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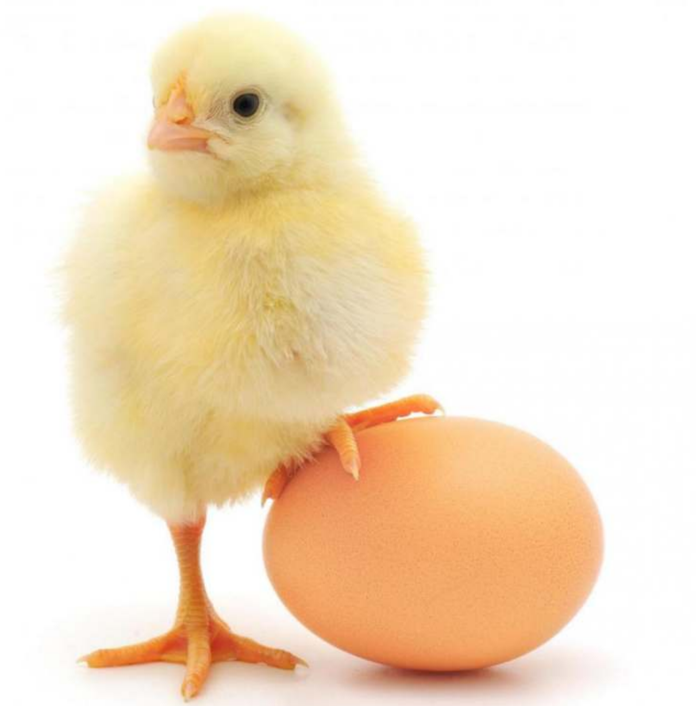

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ANSInet
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
Mob: +92 300 3008585, Fax: +92 41 8815544
E-mail: editorijps@gmail.com

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Meta-analysis of Broiler Chicken Pen Trials Evaluating Dietary Mannan Oligosaccharide, 1993-2003

Danny M. Hooge
Hooge Consulting Service, Inc., 8775 North Cedar Pass Road, Eagle Mountain, Utah 84043 USA
E-mail: danhooge@fiber.net

Abstract: Global broiler chicken pen trial reports (1993-2003) were analyzed statistically to determine effects of *Saccharomyces cerevisiae* var. *boulardii* yeast outer cell wall mannan oligosaccharide (MOS; Bio-Mos®, Alltech, Nicholasville, Kentucky USA) supplemented diets versus negative control (nCON) or antibiotic-supplemented positive control (pCON) diets. Criteria for selecting studies were: 1) pen trial, 2) written report, 3) MOS fed for entire study period, 4) negative and/or positive control, 5) antibiotic stated (for positive control), 6) replication and 7) age, body weight (BWT) and feed conversion ratio (FCR) given. Mortality (MORT) was used when reported. Results were averaged "by treatments" (all comparisons) and "by trials" (comparisons averaged by trial before analysis) using Paired T-test to compare nCON and pCON means with corresponding MOS means. Slightly different answers but similar patterns emerged by these methods. Considering results averaged by trials, MOS diets gave the following relative improvements compared to nCON diets: BWT, +1.61%; FCR, -1.99% and MORT, -21.4 (all significant at P = 0.020). Relative improvements using MOS feeds compared to the pCON diets were: BWT, -0.36% and FCR, -0.11% (P = 0.473; nonsignificant differences). The MOS diets significantly (P = 0.008) lowered mortality (-18.10%) relative to pCON diets, indicating a strong beneficial effect. The MOS diets produced BWT and FCR comparable to those of pCON diets but significantly lowered MORT compared to antibiotic diets. Currently recommended optimal MOS levels of addition for broiler chicken feeds are: 0.2%, 0 to 7 days; 0.1%, 7 to 21 days and 0.05%, 21 to 42 days (or market).

Key words: Antibiotic, Bio-Mos, broiler, mannan oligosaccharide, meta-analysis

Introduction

Saccharomyces cerevisiae var. *boulardii* yeast outer cell wall component, mannan oligosaccharide (MOS), was introduced as a feed additive for broiler chickens in 1993 (Bio-Mos®, Alltech, Nicholasville, Kentucky USA). Since then MOS has been shown in many trials to improve body weight, feed conversion ratio and livability. One particular advantage of MOS is its stability during steam pelleting which allows it to be added in the mixer prior to pelleting or crumbling of broiler diets.

The MOS product is reported to have at least three probable modes of action by which broiler performance is improved: 1) adsorption of pathogenic bacteria containing type 1 fimbriae with mannose-sensitive lectins, sometimes referred to as the "receptor analog" mechanism (strongly binding to and decoying pathogens away from the "sugar coated" intestinal lining), or stated another way, different bacterial strains can agglutinate MOS (Oyofo *et al.*, 1989; Spring *et al.*, 2000); 2) improved intestinal function or "gut health" (for example: increases villi height, uniformity and integrity) (Loddi *et al.*, 2002) and 3) immune modulation simulates gut associated and systemic immunity by acting as a non-pathogenic microbial antigen, giving an adjuvant-like effect (Ferket *et al.*, 2002).

A high level (0.40%) of dietary MOS given to young chicks challenged with *Salmonella typhimurium* reduced cecal counts and challenged with *Salmonella dublin* reduced the number of positively infected birds by day 10. There were no effects on cecal concentrations of *Lactobacilli*, *Enterococci*, anaerobic bacteria, lactate, violative fatty acids, or pH of cecal contents, suggesting that alteration of populations of these species is probably not part of the chick growth promotion mechanism (Spring *et al.*, 2000). In some studies in which certain antibiotics were used in combination with MOS, additive or synergistic beneficial effects on broiler live performance were observed compared to antibiotic alone - for example: virginiamycin + MOS, significant feed conversion improvement (Mathis, 2000); bacitracin-MD and virginiamycin shuttle program + MOS, feed conversion and mortality improvements (Sefton *et al.*, 2002).

