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Effects of supplementation of β-glucan on the growth performance and immunity in broilers ☆

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Abstract

Two experiments were conducted to evaluate the efficacy of β-glucan on commercial broilers. In experiment 1, one hundred and forty-four broiler chicks were employed in a 2×3 factorial design with cage and open floor housing with three levels of β-glucan viz. 0%, 0.02% and 0.04%. In experiment 2, ninety-six broilers were used with 4 treatments: No β-glucan and antibiotic (T1), β-glucan 0.03% (T2), antibiotic (T3), and β-glucan 0.03% + antibiotic (T4) for 34 d with 3 replicates of 8 chicks each in both studies. During experiment 1 there was no significant effect of the feeding system or the β-glucan levels on the performance from 0 to 17 d but during 18–34 days birds housed on the open floor had significantly ($p < 0.0001$) higher weight gain compared with those in cages. In experiment 2, no significant effect was noticed on the weight gains when the effect of β-glucan, antibiotic or their interaction were tested. The retention of dry matter increased in both experiments with β-glucan supplementation. The CD8 and TCR 1 cells were significantly higher in the 0.04% β-glucan group at 42 days as compared with the control. It could be concluded that β-glucan supplementation was beneficial for broilers.

Keywords: β-Glucans; Broilers; Growth; Immunity

1. Introduction

It is well known that antibiotic supplementation in the diet improves growth rate and feed efficiency in domestic animals and poultry. Because antibiotic supplementation may result in bacterial resistance to antibiotics and residues of antibiotics may be hazardous to human health, antibiotic supplementation should be limited and alternative sources of equal efficacy need to be evaluated. Glucans with β-1,3 and β-1,6 glycosidic linkages (β-glucans) are major structural components of yeast and fungal cell walls (Jorgensen and Robertsen, 1995). β-Glucan is known to possess antitumor and antimicrobial activities by enhancing the host immune function. It has a beneficial effect on weaned pigs' growth as it elicits specific immune reactions, increases non-specific immunity and tolerance to oral antigens (Mowat, 1987; Stokes et al., 1987). Supplementing nursery pigs' diets with 0.025% β-glucan increased growth performance but also increased the susceptibility to *Streptococcus suis* infection as reported by Dritz et al. (1995).

Schoenherr et al. (1994) reported that a β-glucan (Macrogard™-S) supplementation improved growth performance and feed efficiency in nursery pigs. Immunopotentiation effected by binding of a $(1 \rightarrow 3)$-β-glucan molecule or particle probably includes activation of cyto-

☆ The project underwent proper ethical standards and approved by Kangwon National University animal care and use committee.

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toxic macrophages, helper T-cells and natural killer (NK) cells, promotion of T cell differentiation and activation of the alternative complement pathway (Bohn and BeMiller, 1995). Stimulatory effects of β-glucan on both specific and non-specific immune responses have been demonstrated in mice (Suzuki et al., 1990), in fish (Robertsen et al., 1990; Jeney and Anderson, 1993) and beneficial effects on growth performances in pigs (Schoenherr et al., 1994; Dritz et al., 1995). But there are no reports about the effects of β-glucan in poultry. The following study was conducted to evaluate the effective dose of β-glucan on the performance of broilers and its immuno-modulating effects, and compare it with antibiotics.

2. Materials and methods

2.1. Design, animals and sample preparation

Two experiments were conducted to evaluate the efficacy of β-glucan.

2.1.1. Experiment 1

For a six-week feeding trial, a total of 144 broiler chicks (Ross, 3-day old, average 49.30 ± 2.89 g body weight) either caged or on rice hull litter material were allotted to three dietary treatments of β-glucan at 0%, 0.02% and 0.04% of diet. Thus, a 2 × 3 factorial study was conducted with 3 replicates consisting of 8 chicks each. From 4 days of age the birds were fed a starter (until 21 days of age) and finisher diet (from 22 to 38 days of age) containing β-glucan levels as stated.

