R. Bras. Zootec., 49:e20180177, 2020
https://doi.org/10.37496/rbz4920180177

Non-ruminants
Full-length research article

Revista Brasileira de Zootecnia

Brazilian Journal of Animal Science
e-ISSN 1806-9290
www.rbz.org.br

Performance responses of broilers and pigs fed diets with β-mannanase

Marcos Kipper[1], Ines Andretta[1*], Vinícius Rodrigues de Quadros[1], Bruna Schroeder[1], Paula Gabriela da Silva Pires[1], Carolina Schell Franceschina[1], Felipe Mathias Weber Hickmann[1], Ismael França[1]

[1] Universidade Federal do Rio Grande do Sul, Departamento de Zootecnia, Porto Alegre, RS, Brasil.

***Corresponding author:**
ines.andretta@ufrgs.br

Received: Julho 28, 2018
Accepted: December 18, 2018

How to cite: Kipper, M.; Andretta, I.; Quadros, V. R.; Schroeder, B.; Pires, P. G. S.; Franceschina, C. S.; Hickmann, F. M. W. and França, I. 2020. Performance responses of broilers and pigs fed diets with β-mannanase. Revista Brasileira de Zootecnia 49:e20180177.
https://doi.org/10.37496/rbz4920180177

ABSTRACT - This study was developed using meta-analysis to evaluate the effect of β-mannanase on both poultry and pig performance. Two databases were constructed using information from previous studies that evaluated the β-mannanase supplementation in diets for broilers (30 papers; 19,643 birds) and pigs (20 papers; 5,319 animals). The meta-analysis followed three sequential analyses: graphical, correlation, and variance-covariance. The effect of β-mannanase supplementation on performance considerably varied in both databases. Data analysis considering the study effect showed that β-mannanase supplementation did not influence feed intake. Diets supplemented with β-mannanase did not influence weight gain, but improved feed conversion (−1%) of broilers compared with the control group. Feeding pigs diets supplemented with β-mannanase improved weight gain (+5%) and feed conversion (−6%) compared with pigs fed non-supplemented diets. β-mannanase supplementation increased the digestibility coefficient of dry matter, crude protein, and energy in both species. The inclusion of β-mannanase also improved the metabolizable energy content in broiler diets and enhanced the digestibility of energy in pig feeds. Current results indicate that β-mannanase can be considered as an important tool for nutritionists who search for improved feed conversions and nutrient digestibility coefficients.

Keywords: enzyme, meta-analysis, nutrition, poultry, swine

1. Introduction

β-mannans (BM) are commonly present in a wide variety of feedstuffs, including soybean meal, and have been described as one of the major anti-nutritional factors for non-ruminant animals (Bertechini, 2013). Dietary BM are associated with negative effects in pigs and broilers, such as increased intestinal viscosity and decreased nutrient digestibility (Shastak et al., 2015). Despite being naturally found in non-pathogenic substances, these compounds may activate the innate immune system (Aderem and Ulevitch, 2000; Gharaei et al., 2012). Thus, the response induced by BM may affect animal performance because energy is drained by the immune system activation (Sato et al., 2009).

The dietary supplementation with exogenous β-mannanase may be an alternative to deal with the adverse effects associated with BM. Positive mechanisms of β-mannanase supplementation include the effects on immunity, releasing energy sources, and the modification of substrate viscosity in the gut lumen, which may improve nutrient availability (Li et al., 2010; Mehri et al., 2010).

Although several studies have been conducted to assess the effects of β-mannanase on poultry and pig performance, more information is needed to better understand the variations in those findings. In this context, the current study was developed by using meta-analytic techniques to assess the effect of β-mannanase supplementation on broiler and pig performance.

2. Material and Methods

Digital databases (Google Scholar, HighWire, ScienceDirect, Scielo, and PubMed) were searched to identify studies published in scientific journals that reported the performance and metabolism of broilers and pigs fed diets supplemented with β-mannanase. The keyword "β-mannanase" combined with "broiler" or "pig" was used in the search. The main criteria for paper selection were: experimental evaluation of β-mannanase supplementation in diets, broilers in different growth phases or pigs from nursery to finishing rearing phases, and performance responses. The literature search was performed in June 2017.