Dietary MOS has other effects that influence performance of broiler chickens. In a caged broiler study, using 0 to 0.3% MOS at 0.05% increments of addition to the diets, 0 to 21 day fiber digestibilities significantly improved with diets containing each level of MOS compared to the negative control diets (Kumprecht *et al.*, 1997). In a trial in which either clean litter or recycled litter was used and results for litter types were combined, water intake per bird from 0 to 14 days of age expressed as dL water/100 g feed (that is, water:feed ratio) was significantly lower for MOS-fed birds (1.91) than for negative control broilers (1.99). As a result, 0 to

Table 1: Broiler chicken body weight results from pen trials (including litter, wire, or slats) worldwide comparing antibiotic-free negative control diets (nCON) versus mannan oligosaccharide diets (MOS) fed at levels stated during the entire study periods

Age (d)	Strain; Strain Cross[1]	Litter (new or used)	MOS level (%) [to given age]	nCON Body Wt, Kg	MOS Body wt, Kg	Rel. Change w/MOS (%)[2]	Reference
35	RxR	New	0.10	1.845	1.872	+1.46	ten Doeschate & Kenyon (2002)
35	Cobb	New	0.20[14d]; 0.10[35d]	1.827	1.907	+4.38	Kenyon (2000)
36	RxR	New	0.10[7d]; 0.05[36d]	1.724	1.818	+5.45	Petersen & Villadsen (2002)
38	RxR	New	0.10[7d]; 0.05[38d]	1.822	1.905	+4.56	Petersen & Villadsen (2002)
39	RxR	New	0.2[11d]; 0.1[32d]; 0.05[39d]	2.391	2.381	-0.42	Bokma - Bakker *et al.* (2002)
42	RxR	New	0.10[21d]; 0.05[42d]	2.673	2.775	+3.82	Roch (1999)
43		New	0.20[28d]; 0.15[43d]	2.033	2.080	+2.31	Valarezo *et al.* (1997)
49	RxR	New	0.10[21d]; 0.05[49d]	2.390	2.505	+4.81	Sims *et al.* (1998)
49	Cobb	New	0.10	3.148	3.174	+0.83	Wilson & Kenyon (2002)
49	RxR	New	0.10[21d]; 0.05[49d]	2.597	2.667	+2.70	Sefton *et al.* (2002)
49	RxR	New	0.15[35d]; 0.05[49d]	2.283	2.365	+3.59	Perez *et al.* (2002)
49		New	0.11	2.240	2.235	-1.12	Savage *et al.* (1996)
39	AF		0.10	1.915	1.915	0	Eren *et al.* (2003)
39			0.10	2.194	2.202	+0.36	Geliot (1999)
39			0.2[10d]; 0.1[21d]; 0.05[39d]	2.194	2.195	+0.05	Geliot (1999)
47			0.10[12d]; 0.05[47d]	1.855	1.822	-1.78	Hadorn & Wiedmer (1999)
47			0.10	1.855	1.839	-0.86	Hadorn & Wiedmer (1999)
47			0.20[12d]; 0.10[47d]	1.855	1.855	0	Hadorn & Wiedmer (1999)
41	RxR		0.2[d]; 0.1[d]; 0.05[41d]	2.599	2.601	+0.08	Rosell (2002)
42	RxR		0.05	2.502	2.535	+1.32	Tucker *et al.* (2003)
42	RxR		0.10	2.502	2.547	+1.80	Tucker *et al.* (2003)
42	RxR		0.20	2.502	2.543	+1.64	Tucker *et al.* (2003)
42	RxR		0.30	2.502	2.500	-0.08	Tucker *et al.* (2003)
42	RxR		0.2[7d]; 0.1[21]; 0.05[42d]	2.502	2.554	+2.08	Tucker *et al.* (2003)
35	RxR	Used	0.10	1.833	1.833	0	ten Doeschate & Kenyon (2002)
42	RxR	Used	0.2[d]; 0.1[d]; 0.05[42d]	2.187	2.216	+1.33	Korosi & Korosi-M. (2003)
42	RxR	Used	0.05	2.275	2.297	+0.97	Mathis (2000)
42	RxR	Used	0.10	2.275	2.296	+0.92	Mathis (2000)
42	RxR	Used	0.15	2.275	2.312	+1.63	Mathis (2000)
42	Hybro	Used	0.10	2.331	2.416	+3.65	Clementino d.S. *et al.* (2002)
42	RxR	Used	0.20[21d]; 0.05[42d]	2.249	2.292	+1.91	Short & Kenyon (2002)
42	RxR	Used	0.10	2.702	2.706	+0.15	Kenyon (1999)
45	RxR	Used	0.2[7d]; 0.1[21d]; 0.05[45d]	2.688	2.691	+0.11	Kenyon (2002)
35	Cobb	Wire	0.15	1.563	1.596	+2.11	Shafey *et al.* (2001)
35	Cobb	Wire	0.30	1.563	1.594	+1.98	Shafey *et al.* (2001)