Basal diets (mash) were formulated to contain 22.04% and 20.26% crude protein for starter and finisher diets, respectively (Table 1). β-Glucan was added in the vitamin premix and then mixed in the diet. The source of β-glucan was *Saccharomyces cerevisiae* IS 2 (KCTC 0959BP), IS 9 (KCTC 0960BP), IB 54 (KCTC 0961BP) and IB 56 (KCTC 0962BP) strains (GLUCAGEN; Enbiotec Company, Seoul, Korea). The product contains 10% moisture, 30% crude protein, 3% crude fiber, 10% crude ash and the concentration of β-1,3/1,6-glucan was more than 40% as stated by the company specifications. In a room (floor with rice hull bedding), 4 days old chicks were raised in pens of 1.0 × 1.5 meters on their respective diets with ad libitum access to feed and water. Room temperature was controlled until three weeks of age. The temperature during the first week was 34 ± 1 °C and was gradually reduced to 26 ± 1 °C by 21 days of age, after which the chicks were maintained at room temperature (15–34 °C). For the first three days the chicks were raised on a commercial starter diet. In the same room with the same environmental conditions and management another set of broilers were reared in cages of 1.0 m length and 0.5 m breadth with the same experimental diets.

Table 1
Formula and chemical composition of experimental diets (experiment 1)

	Starter (d 0–17)	Finisher (d 18–34)
Ingredients (g/kg)		
Maize	560.6	599.0
Soybean meal	224.4	207.6
Maize germ meal	70.0	80.0
Fish meal	61.6	30.0
Animal fat	60.0	57.0
Tri-calcium phosphate	9.2	11.2
Limestone	5.9	8.7
Vitamin premix[a]	1.0	1.0
Trace mineral premix[b]	2.0	2.0
Salt	2.5	2.5
L-Lysine	–	0.3
DL-Methionine (50%)	2.0	–
Choline chloride (25%)	0.8	0.7
Total	1000.0	1000.0
Chemical composition (g/kg)		
ME (MJ/kg)	13.4	13.4
Crude protein	220.4	202.6
Calcium	9.0	9.0
Available phosphorus	4.0	3.5
Lysine	11.4	10.0
Methionine	5.3	4.0
Met + Cys	9.0	7.5

[a] Supplied per kg diet: 9000 IU vitamin A, 1800 IU vitamin D_3, 10 IU vitamin E, 1 mg vitamin B_1, 10 mg vitamin B_2, 2 mg vitamin B_6, 0.02 mg vitamin B_{12}, 1 mg vitamin K_3, 12 mg pantothenic acid, 30 mg niacin, 0.03 mg biotin, 0.5 mg folic acid, 4 mg pyridoxine, 3 mg ethoxyquin.

[b] Supplied per kg diet: 80 mg Fe, 80 mg Cu, 100 mg Zn, 120 mg Mn, 2 mg I, 0.1 mg Co, 0.2 mg Se.

For nutrient retention studies, chicks in cages were fed finisher diets containing 0.25% chromic oxide as an indigestible marker at 38 days of age. Fecal samples were taken from each pen on the fourth day. Feces were dried in a forced-air drying oven at 60 °C for 3 days and stored.

To study the β-glucan effect on lymphocyte subpopulation, blood was collected from the wing vein of six chicks in each group (two per replicate) at 28 and 42 days of age only from birds reared in cages.

2.1.2. Experiment 2

For a six-week feeding trial, a total of ninety-six broiler chicks (Ross, 3-day old, average 53.51 ± 1.83 g body weight) in cages were allotted to four dietary treatments. Each treatment was assigned to 3 replicate cages containing 8 chicks each. The diets contained: T1 (No β-glucan or antibiotic), T2 (β-glucan 0.03%), T3 (antibiotic) and, T4 (β-glucan 0.03% + antibiotic). The antibiotic fed during the starter and finisher phase was flavomycin (5 mg/kg) as detailed in Tables 2 and 3, respectively. The source of β-glucan and the facilities and management were the same as in experiment 1. The experiment was conducted for 5 weeks during which the body weights

Table 2
Formula and chemical composition of experimental diets (d 0–17) in experiment 2