After paper selection, the information related to the proposed theoretical model and other additional variables were extracted from both Material and Methods and Results sections in the original publications and transferred to an electronic spreadsheet. Results collected in animals subjected to any health or environmental challenge were not included in the database.

The methodology applied to database construction and coding followed the proposals described in the literature (Lovatto et al., 2007; Sauvant et al., 2008). Codes were used with qualitative grouping criteria in the analytical models. In this item, the main codes were applied for supplementation (control or β-mannanase-supplemented diet) and dietary energy content [adequate levels according to the growth phase or lower levels than Rostagno et al. (2011) recommendations]. Other codes were used to consider the variability among all compiled experiments (e.g., the effect of study or trial).

Performance results were evaluated as raw data (as presented in the original papers) or as relativized information (responses of β-mannanase-supplemented treatments were relativized to the respective control treatment and expressed as a percentage of variation). This second procedure was adopted because it considerably reduced variations among experiments in the database.

Statistical analyses were performed using the Minitab software (Minitab for Windows, v. 17, Pine Hall Rd, Pennsylvania, USA). Meta-analyses were independently performed for poultry and pigs, following three sequential analyses: graphical (to control database quality and observe biological coherence of data), correlation (to identify related factors among variables), and variance-covariance (to compare treatments and obtain prediction equations). Variance analysis was performed considering the following statistical model:

$$Y_{ijk} = \beta_i + \delta_j + \alpha_k + \varepsilon_{ijk},$$

in which Y_{ijk} is the response, β_i is the fixed effect of treatment, δ_j is the fixed effect of energy content, α_k is the random effect of study, and ε_{ijk} is the residual variation.

Equations were used to predict the effect of β-mannanase supplementation on energy expenditure of the animal for growth, which was obtained estimating the metabolizable energy (ME) amount spent for each unit of body weight gain. These equations were independently fitted for control and supplemented treatments. This paper presents only equations in which all components were significant (P<0.05). Estimated values for both control and supplemented groups were simulated to assess potential energy savings due to dietary β-mannanase supplementation.

3. Results

The broiler database was composed of 30 scientific papers (Table 1) published from 2002 to 2016, which used 19,643 broilers in total. The genetic line was Cobb in 58% of the treatments, while the other 25% were Ross (other treatments used less representative genetic lines or the information was not available in the papers). Male broilers were used in 52% of the studies, while 34% of the trials used mixed sexes and 14% did not describe this trait.

The pig database was composed of 20 scientific papers (Table 2) published from 2002 to 2017, which used 5,319 pigs in total. On average, initial and final body weights were 32.5 kg and 56.2 kg, respectively. The growing and finishing phases were studied in most treatments, while nursery piglets were only studied in 28% of the treatments of the database. Barrows and females were used mixed in 34% of the studies, while 29% of the trials used only barrows, 6% of the trials used only females, and 31% did not describe this trait.

Feeds based on corn and soybean meal were used in most treatments in both databases (57% in the broiler database and 45% in the pig database). Alternative ingredients were used in 39% of the treatments in the broiler database and in 44% of the treatments in the pig database. In addition, 4% of the treatments in the broiler database and 11% of the treatments in the pig database could not be classified for this trait due to the lack of information in the articles. Feed was provided in mash form in 31% of the treatments in the broiler database and in 78% of the treatments in the pig database, while the pelleted form was used in 36% of the treatments in the broiler database and in 5% of the treatments in the pig database. Feed form was not described for the other treatments, which comprised 33% of the broiler database and 17% of the pig database. In both databases, most of the treatments used feeds with a conventional (normal) energy level. Only a minor part of the treatments (5% of all treatments in the broiler database and 8% of treatments in the pig database) used feeds with energy levels lower than the nutritional recommendations.