Age (d)	Strain; Strain Cross[1]	Litter (new or used)	MOS level (%) [to given age]	nCON Body Wt, Kg	MOS Body wt, Kg	Rel. Change w/MOS (%)[2]	Reference
35	RxR	Wire	0.10	2.216	2.185	-1.40	Thomas & Cook (2002)
42	RxR	Wire	0.05	1.809	1.889	+4.42	Kumprecht *et al.* (1997)
42	RxR	Wire	0.10	1.809	1.858	+2.71	Kumprecht *et al.* (1997)
42	RxR	Wire	0.15	1.809	1.893	+4.64	Kumprecht *et al.* (1997)
42	RxR	Wire	0.20	1.809	1.888	+4.37	Kumprecht *et al.* (1997)
42	RxR	Wire	0.25	1.809	1.901	+5.09	Kumprecht *et al.* (1997)
42	RxR	Wire	0.30	1.809	1.886	+4.26	Kumprecht *et al.* (1997)
44		Wire	0.2[21d]; 0.1[35d]; 0.05[44d]	2.602	2.631	+1.11	Fuchs (2003)
42	AA	Slats	0.10[21d]; 0.05[42d]	1.842	1.894	+2.82	Mateo (1999)
41.8	Average by treatment (n = 44; P = 0.000):			2.168[b]	2.206[a]	+1.75	
41.7	Average by trial (n = 29; P = 0.000):			2.231[b]	2.267[a]	+1.61	

[a-b]Means within a row and without a common superscript differ by Paired T-test.
[1]RxR = Ross x Ross; AA = Arbor Acres and AF = Avian Farms. Blanks indicate missing information (not stated).
[2]Change in results with MOS diets relative to nCON diets.

35 day subjective or visual litter scores, using 0 as worst to 10 as best, were significantly improved with the MOS diets (4.0) compared to the negative control diets (3.0) (ten Doeschate and Kenyon, 1999). It is conceivable that better health of the intestinal mucosa due to feeding MOS diets improves carcass and breast meat yield. Although limited research has been done on processing yields, it was reported from a Brazilian pen trial that dietary MOS (0.1%) significantly increased breast yield as a percentage of dressed carcass plus head and feet compared to the negative control treatment (32.91 vs 31.07%, respectively) (Clementino dos Santos, 2002).
The purpose of this paper is to present a summary of global pen trial research, conducted with a variety of diet formulations and under many different environmental conditions, to evaluate MOS as an alternative growth promoter and to quantify its effects on broiler live performance. This analysis utilizes the same 1993-2002 database as Hooge (2003), but expands it to include five more pen trials conducted in 2003. This exercise covers a full decade of broiler research.

Materials and Methods

Criteria for Selecting Studies: The following minimum selection criteria were used in deciding which pen trial results to include in the meta-analysis.

1. Broiler chicken pen trials only were used (including litter, cages and slatted floors); no commercial field trials were included in this comparison.
2. Written research reports, 1993-2003, were collected from MOS trials around the world (Brazil, Canada, China, Colombia, Czech Republic, Denmark, Equador, France, Mexico, Netherlands, New Zealand, Philippines, Spain, Switzerland, UK and USA).
3. The MOS must have been fed during the entire study period (not starter period only or grower period only, for example) and supplementation levels given.
4. There must have been a negative control and/or a positive (antibiotic) control treatment.
5. There must have been two or more replicate groups per treatment.
6. For positive control treatments, the name of the antibiotic should have been mentioned.
7. Final age (25 days or more), body weight and feed conversion ratio must have been stated; mortality was used when given. Feed conversion ratio was acceptable if corrected for mortality or regular.

Statistical Analysis: The means of the various parameters of interest (body weight, feed conversion ratio and mortality) were analyzed statistically as pairs of observations, using either negative control (nCON) versus MOS diets or antibiotic-supplemented, positive control (pCON) versus MOS diets, by the Paired T-test and the determined levels of probability were stated (Statistic 8, 2003).

Table 2: Feed conversion ratios (FCR) of broiler chickens from pen trials (including litter, wire, or slats) worldwide comparing antibiotic-free negative control diets (nCON) versus mannan oligosaccharide diets (MOS) fed at levels stated during the entire study periods