Treatments[c]	T1	T2	T3	T4
Ingredients (g/kg)				
Maize	560.6	560.3	559.6	559.3
Soybean meal	224.4	224.4	224.4	224.4
Maize germ meal	70.0	7.00	70.0	70.0
Fish meal	61.6	61.6	61.6	61.6
Animal fat	60.0	60.0	60.0	60.0
Tri-calcium phosphate	9.2	9.2	9.2	9.2
Limestone	5.9	5.9	5.9	5.9
Vitamin premix[a]	1.0	1.0	1.0	1.0
Trace mineral premix[b]	2.0	2.0	2.0	2.0
Salt	2.5	2.5	2.5	2.5
L-Lysine	–	–	–	–
DL-Methionine (50%)	2.0	2.0	2.0	2.0
Flavomycin	–	–	1.0	1.0
Choline chloride (25%)	0.8	0.8	0.8	0.8
β-Glucan	–	0.3	–	0.3
Total	1000.0	1000.0	1000.0	1000.0
Chemical composition (g/kg)				
ME (MJ/kg)	13.4	13.4	13.4	13.4
Crude protein	220.4	220.4	220.4	220.4
Calcium	9.0	9.0	9.0	9.0
Available phosphorus	4.0	4.0	4.0	4.0
Lysine	11.4	11.4	11.4	11.4
Methionine	5.3	5.3	5.3	5.3
Met + Cys	9.0	9.0	9.0	9.0

[a] Supplied per kg diet: 9000 IU vitamin A, 1800 IU vitamin D_3, 10 IU vitamin E, 1 mg vitamin B_1, 10 mg vitamin B_2, 2 mg vitamin B_6, 0.02 mg vitamin B_{12}, 1 mg vitamin K_3, 12 mg pantothenic acid, 30 mg niacin, 0.03 mg biotin, 0.5 mg folic acid, 4 mg pyridoxine, 3 mg ethoxyquin.
[b] Supplied per kg diet: 80 mg Fe, 80 mg Cu, 100 mg Zn, 120 mg Mn, 2 mg I, 0.1 mg Co, 0.2 mg Se.
[c] T1, β-glucan 0%; T2, β-glucan 0.03%; T3, Flavomycin 0.1%; T4, Flavomycin 0.1% + β-glucan 0.03%.

Table 3
Formula and chemical composition of experimental diets (d 18–34) in experiment 2

Treatments[c]	T1	T2	T3	T4
Ingredients (g/kg)				
Maize	599.0	598.7	598.0	597.7
Soybean meal	207.6	207.6	207.6	207.6
Maize germ meal	80.0	80.0	80.0	80.0
Fish meal	30.0	30.0	30.0	30.0
Animal fat	57.0	57.0	57.0	57.0
Tri-calcium phosphate	11.2	11.2	11.2	11.2
Limestone	8.7	8.7	8.7	8.7
Vitamin premix[a]	1.0	1.0	1.0	1.0
Trace mineral premix[b]	2.0	2.0	2.0	2.0
Salt	2.5	2.5	2.5	2.5
L-Lysine	0.3	0.3	0.3	0.3
DL-Methionine (50%)	–	–	–	–
Flavomycin	–	–	1.0	1.0
Choline chloride (25%)	0.7	0.7	0.7	0.7
β-glucan	–	0.3	–	0.3
Total	1000.0	1000.0	1000.0	1000.0
Chemical composition (g/kg)				
ME (MJ/kg)	13.4	13.4	13.4	13.4
Crude protein	202.6	202.6	202.6	202.6
Calcium	9.0	9.0	9.0	9.0
Available phosphorus	3.5	3.5	3.5	3.5
Lysine	10.0	10.0	10.0	10.0
Methionine	4.0	4.0	4.0	4.0
Met + Cys	7.5	7.5	7.5	7.5

[a] Supplied per kg diet: 9000 IU vitamin A, 1800 IU vitamin D_3, 10 IU vitamin E, 1 mg vitamin B_1, 10 mg vitamin B_2, 2 mg vitamin B_6, 0.02 mg vitamin B_{12}, 1 mg vitamin K_3, 12 mg pantothenic acid, 30 mg niacin, 0.03 mg biotin, 0.5 mg folic acid, 4 mg pyridoxine, 3 mg ethoxyquin.
[b] Supplied per kg diet: 80 mg Fe, 80 mg Cu, 100 mg Zn, 120 mg Mn, 2 mg I, 0.1 mg Co, 0.2 mg Se.
[c] T1, β-glucan 0%; T2, β-glucan 0.03%; T3, Flavomycin 0.1%; T4, Flavomycin 0.1% + β-glucan 0.03%.

and feed intake were recorded after each phase of feeding. The nutrient retention study was also conducted using chromic oxide (0.25%) as an indicator as per experiment 1.