Table 1 - Dietary β-mannanase levels in the studies of broilers database

Reference[1]	Dietary β-mannanase level[2]
Ouhida et al., 2002	0, 0.35, and 0.875 g kg^{-1} of a product (1,400,000 U g^{-1})
Jackson et al., 2003	0 and 100 million U ton^{-1}
Lee et al., 2003	0 and 1.09 × 10^5 U kg^{-1}
Daskiran et al., 2004	Exp 1: 0 and 0.05% of a product (158 million U kg^{-1})
	Exp 2: 0, 0.05, 0.1, and 0.15% of a product (158 million U kg^{-1})
Jackson et al., 2004	0, 50, 80, and 110 million U ton^{-1}
Lee et al., 2005	0 and 1.09 × 10^5 U kg^{-1}
Saki et al., 2005	0 and 0.5 g kg^{-1} of a product
Khanongnuch et al., 2006	-
Sundu et al., 2006	0, 0.02, and 0.05% of a product
Zou et al., 2006	0, 0.025, 0.05, and 0.075% of a product (165 × 10^6 U kg^{-1})
Zakaria et al., 2008	0 and 0.05% of a product (14,000 U g^{-1})
Li et al., 2010	0, 10, and 20 million U ton^{-1}
Mehri et al., 2010	0, 500, 700, and 900 g ton^{-1} of a product
Zangiabadi and Torki, 2010	0 and 0.4 g kg^{-1} of a product (158 million U kg^{-1})
Kong et al., 2011	0 and 400 U kg^{-1}
Mussini et al., 2011	0, 0.25, 0.5, and 1 g kg^{-1} of a product
Torki, 2011	0 and 0.4 g kg^{-1} of a product (165 × 10^6 U kg^{-1})
Gharaei et al., 2012	0 and 0.5 g kg^{-1} of a product
Mohayayee and Kazem, 2012	-
Azarfar, 2013	0, 0.5, and 1 g kg^{-1} of a product
Cho and Kim, 2013b	0 and 0.04% of a product (1.09 × 10^5 U kg^{-1})
Mishra et al., 2013	0 and 32 million U kg^{-1}
Sornlake et al., 2013	0, 200, 400, and 800 U kg^{-1}
Zou et al., 2013	0 and 140 × 10^6 U kg^{-1}
Farahiyah et al., 2014	-
Williams et al., 2014	0 and 363.2g t^{-1} of a product (159.5 × 10^6 U kg^{-1})
Barros et al., 2015	0 and 0.500 kg ton^{-1} of a product
Klein et al., 2015	0 and 100 mL ton^{-1} of a product (720 million U L^{-1})
Ferreira et al., 2016	0 and 800 U g^{-1}
Latham et al., 2016	0 and 800,000 U kg^{-1}

[1] Chronological sequence, according to publication year.
[2] Levels are presented as in the original publication to highlight the lack of uniformity among studies.

Table 2 - Dietary β-mannanase levels in the studies of pig database

Reference[1]	Dietary β-mannanase level[2]
Pettey et al., 2002	0 and 103 mm U t^{-1}
Wang et al., 2009	0 and 0.5 g kg^{-1} of a product (800,000 U kg^{-1})
Jacela et al., 2010	0 and 0.5 g kg^{-1} of a product
Jones et al., 2010	0 and 0.5 g kg^{-1} of a product
Yoon et al., 2010	Exp 1: 0, 200, 400, and 600 U kg^{-1}
	Exp 2: 0, 200, 400, and 600 U kg^{-1}
	Exp 3: 0 and 400 U kg^{-1}
	Exp 4: 0 and 400 U kg^{-1}
Oluwafemi and Akpodiete, 2011	-
Jo et al., 2012	Exp 1: 0 and 0.05% of a product (800,000 U kg^{-1})
	Exp 2: 0 and 0.05% of a product (800,000 U kg^{-1})
Oluwafemi et al., 2012	0 and 600 g ton^{-1} of a product
Cho and Kim, 2013a	0 and 0.5 g kg^{-1} of a product (800 U g^{-1})
Kerr and Shurson, 2013	0 and 500 mg kg^{-1} of a product
Kim et al., 2013	0 and 400 U kg^{-1}
Lv et al., 2013	0, 200, 400, and 600 U kg^{-1}
Mok et al., 2013	0 and 1600 U kg^{-1}
Carr et al., 2014	0 and 0.25 g kg^{-1} of a product
Kwon and Kim, 2015	0 and 2400 U kg^{-1}
Kwon et al., 2015	0, 400, 800, 1600, 2400, and 3200 U kg^{-1}
Mok et al., 2015	0 and 800 U kg^{-1}
Upadhaya et al., 2016	0 and 400 U kg^{-1}
Kim et al., 2017	Exp 1: 0, 400, 800, and 1600 U kg^{-1}
	Exp 2: 0, 400, and 800 U kg^{-1}
Diarra, 2017	0 and 0.3 g kg^{-1} of a product

[1] Chronological sequence, according to publication year.
[2] Levels are presented as in the original publication to highlight the lack of uniformity among studies.