Age (d)	Strain; Strain Cross[1]	Litter (new or used)	MOS level (%) [to given age]	nCON FCR (kg/kg)	MOS FCR (kg/kg)	Rel. Change w/MOS[3] (%)	Reference
35	RxR	New	0.10	1.460	1.435	-1.71	ten Doeschate & Kenyon (2002)
35	Cobb	New	0.20[14d]; 0.10[35d]	1.674	1.659	-1.50	Kenyon (2000)
36	RxR	New	0.10[7d]; 0.05[36d]	1.640	1.560	-4.88	Petersen & Villadsen (2002)
38	RxR	New	0.10[7d]; 0.05[38d]	1.650	1.610	-2.42	Petersen & Villadsen (2002)
39	RxR	New	0.2[11d]; 0.1[32d]; 0.05[39d]	1.658	1.650	-0.48	Bokma - Bakker *et al.* (2002)
42	RxR	New	0.10[21d]; 0.05[42d]	1.739	1.641	-5.64	Roch (1999)
43		New	0.20[28d]; 0.15[43d]	2.120	2.050	-3.30	Valarezo *et al.* (1997)
49	RxR	New	0.10[21d]; 0.05[49d]	2.014	1.830	-9.14	Sims *et al.* (1998)
49	Cobb	New	0.10	1.930	1.910	-1.04	Wilson & Kenyon (2002)
49	RxR	New	0.10[21d]; 0.05[49d]	1.955	1.908	-2.40	Sefton *et al.* (2002)
49	RxR	New	0.15[35d]; 0.05[49d]	2.091	2.002	-4.26	Perez *et al.* (2002)
49		New	0.11	2.020	2.070	+2.48	Savage *et al.* (1996)
39	AF		0.10	1.850	1.840	-0.54	Eren *et al.* (2003)
39			0.10	1.749	1.761	+0.69	Geliot (1999)
39			0.2[10d]; 0.1[21d]; 0.05[39d]	1.749	1.773	+1.37	Geliot (1999)
41	RxR		0.2[d]; 0.1[d]; 0.05[41d]	1.708	1.679	-1.70	Rosell (2002)
42	RxR		0.05	1.742	1.723	-1.09	Tucker *et al.* (2003)
42	RxR		0.10	1.742	1.735	-0.40	Tucker *et al.* (2003)
42	RxR		0.20	1.742	1.721	-1.21	Tucker *et al.* (2003)
42	RxR		0.30	1.742	1.728	-0.80	Tucker *et al.* (2003)
42	RxR		0.2[7d]; 0.1[21]; 0.05[42d]	1.742	1.734	-0.46	Tucker *et al.* (2003)
47			0.10[12d]; 0.05[47d]	1.888[2]	1.888[2]	0	Hadorn & Wiedmer (1999)
47			0.10	1.888[2]	1.869[2]	-1.01	Hadorn & Wiedmer (1999)
47			0.20[12d]; 0.10[47d]	1.888[2]	1.888[2]	0	Hadorn & Wiedmer (1999)
35	RxR	Used	0.10	1.460	1.430	-2.05	ten Doeschate & Kenyon (2002)
42	RxR	Used	0.2[d]; 0.1[d]; 0.05[d]	1.770	1.770	0	Korosi & Korosi-M. (2003)
42	RxR	Used	0.05	1.835	1.836	+0.05	Mathis (2000)
42	RxR	Used	0.10	1.835	1.847	+0.65	Mathis (2000)
42	RxR	Used	0.15	1.835	1.827	-0.44	Mathis (2000)
42	Hybro	Used	0.10	1.920	1.800	-6.25	Clementino d.S. *et al.* (2002)
42	RxR	Used	0.20[21d];0.05[42d]	1.870	1.800	-3.74	Short & Kenyon (2002)
42	RxR	Used	0.10	1.773	1.756	-0.96	Kenyon (1999)
45	RxR	Used	0.2[7d]; 0.1[21d]; 0.05[45d]	1.794	1.789	-0.28	Kenyon (2002)
35	Cobb	Wire	0.15	1.820	1.810	-0.55	Shafey *et al.* (2001)
35	Cobb	Wire	0.30	1.820	1.800	-1.10	Shafey *et al.* (2001)

Age (d)	Strain; Strain Cross[1]	Litter (new or used)	MOS level (%) [to given age]	nCON FCR (kg/kg)	MOS FCR (kg/kg)	Rel. Change w/MOS[3] (%)	Reference
35	RxR	Wire	0.10	1.550	1.53	-1.29	Thomas & Cook (2002)
42	RxR	Wire	0.05	2.164	2.109	-2.54	Kumprecht *et al.* (1997)
42	RxR	Wire	0.10	2.164	2.091	-3.37	Kumprecht *et al.* (1997)
42	RxR	Wire	0.15	2.164	2.071	-4.30	Kumprecht *et al.* (1997)
42	RxR	Wire	0.20	2.164	2.089	-3.47	Kumprecht *et al.* (1997)
42	RxR	Wire	0.25	2.164	2.089	-3.47	Kumprecht *et al.* (1997)
42	RxR	Wire	0.30	2.164	2.069	-4.39	Kumprecht *et al.* (1997)
42	AA	Slats	0.10[21d]; 0.05[42d]	1.883	1.849	-1.81	Mateo (1999)
41.8	Average by treatment (n = 44; P = 0.000):			1.850[a]	1.815[b]	-1.89	
41.7	Average by trial (n = 29; P = 0.000):			1.808[a]	1.772[b]	-1.99	

[a-b]Means within a row and without a common superscript differ by Paired T-test.
[1]RxR = Ross x Ross; AA = Arbor Acres and AF = Avian Farms. Blanks indicate missing information (not stated).
[2]Feed conversion values of Hadorn and Wiedmer (1999) were estimated from bar graphs.
[3]Change in results with MOS diets relative to nCON diets.

Results

Negative Control Diets Versus MOS Diets: There were 29 pen trials involving 44 comparisons of antibiotic-free, negative control (nCON) diets versus MOS diets. An average nCON broiler in this analysis (see Tables 1, 2 and 3) can be characterized as having the following profile "by treatment" 41.8 days of age, 2.168 kg, 1.850 kg feed/kg body weight and 4.627% mortality or "by trial" 41.7 days of age, 2.231 kg, 1.808 kg feed/kg body weight and 4.494% mortality.

Broiler chicken body weight means from pen trials comparing nCON and MOS diets are shown in Table 1. As indicated for averages by treatment, MOS-fed broilers had higher weight gain (+1.75%) than nCON birds and by trial a similar result occurred (+1.61%). These results were highly significant ($P < 0.001$). Feed conversion ratios for the non-antibiotic pen trials are presented in Table 2. Averages by treatment for feed conversion ratios favored the MOS group (-1.89%) and by trial the improvement with MOS was similar (-1.99%) compared to the nCON results. These values were significant ($P < 0.001$). Mortality percentages for the non-antibiotic pen trials are given in Table 3. Mortality percentages were lowered by MOS diets, with the relative reductions compared to nCON being -16.4% averaged by treatment ($P = 0.051$; by arcsine transformation, $P = 0.062$) and -21.4% averaged by trial ($P = 0.020$; by arcsine transformation, $P = 0.032$).