2.2. Analyses

Body weight gain and feed intake were recorded at 17 and 34 days of experimental feeding. Proximate analysis of samples was made according to the methods of AOAC (1990). Gross energy was measured with an adiabatic bomb calorimeter (Model 1241, Parr Instrument Co. Molin, IL.), and chromium was measured by perchloric acid digestion and then colorimetric determination using a spectrophotometer (Jasco Co. Model V-550, Japan), as described in AOAC (1990).

Blood collected to analyze the avian leukocyte subpopulation was prepared according to the Davis et al. (1990) with minor modification. The peripheral blood lymphocytes were isolated from the buffy coat layer of the centrifuged blood using Hypaque Ficoll (Histopaque 1.803, Sigma), washed three times and resuspended at 1×10^7 cells/mL in a FB-PBS (11.3 millimole (mM) sodium phosphate, 3.8 mM potassium phosphate, 125 mM sodium chloride, 10 mM EDTA, 0.1% sodium azide, 10% acid citrate dextrose, 2% globulin free horse serum). A 100 μL aliquot of cell suspension was added to a 96 well plate and mixed with 15 μL of each mouse-anti-chicken monoclonal antibodies (mAb) specific for various avian leukocyte differentiation antigen markers. The panel of mAb included mAb specific for CD4 (T helper cell), CD8a (cytotoxic T cells), TCR-I cell, TCR-II and B-lymphocyte. After incubation and washing, the cell suspension was incubated with 100 μL of 1/200 diluted fluorescein isothiocyanate (FITC)-conjugated goat anti-mouse IgG + IgM antibody (Caltag Lab, USA). Labeled lymphocytes were counted and analyzed with FACs Calibur and Cell Quest program (Becton Dickinson, USA).

2.3. Statistical analysis

Data collected was subjected to statistical analysis using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). A p-value of 0.05 was used to determine statistical significance in most analyses, and a level of 0.10 was used wherever specified. The performance data collected during experiment 1 was analyzed as a 2×3 factorial design and the performance and retention data generated during experiment 2 was analyzed as a 2×2 factorial design. The pen was the experimental unit, but for immunity studies each chick was considered the experimental unit. The data for immune studies was analyzed by GLM procedure of SAS by one-way analysis of variance.

3. Results

3.1. Effect on growth performance

The weight gain, feed intake or feed to gain ratio was not affected due to cage or open floor, or by the levels of β-glucan or either floor condition and levels interactions during the starter phase (Table 4). The weight gain was greater ($p < 0.0001$) in the open floor as compared with the cage during the finisher phase but greater at 0.02% and 0.04% as compared with the non-supplemented group. The higher weight gain seemed to be the effect of higher ($p = 0.0001$) feed intake in the open floor as compared with caged birds. A similar trend of increased weight gain and feed intake in open floor broilers compared to cage-reared birds was also noted during the overall study (0–34 days). The feed to gain ratio was neither affected at any of the phases of study nor by floor condition or β-glucan levels.

The weight gain was not affected by β-glucan, antibiotic or their interaction during the starter, finisher or overall study (Table 5). However, a higher ($p < 0.10$) feed intake was noted in the β-glucan supplemented group as compared with the non-supplemented group during the starter and overall phases. There was no effect on weight gain, feed intake or feed to gain ratio during the finisher study. But feed to gain ratio was improved ($p < 0.05$) by β-glucan and antibiotic supplementation during the starter phase and an interaction effect was noticed during the starter and overall study.