In both databases, most trials were developed using commercially available enzymes. However, the supplementation greatly varied among studies in terms of β-mannanase units contained in each product. In addition, the dietary inclusion of these products was expressed in different ways among studies. This is an important factor to be considered and should be better described in future publications. Due to the lack of standardization in the description of dietary enzyme concentration, it was not possible to access the effect of this factor on animal performance in the current meta-analytical study.

Improvements in weight gain were observed in 57% of the comparisons between supplemented and control treatments in the broiler database and in 81% of the comparisons in the pig database (Figures 1 and 2). In addition, 63 and 83% of all treatments containing β-mannanase reported improved feed conversion ratio compared with control treatments, respectively, in broilers and pigs (Figures 1 and 2). The magnitude of this performance change greatly varied in both databases. This is probably due to the large diversity of experimental conditions, such as BM source or enzyme supplementation. Meta-analysis is a useful tool to deal with experimental variability as it allows establishing systematic responses adjusted to the diversity of available publications. The meta-analysis also increases the sample number, thereby highlighting possible effects that would not be observed in conventional studies.

Diets supplemented with β-mannanase did not influence ($P>0.05$) feed intake and weight gain of broilers (Table 3). However, β-mannanase improved feed conversion (−1%; $P = 0.04$) compared with the control group. The inclusion of β-mannanase in broiler diets also improved the digestibility coefficient of dry matter (+6%; $P<0.01$) and crude protein (+5%; $P<0.01$). In addition, feeds supplemented with β-mannanase showed a 2% higher ($P = 0.04$) content of ME.

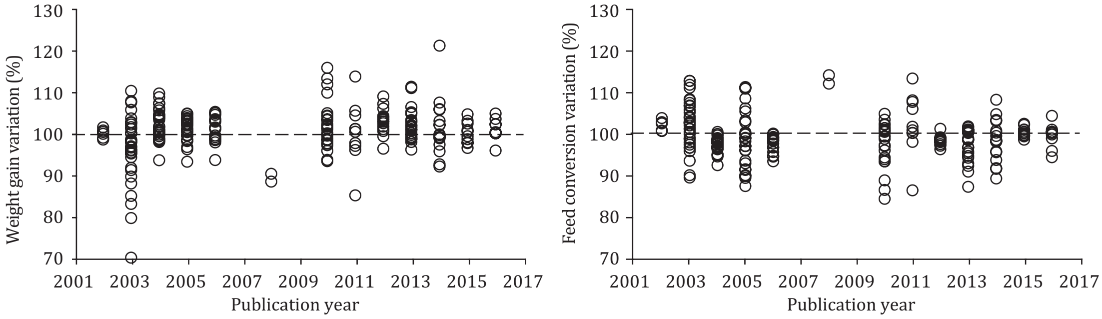

Figure 1 - Performance responses of β-mannanase-supplemented treatments relativized to the respective control treatment in the broiler database.

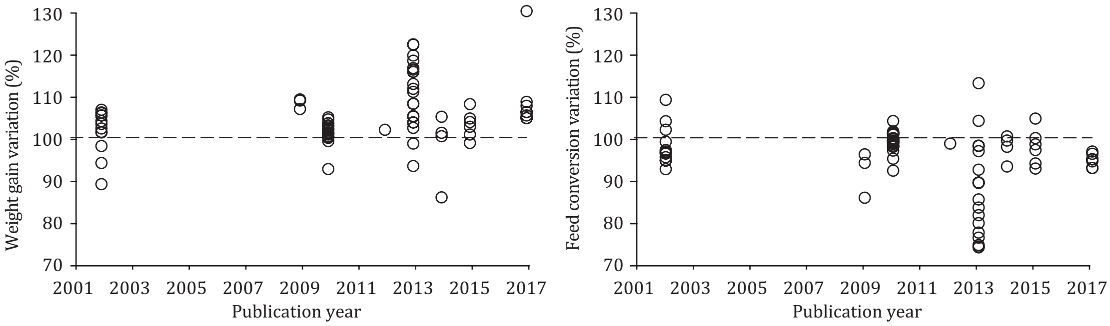

Figure 2 - Performance responses of β-mannanase-supplemented treatments relativized to the respective control treatment in the pig database.