Positive (Antibiotic) Control Diets Versus MOS Diets: There were 21 pen trials involving 26 comparisons of antibiotic-supplemented, positive control (pCON) diets versus MOS diets. In some cases, there were negative and positive control groups in the same studies. Therefore, some references appear in both nCON and pCON tables. An average pCON broiler in this analysis (see Tables 4, 5 and 6) can be characterized as having the following profile "by treatment" 39.8 days of age, 2.161 kg, 1.810 kg feed/kg body weight and 4.833% mortality or "by trial" 41.0 days of age, 2.246 kg, 1.822 kg feed/kg body weight and 5.404% mortality.

Table 4 contains broiler body weight means from comparisons of positive control diets with an antibiotic or antibiotic shuttle program versus MOS diets. Table 7 gives the name of the antibiotics used and when known, the antibiotic level(s) and coccidiostats. There were no significant differences in body weight for pCON versus MOS diets either for averages by treatment (-0.32% for MOS) or by trial (-0.36% for MOS). Feed conversion ratios for pCON and MOS diets are shown in Table 5. There were no significant differences between pCON and MOS groups for feed conversion ratio averages by treatment (-0.44% using MOS) or by trial (-0.11% using MOS). Mortality percentages for pCON versus MOS diets are presented in Table 6. The strong beneficial effect of MOS in lowering mortality observed in the nCON versus MOS trials (Table 3) was demonstrated again in comparison to antibiotic supplemented diets (-17.17% relative change in mortality averaging by treatment and -18.10% averaging by trial). The MOS had a significantly greater ($P = 0.008$) beneficial influence on broiler chicken livability than did the antibiotics against which it was evaluated.

Table 3: Mortality percentages of broiler chickens from pen trials (including litter, wire, or slats) worldwide comparing antibiotic-free negative control (nCON) diets versus mannan oligosaccharide (MOS) diets fed at levels stated during the entire study periods

Age (d)	Strain; Strain Cross	Litter (new or used)	MOS level (%) [to given age]	nCON Mort. (%)	MOS Mort. (%)	Rel. Change w/MOS (%)[3]	Reference
35	RxR[1]	New	0.10	2.20	1.80	-22.2	ten Doeschate & Kenyon (2002)
35	Cobb	New	0.20[14d]; 0.10[35d]	4.47	1.03	-77.0	Kenyon (2000)
36	RxR	New	0.10[7d]; 0.05[36d]	3.30	2.50	-24.2	Petersen & Villadsen (2002)
38	RxR	New	0.10[7d]; 0.05[38d]	5.40	4.20	-22.2	Petersen & Villadsen (2002)
39	RxR	New	0.2[11d]; 0.1[32d]; 0.05[39d]	6.00	3.10	-48.3	Bokma - Bakker *et al.* (2002)
42	RxR	New	0.10[21d]; 0.05[42d]	6.67	8.33	+24.9	Roch (1999)
43		New	0.20[28d]; 0.15[43d]	6.40	4.10	-35.9	Valarezo *et al.* (1997)
49	RxR	New	0.10[21d]; 0.05[49d]	7.08	4.58	-25.0	Sims *et al.* (1998)
49	Cobb	New	0.10	6.50	7.50	+15.4	Wilson & Kenyon (2002)
49	RxR	New	0.10[21d]; 0.05[49d]	4.34	3.92	-9.7	Sefton *et al.* (2002)
49		New	0.11	22.17	15.93	-28.1	Savage *et al.* (1996)
41	RxR		0.2[d]; 0.1[d]; 0.05[41d]	5.00	7.10	+42.0	Rosell (2002)
42	RxR		0.05	2.00	2.70	+35.0	Tucker *et al.* (2003)
42	RxR		0.10	2.00	1.20	-40.0	Tucker *et al.* (2003)
42	RxR		0.20	2.00	4.20	+210.0	Tucker *et al.* (2003)
42	RxR		0.30	2.00	3.30	+65.0	Tucker *et al.* (2003)
42	RxR		0.2[7d]; 0.1[21d]; 0.05[42d]	2.00	2.20	+10.0	Tucker *et al.* (2003)
47			0.10[12d]; 0.05[47d]	1.60	1.30	-18.8	Hadorn & Wiedmer (1999)
47			0.10	1.60	1.30	-18.8	Hadorn & Wiedmer (1999)
47			0.20[12d]; 0.10[47d]	1.60	1.40	-12.5	Hadorn & Wiedmer (1999)
35	RxR	Used	0.10	3.80	2.70	-28.9	ten Doeschate & Kenyon (2002)
42	RxR	Used	0.2[d]; 0.1[d]; 0.05[d]	1.25	1.00	-20.0	Korosi & Korosi-M. (2003)
42	RxR	Used	0.05	0.50[2]	3.50	+700.0	Mathis (2000)
42	RxR	Used	0.10	0.50[2]	1.75	+350.0	Mathis (2000)
42	RxR	Used	0.15	0.50[2]	2.75	+550.0	Mathis (2000)
42	Hybro	Used	0.10	3.00	0.88	-70.7	Clementino d.S. *et al.* (2002)
42	RxR	Used	0.10	10.00	7.08	-29.2	Kenyon (1999)
45	RxR	Used	0.2[7d]; 0.1[21d]; 0.05[45d]	4.93	4.21	-14.6	Kenyon (2002)
44		Wire	0.2[21d]; 0.1[35d]; 0.05[44d]	3.00	3.00	0	Fuchs (2003)
42.5	Average by treatment (n =29-3; P = 0.051):			4.627	3.868	-16.4	
42.2	Average by trial (n = 21-1; P = 0.020):			4.494[a]	3.534[b]	-21.4	

[a-b]Means within a row and without a common superscript differ by Paired T-test. By arcsine transformation, differences were P = 0.062 by treatment and P = 0.032 by trials. [1]RxR = Ross x Ross; AA = Arbor Acres. Blanks indicate missing information (not stated). [2]By chance mortality in antibiotic-free negative control group was very low at 0.50% compared to a range of 1.75 to 3.5% and average of 2.47% for all eight other dietary treatments (copper, MOS, virginiamycin). This data was excluded when calculating the averages. [3]Change in results with MOS diets compared to nCON diets.