3.2. Effect on nutrient retention

In experiment 1, except for dry matter, the retention of all the nutrients was not affected by β-glucans in cage-reared birds (Table 6). The retention of dry matter was higher in β-glucan supplemented diets at 0.02% and 0.04% than in non-added diets.

In experiment 2, the retention of dry matter, calcium and phosphorus was higher ($p < 0.05$) in β-glucan supplemented diets than non-supplemented ones (Table 7). In addition to dry matter, calcium and phosphorus, the digestibility of ether extract was also higher ($p < 0.05$) in antibiotic added diets when compared with its counterpart but the interaction studies remained comparable for all the nutrients tested.

3.3. Effect on lymphocyte subpopulation

The MHC-Class II, CD4, CD8, TCR 1, TCR 2 and B-lymphocyte population was not affected by dietary supplementation at the 28th day of age but at the 42nd day, CD8 and TCR 1 cells were higher in the 0.04% β-glucan supplemented diet as compared with non-added diets (Fig. 1).

Table 4
Growth performance of broilers as affected by floor conditions and dietary β-glucan levels

Conditions (C) and levels (L) in %	Cage (wire)			Open floor house (rice hull)			SEM[a]	Conditions	Levels	C × L
	0	0.02	0.04	0	0.02	0.04				
d 0–17										
Weight gain (g)	487	496	493	486	511	504	4.69	NS[b]	NS	NS
Feed intake (g)	791	843	829	858	844	852	11.44	NS	NS	NS
F/G	1.62	1.70	1.68	1.77	1.65	1.69	0.02	NS	NS	NS
d 18–34										
Weight gain (g)	843	877	862	1024	1086	1109	23.83	0.0001	0.0208	NS
Feed intake (g)	1579	1701	1680	2068	2130	2047	48.93	0.0001	NS	NS
F/G	1.87	1.94	1.95	2.02	1.96	1.85	0.02	NS	NS	NS
d 0–34										
Weight gain (g)	1331	1373	1355	1510	1598	1614	25.68	0.0001	0.0228	NS
Feed intake (g)	2370	2544	2509	2926	2974	2899	53.48	0.0001	NS	NS
F/G	1.78	1.85	1.85	1.94	1.86	1.80	0.02	NS	NS	0.0687

[a] Mean standard error.
[b] NS, not significant ($n = 3$ replicates per treatment).

Table 5
The effect of supplemental β-glucan and antibiotics on growth performance in broiler (d 0–34)

β-Glucan	0%		0.03%		SEM[c]	β-Glucan	Antibiotics	β-Glucan × antibiotics
Antibiotics	0%	0.1%	0%	0.1%				
d 0–17								
Weight gain (g)	471	498	494	508	9.65	NS[d]	NS	NS
Feed intake (g)[a]	745	797	834	816	16.20	0.0987	NS	NS
F/G[b]	1.58	1.60	1.69	1.61	0.01	0.0004	0.0214	0.0024
d 18–34								
Weight gain (g)	835	862	857	872	11.65	NS	NS	NS
Feed intake (g)	1557	1676	1680	1648	24.80	NS	NS	NS
F/G	1.87	1.94	1.96	1.89	0.02	NS	NS	NS
d 0–34								
Weight gain (g)	1306	1361	1351	1379	16.05	NS	NS	NS
Feed intake (g)[a]	2301	2473	2514	2465	30.45	0.0598	NS	0.0451
F/G[b]	1.76	1.82	1.86	1.79	0.02	NS	NS	0.0363

($n = 3$ replicates per treatment).
[a] ($p < 0.10$).
[b] ($p < 0.05$).
[c] Mean standard error.
[d] NS, not significant.

Table 6
The effect of supplemental β-glucan on nutrient retention (%) in caged broilers (d 0–34)

Treatments	β-Glucan (%)			SEM[B]	*p*-Value
	0	0.02	0.04		
Dry matter[A]	74.95[b]	77.50[a]	78.18[a]	0.60	0.0373
Gross energy	77.79	79.92	79.40	0.54	NS[C]
Crude protein	62.77	66.26	67.46	1.13	NS
Ether extract	85.25	86.57	86.76	0.83	NS
Crude ash	28.18	31.13	31.99	1.73	NS
Calcium	35.89	39.04	42.52	2.35	NS
Phosphorus	39.31	38.77	44.34	2.05	NS

[A] Values with different superscripts in the same row differ significantly ($p < 0.05$).
[B] Mean standard error. ($n = 3$ replicates per treatment).
[C] NS, not significant.