Table 3 - Performance and digestibility coefficients in broilers fed diets supplemented or not with β-mannanase

	β-mannanase[1]		R^2	RES	P-value*
	–	+			
Performance					
Mean body weight (g)	567.60	574.40	62.31	285.20	0.838
Daily feed intake (g day^{-1})	100.10	99.58	60.48	51.91	0.926
Daily weight gain (g day^{-1})	53.11	53.73	81.96	10.82	0.568
Feed conversion ratio (g g^{-1})	1.74	1.72	79.53	0.182	0.041
Digestibility coefficients					
Dry matter (%)	73.11	77.84	90.65	1.57	0.002
Crude protein (%)	69.54	72.91	93.14	2.05	<0.001
Metabolizable energy (kcal kg^{-1})	2,710	2,768	97.42	85.91	0.044

R^2 - coefficient of determination; RSE - residual standard error.
[1] Values adjusted by covariance to average live body weight.
* P-value - probability of treatment effect. Statistical model also considered the study effect (P<0.01 in all performed analysis) and the energy level effect (P<0.01 in all performed analysis).

The relationship between weight gain and ME intake in broilers was studied in control treatments (y = 10.54 + 143.91x; R^2 = 0.95, in which y is weight gain, expressed in g, and x is energy intake, expressed in Mcal) and in broilers fed diets containing β-mannanase (y = 10.45 + 147.84x; R^2 = 0.95). According to the estimation, β-mannanase saved about 2.7% of ME expenditure for growth.

Feeding pigs diets supplemented with β-mannanase did not influence (P>0.05) feed intake (Table 4). However, β-mannanase improved weight gain (+5%; P = 0.04) and feed conversion (−6%; P<0.01) compared with non-supplemented pigs. Pigs fed diets containing β-mannanase also presented higher digestibility coefficients of dry matter (+2%; P<0.01), crude protein (+2%; P<0.01), phosphorus (+6%; P = 0.04), and energy (+1%; P = 0.03).

The relationship between weight gain and ME intake in pigs was studied in control treatments (y = 284.20 + 108.52x; R^2 = 0.84, in which y is weight gain, expressed in g, and x is energy intake, expressed in Mcal) and in animals fed diets containing β-mannanase (y = 284.69 + 113.72x; R^2 = 0.89). According to the estimation, β-mannanase saved about 4.6% of ME expenditure for growth.

Table 4 - Performance and digestibility coefficients in pigs fed diets supplemented or not with β-mannanase

	β-mannanase[1]		R^2	RES	P-value*
	−	+			
Performance					
Mean body weight (kg)	59.17	58.26	84.30	11.84	0.784
Daily feed intake (kg day^{-1})	1.72	1.72	97.88	0.127	0.822
Daily weight gain (g day^{-1})	657.10	687.00	89.48	85.27	0.036
Feed conversion ratio (g g^{-1})	2.64	2.49	84.45	0.30	0.002
Digestibility coefficients					
Dry matter (%)	80.67	82.04	93.69	0.97	<0.001
Crude protein (%)	77.13	78.75	90.69	1.69	0.001
Phosphorus (%)	42.58	45.07	74.20	3.38	0.041
Energy (%)	79.72	80.64	90.12	1.58	0.027

R^2 - coefficient of determination; RSE - residual standard error.
[1] Values adjusted by covariance to average live body weight.
* P-value - probability of treatment effect. Statistical model also considered the study effect (P<0.01 in all performed analysis) and the energy level effect (P<0.01 in all performed analysis).