Table 4: Broiler chicken body weight results from pen trials (including litter, wire, or slats) worldwide comparing antibiotic-supplemented positive control (pCON) diets versus mannan oligosaccharide (MOS) diets fed at levels stated during the entire study periods

Age (d)	Strain; Strain Cross[1]	Litter (new or used)	MOS level (%) [to given age]	pCON Body wt (kg)	MOS Body wt (kg)	Rel. Change w/MOS (%)[2]	Reference
35	RxR	New	0.10	1.908	1.872	-1.89	ten Doeschate & Kenyon (2002)
34	Cobb	New	0.1[17d]; 0.05[27d]; 0.025[34d]	1.751	1.728	-1.31	McElroy (2001)
39	RxR	New	0.20[7d]; 0.1[21d]; 0.05[39d]	2.409	2.381	-1.16	Bokma - Bakker *et al.* (2002)
42	RxR	New	0.10[21d]; 0.05[42d]	2.717	2.775	+2.13	Roch (1999)
43		New	0.20[28d]; 0.15[43d]	2.059	2.080	+1.02	Valarezo *et al.* (1997)
49	RxR	New	0.10[21d]; 0.05[49d]	2.578	2.505	-2.83	Sims *et al.* (1998)
49	Cobb	New	0.10	3.071	3.174	+3.35	Wilson & Kenyon (2002)
49	RxR	New	0.10[21d]; 0.05[49d]	2.697	2.667	-1.11	Sefton *et al.* (2002)
39	AF		0.10	1.094	1.915	+0.58	Eren *et al.* (2003)
39			0.10	2.208	2.202	-0.60	Geliot (1999)
39			0.2[10d]; 0.1[21d]; 0.05[39d]	2.208	2.195	-0.59	Geliot (1999)
41	RxR		0.2[d]; 0.1[d]; 0.05[39d]	2.622	2.601	-0.80	Rosell (2002)
42	RxR		0.05	1.942	1.961	+0.98	Betancourt *et al.* (2001)
49	RxR		0.15[35d]; 0.05[49d]	2.393	2.365	-1.17	Perez *et al.* (2002)
49			0.20	2.387	2.351	-1.51	Wang & Qui (2001)
35	RxR	Used	0.10	1.876	1.833	-2.29	ten Doeschate & Kenyon (2002)
42	RxR	Used	0.05	2.320	2.297	-0.99	Mathis (2000)
42	RxR	Used	0.10	2.320	2.296	-1.03	Mathis (2000)
42	RxR	Used	0.15	2.320	2.312	-0.34	Mathis (2000)
42	Hybro	Used	0.10	2.347	2.416	+2.94	Clementino d.S. *et al.* (2002)
42	RxR	Used	0.10	2.804	2.706	-3.50	Kenyon (1999)
35	RxR	Wire	0.10	2.254	2.185	-3.06	Thomas & Cook (2002)
25	Avian	Slats	0.05	1.086	1.091	+0.46	Christodoulou (2001)
25	Avian	Slats	0.075	1.086	1.097	+1.01	Christodoulou (2001)
25	Avian	Slats	0.10	1.086	1.100	+1.29	Christodoulou (2001)
42	AA	Slats	0.10[21d]; 0.05[42d]	1.839	1.894	+2.99	Mateo (1999)
39.8	Average by treatment (n = 26; P = 0.408):			2.161	2.154	-0.32	
41.0	Average by trial (n = 21; P = 0.473):			2.246	2.238	-0.36	

[1]RxR = Ross x Ross; AA = Arbor Acres and AF = Avian Farms. Blanks indicate missing information (not stated).

[2]Change in results with MOS diets relative to CON diets.

Table 5: Feed conversion ratios (FCR) of broiler chickens from pen trials (including litter, wire, or slats) worldwide comparing antibiotic-supplemented positive control (pCON) diets versus mannan oligosaccharide (MOS) diets fed at levels stated during entire study periods