Table 7
The effect of supplemental β-glucan and antibiotics on nutrient retention (%) in broilers (d 0–34)

β-Glucan	0%		0.03%		SEM[a]	β-Glucan	Antibiotics	β-Glucan × antibiotics
Antibiotics	0%	0.1%	0%	0.1%				
Dry matter	74.64	79.16	77.82	79.58	0.67	0.0521	0.0040	NS[b]
Gross energy	79.71	79.85	79.01	80.81	0.66	NS	NS	NS
Crude protein	70.68	72.95	71.44	74.24	0.81	NS	NS	NS
Ether extract	82.96	86.45	83.06	87.70	0.67	NS	0.0001	NS
Calcium	44.51	49.09	48.72	55.87	1.30	0.0005	0.0003	NS
Phosphorus	38.63	43.97	41.96	46.24	0.94	0.0225	0.0013	NS

($n = 3$ replicates per treatment).
[a] Mean standard error.
[b] NS, not significant.

4. Discussion

Neither the weight gain nor the feed intake or feed to gain ratio was affected during the starter phase (Table 4) suggesting that β-glucan did not have any role in growth performance during the initial stages of development. But the greater weight gain in the finisher phase was the effect of increased feed intake, which was more prominent in litter-reared broilers than in caged birds. Body weight at 3 weeks of age was affected by the husbandry systems, being greatest for the birds reared in floor pens than those reared on wire mesh floored cages