4. Discussion

The BM are water-soluble non-starch polysaccharides fibers, which are commonly present in various ingredients used in animal feeding, especially soybean meal (Choct, 2015). The BM are resistant to most chemical and physical processes commonly used in feed manufacture, even when exposed to high temperatures (Hsiao et al., 2006). Ruminants are little or not affected by dietary BM, as they are degraded by rumen microorganisms. However, BM are not digested by non-ruminant animals and represent a major anti-nutritional factor for both pigs and broilers (Choct, 2015; Shastak et al., 2015; Singh et al., 2018).

Even small amounts of BM crossing the intestinal mucosa can trigger an innate immune-system response in animals (Jackson et al., 2003). The activation of macrophages occurs either by phagocytosis or by contact with surface receptors (Duncan et al., 2002). Furthermore, BM showed bilateral synergism with some substances, such as interferon-γ, leading to a stronger macrophage activation than other mechanisms (Hibbs et al., 1988). This feed-induced immune response consumes energy that, in a normal metabolic state, would be used for animal growth (Ferreira et al., 2016). This condition was observed in the current meta-analysis, in which the relation between weight gain and energy intake was studied in broilers and pigs. The relationship was studied using empirical equations, which means that other influential factors may probably influence the data. One example was the animal age, as the simulations were performed considering a constant efficiency of weight gain in relation to energy intake over the growing period. Despite the empirical approach, the models clearly indicated changes in the energy metabolism of animals fed diets supplemented with β-mannanase.

The dietary BM fibers were associated with reduced nutrient absorption, hormonal changes, increasing viscosity, and intestinal transit time modifications in previous publications (Shastak et al., 2015). Changes in nutrient digestibility were observed in both broiler and pig databases used in the current study. This effect may also be due to the interaction between BM and glycocalyx, which leads to mucus layer thickening and physically prevents the absorption (Montanhini Neto et al., 2013). In addition, animals fed diets containing high BM levels have lower glucose uptake (El-Masry et al., 2017) and tend to reduce insulin secretion, leading to a lower amino acid absorption rate (Nunes et al., 1991). Increasing the availability of non-absorbed nutrients into the intestinal lumen creates a favorable environment for microorganism proliferations. Some of them are pathogenic and may suppress performance by reducing health status (Teirlynck et al., 2009). In summary, the combination of all these previously mentioned factors leads to a reduction in feed efficiency responses, a trend clearly observed in this meta-analysis for animals fed non-supplemented diets.

Previous research has addressed the beneficial effects of using β-mannanase in pigs and broilers. However, several experimental features may influence enzyme effectiveness. Dietary composition is one of the most important factors, considering that β-mannanase shows better results when supplemented in diets containing higher BM levels (Jacela et al., 2010; Mussini et al., 2011). This condition could not be quantified in the current study due to the lack of information concerning BM levels.

Although the enzyme action mechanism is well-known, its effect may differ on broilers and pigs (Fang et al., 2007). In birds, β-mannanase appears to act earlier in the digestive tract, which facilitates the absorption of BM catabolites and the reduction of excreta humidity (Oliveira and Moraes, 2007). Reduction in feces viscosity is also observed in pigs. However, the absorption of BM catabolites may not necessarily be enhanced as BM is degraded at the end of the ileal portion (Johansen et al., 1997).

The current meta-analytic study showed that β-mannanase supplementation improves feed conversion ratio in both broilers and pigs. Previous studies indicated that β-mannanase can stimulate the activity of other digestive enzymes, such as amylases and trypsin, which improves both nutrient digestion and absorption in non-ruminant species (Li et al., 2010). Positive effects of β-mannanase on nutrient digestibility were also reported in the current meta-analysis.

5. Conclusions

The supplementation of β-mannanase in diets for broilers and pigs saves energy for animal growth, improving the feed conversion ratio. The β-mannanase enzyme is an important tool for nutritionists searching for improved nutrient digestibility coefficients.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: M. Kipper and V.R.Q. Quadros. Data curation: M. Kipper, I. Andretta, V.R.Q. Quadros, B. Schroeder, P.G.S. Pires, C.S. Franceschina, F.M.W. Hickmann and I. França. Formal analysis: M. Kipper, I. Andretta, B. Schroeder, P.G.S. Pires, C.S. Franceschina, F.M.W. Hickmann and I. França. Investigation: M. Kipper, I. Andretta, V.R.Q. Quadros, B. Schroeder, P.G.S. Pires, C.S. Franceschina, F.M.W. Hickmann and I. França. Methodology: M. Kipper. Project administration: I. Andretta. Supervision: I. Andretta. Writing-original draft: M. Kipper and I. Andretta. Writing-review & editing: V.R.Q. Quadros, B. Schroeder, P.G.S. Pires, C.S. Franceschina, F.M.W. Hickmann and I. França.