Age (d)	Strain; Strain Cross[1]	Litter (new or used)	MOS level (%) [to given age]	pCON FCR (kg/kg)	MOS FCR (kg/kg)	Rel. Change w/MOS (%)[2]	Reference
35	RxR	New	0.10	1.422	1.435	-0.91	ten Doeschate & Kenyon (2002)
34	Cobb	New	0.10[17d]; 0.05[27d]; 0.025[34d]	1.629	1.660	+1.90	McElroy (2001)
39	RxR	New	0.2[7d]; 0.1[21d]; 0.05[39d]	1.656	1.650	-0.36	Bokma - Bakker *et al.* (2002)
42	RxR	New	0.10[21d]; 0.05[42d]	1.637	1.641	+0.40	Roch (1999)
43	New		0.20[28d]; 0.15[43d]	2.090	2.050	-1.91	Valarezo *et al.* (1997)
49	RxR	New	0.10[21d]; 0.05[49d]	1.815	1.830	+0.83	Sims *et al.* (1998)
49	Cobb	New	0.10	1.900	1.910	+0.53	Wilson & Kenyon (2002)
49	RxR	New	0.10[21d]; 0.05[49d]	1.904	1.908	+0.21	Sefton *et al.* (2002)
39	AF		0.10	1.860	1.840	-1.08	Eren *et al.* (2003)
39			0.10	1.753	1.761	+0.46	Geliot (1999)
39			0.2[10d]; 0.1[21d]; 0.05[39d]	1.753	1.773	+1.14	Geliot (1999)
41	RxR		0.2[d]; 0.1[d]; 0.05[41d]	1.661	1.679	+1.08	Rosell (2002)
42	RxR		0.05	1.950	1.930	+1.03	Betancourt *et al.* (2001)
49	RxR		0.15[35d]; 0.05[49d]	2.030	2.002	-1.38	Perez *et al.* (2002)
49	AA		0.20	2.995	3.134	+4.64	Wang & Qui (2001)
35	RxR	Used	0.10	1.446	1.430	-1.11	ten Doeschate & Kenyon (2002)
42	RxR	Used	0.05	1.842	1.836	-0.33	Mathis (2000)
42	RxR	Used	0.10	1.842	1.847	+0.27	Mathis (2000)
42	RxR	Used	0.15	1.842	1.827	+0.81	Mathis (2000)
42	Hybro	Used	0.10	1.920	1.800	-6.25	Clementino d.S. *et al.* (2002)
42	RxR	Used	0.10	1.711	1.756	+2.63	Kenyon (1999)
35	RxR	Wire	0.10	1.500	1.530	+2.00	Thomas & Cook (2002)
25	Avian	Slats	0.05	1.682	1.610	-4.28	Christodoulou (2001)
25	Avian	Slats	0.075	1.682	1.592	-5.35	Christodoulou (2001)
25	Avian	Slats	0.10	1.682	1.565	-6.96	Christodoulou (2001)
42	AA	Slats	0.10[21d]; 0.05[42d]	1.866	1.849	-0.91	Mateo (1999)
39.8	Average by treatment (n = 26; P = 0.406):			1.810	1.802	-0.44	
41.0	Average by trial (n = 21; P = 0.857):			1.822	1.820	-0.11	

[1]RxR = Ross x Ross; AA = Arbor Acres and AF = Avian Farms. Blank spaces indicate missing information (not stated).

[2]Change in results with MOS diets relative to pCON diets.

Table 6.: Mortality percentages of broiler chickens from pen trials worldwide comparing antibiotic-supplemented positive control (pCON) diets versus mannan oligosaccharide (MOS) diets fed at levels stated during the entire study periods.

Age (d)	Strain; Strain Cross	Litter (new or used)	MOS level (%) [to given age]	pCON Mort. (%)	MOS Mort. (%)	Rel. Change w/MOS (%)[2]	Reference
35	RxR[1]	New	0.10	3.50	1.80	-48.6	ten Doeschate & Kenyon (2002)
34	Cobb	New	0.10[17d]; 0.05[27d]; 0.025[34d]	2.38	1.90	-20.2	McElroy (2001)[4]
39	RxR	New	0.2[7d]; 0.1[21d]; 0.05[39d]	5.80	3.10	-2.7	Bokma - Bakker *et al.* (2002)
42	RxR	New	0.10[21d]; 0.05[42d]	1.67	8.33	+398.8[3]	Roch (1999)
43		New	0.20[28d]; 0.15[43d]	6.40	4.10	-35.9	Valarezo *et al.* (1997)
49	RxR	New	0.10[21d]; 0.05[49d]	5.42	4.58	-15.5	Sims *et al.* (1998)
49	Cobb	New	0.10	8.00	7.50	-6.2	Wilson & Kenyon (2002)
49	RxR	New	0.10[21d]; 0.05[49d]	6.36	3.92	-38.4	Sefton *et al.* (2002)
41	RxR		0.2[d]; 0.1[d]; 0.05[41d]	5.40	7.10	+31.5	Rosell (2002)
42	RxR		0.05	4.10	4.50	+9.8	Betancourt *et al.* (2001)[4]
49	RxR		0.15[35d]; 0.05[49d]	4.64	3.92	-15.5	Perez *et al.* (2002)
49	AA		0.20	16.51	13.12	-20.5	Wang & Qui (2001)
35	RxR	Used	0.10	4.10	2.70	-34.1	ten Doeschate & Kenyon (2002)
42	RxR	Used	0.05	2.75	3.50	+27.3	Mathis (2000)
42	RxR	Used	0.10	2.75	1.75	-36.4	Mathis (2000)
42	RxR	Used	0.15	2.75	2.75	0	Mathis (2000)
42	Hybro	Used	0.10	1.25	0.88	-29.6	Clementino d.S. *et al.* (2002)
42	RxR	Used	0.10	7.50	7.08	-5.6	Kenyon (1999)
25	Avian	Slats	0.05	2.35	2.10	-10.6	Christodoulou (2001)
25	Avian	Slats	0.075	2.35	1.92	-18.3	Christodoulou (2001)
25	Avian	Slats	0.10	2.35	1.85	-21.3	Christodoulou (2001)
40.0	Average by treatment (n =21-1; P = 0.007):			4.833[a]	4.003[b]	-17.2	
41.6	Average by trial (n =17-1; P = 0.008):			5.404[a]	4.426[b]	-18.1	

[a-b]Means within a row and without a common superscript differ by Paired T-test. By arcsine.
transformation, differences were P = 0.009 by treatments and P = 0.011 by trials.
[1]RxR = Ross x Ross; AA = Arbor Acres and AF = Avian Farms. Blank spaces indicate missing information.
[2]Change in results with MOS diets relative to pCON diets.
[3]Small pen trial with 60 chicks total per treatment (three replicates of 20 chicks each). This mortality data was considered an outlier in the dataset and removed from calculations.
[4]Mortality plus culls reported.

