both WSP and xylanase increased the concentration of gut *Lactobacillus*. WSP tended to increase digesta viscosity, whereas xylanase tended to reduce digesta viscosity in the gut. The mechanisms by which WSP and xylanase supplementation improved growth in the broiler chicks fed a corn-soybean based diet may differ. The results of this study suggest that inclusion of a low level of WSP in animal feed may provide beneficial prebiotic functions and avoid the anti-nutritive effect often associated with high levels of dietary fiber. Further studies are warranted to verify the efficacy of WSP50 in animal feed and to elucidate their functional mechanisms.

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