References

Aderem, A. and Ulevitch, R. J. 2000. Toll-like receptors in the induction of the innate immune response. Nature 406:782-787. https://doi.org/10.1038/35021228

Azarfar, A. 2013. Effect of hemicell enzyme on the performance, growth parameter, some blood factors and ileal digestibility of broiler chickens fed corn/soybean-based diets. Journal of Cell and Animal Biology 7:85-91. https://doi.org/10.5897/JCAB2013.0373

Barros, V. R. S. M.; Lana, G. R. Q.; Lana, S. R. V.; Lana, A. M. Q.; Cunha, F. S. A. and Neto, J. V. E. 2015. β-mannanase and mannan oligosaccharides in broiler chicken feed. Ciência Rural 45:111-117. https://doi.org/10.1590/0103-8478cr20131544

Bertechini, A. G. 2013. Aditivos não nutrientes. p.257-275. In: Nutrição de monogástricos. Bertechini, A. G., ed. UFLA, Lavras.

Carr, S. N.; Alle, G. L.; Rincker, P. J.; Fry, R. S. and Boler, D. D. 2014. Effects of endo-1,4-β-D-mannanase enzyme (Hemicell HT 1.5x) on the growth performance of nursery pigs. The Professional Animal Scientist 30:393-399. https://doi.org/10.15232/pas.2014-01326

Cho, J. H. and Kim, I. H. 2013a. Effects of beta mannanase and xylanase supplementation in low energy density diets on performances, nutrient digestibility, blood profiles and meat quality in finishing pigs. Asian Journal of Animal and Veterinary Advances 8:622-630. https://doi.org/10.3923/ajava.2013.622.630

Cho, J. H. and Kim, I. H. 2013b. Effects of beta-mannanase supplementation in combination with low and high energy dense diets for growing and finishing broilers. Livestock Science 154:137-143. https://doi.org/10.1016/j.livsci.2013.03.004

Choct, M. 2015. Feed non-starch polysaccharides for monogastric animals: classification and function. Animal Production Science 55:1360-1366. https://doi.org/10.1071/AN15276

Daskiran, M.; Teeter, R. G.; Fodge, D. and Hsiao, H. Y. 2004. An evaluation of endo-β-D-mannanase (Hemicell) effects on broiler performance and energy use in diets varying in β-mannan content. Poultry Science 83:662-668. https://doi.org/10.1093/ps/83.4.662

Diarra, S. S. 2017. Effects of enzyme products in the diet on growth, dressing-out percent and organ weights of light pigs fed copra-meal-based diets. Animal Production Science 57:683-689. https://doi.org/10.1071/AN15545

Duncan, C. J. G.; Pugh, N.; Pasco, D. S. and Ross, S. A. 2002. Isolation of a galactomannan that enhances macrophage activation from the edible fungus *Morchella esculenta*. Journal of Agricultural and Food Chemistry 50:5683-5685. https://doi.org/10.1021/jf020267c

El-Masry, K. N.; Ragaa, N. M.; Tony, M. A. and El-Banna, R. A. 2017. Effect of dietary inclusion of guar meal with or without β-mannanase supplementation on broiler performance and immunity. Pakistan Journal of Nutrition 16:341-350. https://doi.org/10.3923/pjn.2017.341.350

Fang, Z. F.; Peng, J.; Liu, Z. L. and Liu, Y. G. 2007. Responses of non-starch polysaccharide-degrading enzymes on digestibility and performance of growing pigs fed a diet based on corn, soya bean meal and Chinese double-low rapeseed meal. Journal of Animal Physiology and Nutrition 91:361-368. https://doi.org/10.1111/j.1439-0396.2006.00664.x

Farahiyah, I. J.; Wong, H. K. and Marhati, M. 2014. Effect of mannanase-supplemented PKE-based diets on the growth performance, feed efficiency and dressing percentage of broilers. Journal Tropical Agriculture and Feed Science 42:125-133.