Table 7: Age, dietary antibiotic and level, cocciostat and reference cited concerning broiler chicken pen trials (including litter, cages, or slats) worldwide comparing antibiotic-supplemented positive control diets (pCON) versus mannan oligosaccharide diets (MOS) during the entire study periods; corresponds to Table 4, 5 and 6

Age (d)	Dietary Antibiotic	Antibiotic level (ppm) [to given age][2]	Coccidiostat[2]	Reference
35	Avilamycin	10	Nicarb; Monensin	ten Doeschate & Kenyon (2002)
34	BMD; Virginiamycin[1]	55[27d]; 11[34d]		McElroy (2001)
39	Avilamycin	10	Diclazuril	Bokma - Bakker *et al*. (2002)
42	Flavomycin		Monensin	Roch (1999)
43	Flavomcyin			Valarezo *et al*. (1997)
49	Bacitracin-MD	55[35d]; 27.5[49d]	Lasalocid	Sims *et al*. (1998)
49	Avilamycin	10	Monensin	Wilson & Kenyon (2002)
49	BMD; Virginiamycin	27.5[21d]; 55[42d]; 11	Nicarb; Monensin	Sefton *et al*. (2002)
35	Zinc bacitracin	50	Methylchlorpyndol	Eren *et al*. (2003)
39	Avilamycin	10[10d]; 5[39d]		Geliot (1999)
39	Avilamycin	10[10d]; 5[39d]		Geliot (1999)
41	Avilamycin			Rosell (2002)
42	Avilamycin	400? (400 g/tonne)		Betancourt *et al*. (2001)
49	Flavomycin	50?	Nicarb; Monensin	Perez *et al*. (2002)
49	Flavomycin	140?		Wang & Qui (2001)
35	Avilamycin	10	Nicarb; Monensin	ten Doeschate & Kenyon (2002)
42	Virginiamycin	22		Mathis (2000)
42	Virginiamycin	22		Mathis (2000)
42	Virginiamycin	22		Mathis (2000)
42	Avilamycin	10		Clementino d.S. *et al*. (2002)
42	Avilamycin	10		Kenyon (1999)
35	Avilamycin	20? (Surmax 200 mg/kg		Thomas & Cook (2002)
25	Virginiamycin	15	Monensin	Christodoulou (2001)
25	Virginiamycin	15	Monensin	Christodoulou (2001)
25	Virginiamycin	15	Monensin	Christodoulou (2001)
42	Zinc bacitracin	50		Mateo (1999)

[1]BMD = Bacitracin-MD. [2]Blanks in the table indicate missing information (not stated).

Discussion

Body Weight: Broiler chicken diets containing MOS significantly improved final body weight compared to negative control (nCON) diets but gave statistically equivalent body weight compared to diets containing subtherapeutic levels of antibiotics (pCON). Increased disease or crowding stresses generally result in greater improvements by beneficial additives. Whereas, when there is little stress, the nCON, pCON and alternative growth promoter diets often perform similarly. Beneficial results observed with dietary MOS in commercial flocks or field trials should approximate the qualitative effect or direction and the magnitude of responses observed in pen trials, keeping in mind that larger populations of broilers and more variable management on farms compared to pen trial facilities may increase stress but also variability in the "model" there. In 35 out of 44 comparisons, or 79.5% of the cases, MOS addition to diets improved body weight (+ direction of % change) compared to nCON diets. Either +1.61 to +1.75% improvement in broiler body weight was achieved, depending on method of calculation.

Feed Conversion Ratio: Broiler diets containing MOS resulted in significantly improved feed conversion ratio compared to unsupplemented diets (nCON) whereas MOS and pCON diets gave statistically similar values. In 35 out of 44 pen trials, or 79.5% of the cases, feed conversion ratio was improved (- direction of % change) by MOS diets compared to nCON diets. Either -1.89 or -1.99% decrease in feed conversion ratio was achieved with MOS diets, depending on method of calculation.

Mortality: Compared to nCON diets, broiler diets containing MOS gave an improvement in mortality approaching significance (P = 0.051; arcsine transformed data, P = 0.062) when averaged by treatment and a significant improvement in mortality when averaged by trial (P = 0.020; arcsine transformed data, P = 0.032). This discrepancy was mainly due to inclusion of the study in which mortality in four out of five MOS diets (2.20 to 4.20%) was higher than that of the nCON diets (2.00%) (Tucker *et al*., 2003). However, body weight was improved by four out of five MOS diets and feed conversion ratio was improved by all MOS diets compared to nCON diets in that pen trial, indicating that lower mortality in the nCON group may have been a chance occurrence. There was a -16.4% relative change in mortality for MOS diets compared to nCON diets when averaged by treatment and a -21.4% relative change in mortality when averaged by trial. In 18 out of 26 trials used in the analysis, or 69.2% of the cases, there was a reduction in mortality with MOS diets (- direction of change %) compared to nCON diets.

The MOS diets significantly (P = 0.008) improved mortality compared to pCON diets. This finding is commercially very relevant inasmuch as the mortality lowering effect of subtherapeutic antibiotics is one of the main reasons for including them in broiler diets yet the effect of MOS was significantly greater in this regard than the effect of antibiotics. The mortality lowering ability of MOS was its strongest attribute, with a -17.2% relative change in mortality by treatment and a -18.1% relative change in mortality by trial for MOS diets compared to pCON diets.

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