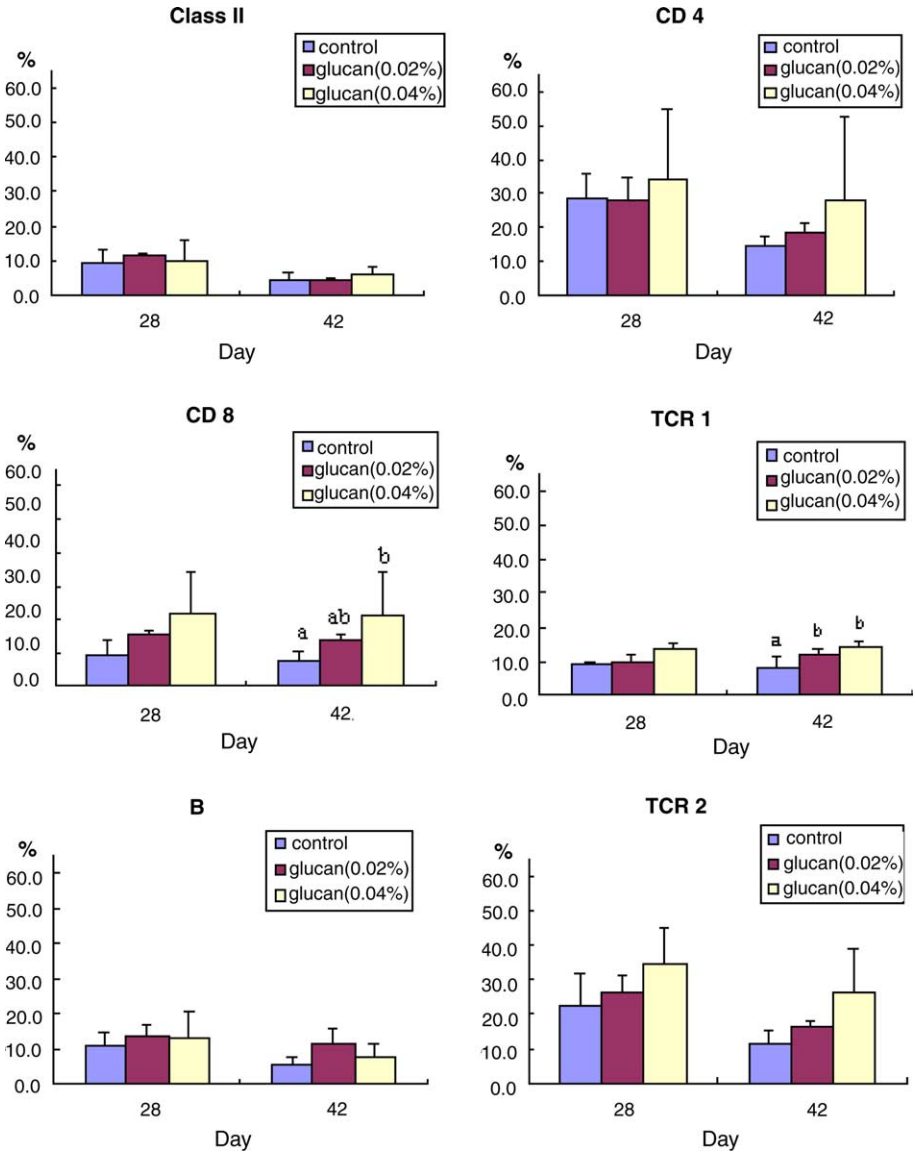

Fig. 1. Changes of proportion of avian class II, CD4, CD8, TCR-I, TCR-II and B lymphocyte subpopulations at post treatment with different percentages of β-glucan in broilers ($n = 6$ per treatment).

(Tolon and Yalcin, 1997). Similar studies revealed a significant reduction in live body weight at 6 and 8 weeks of age of broilers grown on wire mesh floors when compared with other flooring material (Akpobome and Fanguy, 1992). Birds reared on rice husk litter showed the greatest food consumption, greatest weight gain and best food conversion efficiency than those reared on sawdust, paddy straw and sand litters (Anisuzzaman and Chowdhury, 1996). The broilers supplemented with β-glucan at 0.02% and 0.04% showed a higher weight gain than unsupplemented ones in our study. A similar trend of increased weight gains but no effect on feed efficiency by feeding β-glucan at levels between 0.025% and 0.05% was also noted by Schoenherr et al. (1994) in nursery pigs. The feed:gain ratio was not improved by β-glucan supplementation in our study. The overall study (0–34 days) showed improvement ($p < 0.05$) in weight gain due to β-glucan supplementation above 0.02% level, which possibly may be the effect of increased feed intake. The higher weight gains in litter birds than caged birds may be because the latter are more prone to stress than to litter reared birds. The immuno-modulatory role of β-glucan in partitioning nutrients towards growth could be a possible reason for the improved growth seen in our study. This was also noted by Poutsiaka et al. (1993) and Klasing et al. (1987). But average daily gain (ADG) in β-glucan treated pigs at 0.015% or 0.03% was no different than the control 4 weeks post weaning (Hiss and Sauerwein, 2003). They also noted that feed intake had the tendency to increase ($p < 0.10$) at 0.03% β-glucan inclusion without alteration of feed efficiency as in this study. As far as the authors

are aware this is the first report where the effect of β-glucan was tested on broiler performance. Dritz et al. (1995) also found increased ADG and average daily feed intake in pigs fed 0.025% β-glucan for 28 days than pigs fed a control diet. Neither did they report any difference in feed to gain ratio, which supports our findings. The purpose of conducting this experiment in either cage or floor was to create a difference in managemental conditions/rearing methods since broilers are reared in both cages and litter and to note whether β-glucan as an immuno-modulator could improve the performance in either rearing methods. It is also known that respirable dust concentrations and the number of airborne microorganisms are always higher in litter rooms than in broilers raised on netting flooring systems (Madelin and Wathes, 1989).

The growth performance data generated during experiment 2 was at par with that reported for the cage reared birds in experiment 1, showing almost similar weight gains and feed intake in non-supplemented and β-glucan supplemented groups, although the β-glucan level was a little higher in this experiment (0.03%). Weight gain was not affected by β-glucan, antibiotics or their interaction (Table 5). Feed intake was higher ($p < 0.10$) with the β-glucan supplemented diet during the starter and overall study than with non-supplemented diets, which contradicts the findings in experiment 1 where the feed intake tended to be lower in non-supplemented diets but did not achieve statistical significance. Data in experiments 1 and 2 revealed that β-glucan had an impact on feed intake but the possible reason behind this remains obscure. Except for improvement in the feed to gain ratio at the overall phase, no additive effect on weight gain could be noted when antibiotic plus β-glucan was supplemented. The health and growth promoting effects of feeding subtherapeutic levels of antibiotics to chickens are well documented (Eyssen and De Somer, 1963; Engberg et al., 2000). Antibiotic supplementation in growing pig diets improved the weight gain and the feed conversion ratio (Ko et al., 2000) when compared with mannan-oligosaccharides, β-glucan or yucca extract which is contradictory to the present report. They also reported the antibiotic group and β-glucan supplemented diet had higher weight gains and feed conversion ratio than the antibiotic free (control) diet. Even β-glucan alone failed to show any positive effect on performance at 0.03% that paralleled our findings in experiment 1 in cage reared birds but not in litter reared birds. This suggests a mixed interaction exists with β-glucan supplementation and the effect on performance depends on the immune status of the animal. Less exposure to antigens (isolation facility) or a non-activated immune system is desirable for maximizing growth performance by β-glucan as was also suggested by Dritz et al. (1995).

There was a higher retention of dry matter ($p < 0.05$) during the finisher phase in experiment 1. Apparently, numerically higher retention values were noted in supplemented diets that might have culminated into numerically increased weight gains in supplemented diets especially at 0.02% and 0.04% β-glucan levels. Few reports are available with respect to the effect of β-glucan on nutrient retention. No effect on retention of dry matter, gross energy, crude protein, ash and phosphorus due to β-glucan supplementation at 0.1% in growing pigs was reported by Ko et al. (2000) and in finishing pigs by Bae et al. (1999) at the same level. Although β-glucan from barley has been recognized as an anti-nutritional factor that affects the weight gain and feed intake in broilers, β-glucan from microbial sources having a positive role in improving performance and immunity has also been proved in most species.

The retention of dry matter, calcium and phosphorus was higher ($p < 0.05$) in β-glucan, and antibiotic supplemented diets when compared with their respective counterparts (Table 7). The present findings contradict the findings of Yoo et al. (1985) and Min (1992) who did not find any effect on nutrient retention due to antibiotic supplementation on growing-finishing pigs. The increase in nutrient retention however failed to achieve statistical significance in improving weight gains. A similar trend of increased dry matter retention was noticed during the finisher phase with β-glucan supplemented diets than non-supplemented diets during experiment 1.

The subset of avian lymphocyte subpopulations at the 28th day of feeding was not influenced by the dietary treatments during experiment 1 (Fig. 1). The CD8 and TCR 1 cells showed higher ($p < 0.05$) populations in the 0.04% β-glucan fed diet when compared with non-supplemented diets at the 42nd day of measurement. The MHC class II, CD4, TCR 2 and B-lymphocytes were not affected by any of the dietary treatments at the 42nd day. Previously, Suzuki et al. (1989) showed that the proliferative responses of spleen cells from β-glucan administered mice to T-cell and B-cell mitogens were higher than those from normal mice. Oral administration of β-glucan also enhanced the activities of natural killer cells and peritoneal macrophages. In addition, β-glucan stimulated cytotoxic T-lymphocytes, B cells, and macrophages in mice (Cross et al., 2001). Summarily, our results indicate marginal benefits of β-glucan supplementation on avian lymphocyte subpopulations. However, Hiss and Sauerwein (2003) reported that β-glucan supplementation did not show any effect on the immune parameters, e.g., serum haptoglobin and antibody response to porcine reproductive and respiratory syndrome vaccination. No significant effect was found on the Infectious bronchitis and Newcastle disease titers in our study (data not shown). Further studies are needed to confirm the impact of β-glucan on the immune status of broilers.

Conclusively, dietary levels of β-glucan above 0.02% improved growth performance, nutrient retention and immunity in broilers but we recommend conducting more studies on the exact mechanism of action of β-glucan in broilers.

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