Ferreira, H. C.; Hannas, M. I.; Albino, L. F. T.; Rostagno, H. S.; Neme, R.; Faria, B. D.; Xavier Jr, M. L. and Rennó, L. N. 2016. Effect of the addition of β-mannanase on the performance, metabolizable energy, amino acid digestibility coefficients, and immune functions of broilers fed different nutritional levels. Poultry Science 95:1848-1857. https://doi.org/10.3382/ps/pew076

Gharaei, M. A.; Dastar, B.; Nameghi, A. H.; Tabar, G. H. and Shargh, M. S. 2012. Effects of Guar meal with and without β-mannanas enzyme on performance and immune response of broiler chicks. International Research Journal of Applied and Basic Sciences 3:2785-2793.

Hibbs, J. B.; Taintor, R. R.; Vavrin, Z. and Rachlin, E. M. 1988. Nitric oxide: A cytotoxic activated macrophage effector molecule. Biochemical and Biophysical Research Communications 157:87-94. https://doi.org/10.1016/S0006-291X(88)80015-9

Hsiao, H. Y.; Anderson, D. M. and Dale, N. M. 2006. Levels of β-mannan in soybean meal. Poultry Science 85:1430-1432. https://doi.org/10.1093/ps/85.8.1430

Jacela, J. Y.; Dritz, S. S.; DeRouchey, J. M.; Tokach, M. D.; Goodband, R. D. and Nelssen, J. L. 2010. Effects of supplemental enzymes in diets containing distillers dried grains with solubles on finishing pig growth performance. The Professional Animal Scientist 26:412-424. https://doi.org/10.15232/S1080-7446(15)30623-9

Jackson, M. E.; Anderson, D. M.; Hsiao, H. Y.; Mathis, G. F. and Fodge, D. W. 2003. Beneficial effect of β-mannanase feed enzyme on performance of chicks challenged with *Eimeria* sp. and *Clostridium perfringens*. Avian Diseases 47:59-763. https://doi.org/10.1637/7024

Jackson, M. E.; Geronian, K.; Knox, A.; McNab, J. and McCartney, E. 2004. A dose-response study with the feed enzyme beta-mannanase in broilers provided with corn-soybean meal based diets in the absence of antibiotic growth promoters. Poultry Science 83:1992-1996. https://doi.org/10.1093/ps/83.12.1992

Jo, J. K.; Ingale, S. L.; Kim, J. S.; Kim, Y. W.; Kim, K. H.; Lohakare, J. D.; Lee, J. H. and Chae, B. J. 2012. Effects of exogenous enzyme supplementation to corn- and soybean meal-based or complex diets on growth performance, nutrient digestibility, and blood metabolites in growing pigs. Journal of Animal Science 90:3041-3048. https://doi.org/10.2527/jas.2010-3430

Johansen, H. N.; Bach Knudsen, K. E.; Wood, P. J. and Fulcher, R. G. 1997. Physico-chemical properties and the degradation of oat bran polysaccharides in the gut of pigs. Journal of the Science of Food and Agriculture 73:81-92. https://doi.org/10.1002/(SICI)1097-0010(199701)73:1%3C81::AID-JSFA695%3E3.0.CO;2-Z

Jones, C. K.; Bergstrom, J. R.; Tokach, M. D.; DeRouchey, J. M.; Goodband, R. D.; Nelssen, J. L. and Dritz, S. S. 2010. Efficacy of commercial enzymes in diets containing various concentrations and sources of dried distillers grains with solubles for nursery pigs. Journal of Animal Science 88:2084-2091. https://doi.org/10.2527/jas.2009-2109

Kerr, B. J. and Shurson, G. C. 2013. Strategies to improve fiber utilization in swine. Journal of Animal Science and Biotechnology 4:11. https://doi.org/10.1186/2049-1891-4-11

Khanongnuch, C.; Sa-nguansook, C. and Lumyong, S. 2006. Nutritive quality of β-mannanase treated copra meal in broiler diets and effectiveness on some fecal bacteria. International Journal of Poultry Science 5:1087-1091. https://doi.org/10.3923/ijps.2006.1087.1091

Kim, J. S.; Ingale, S. L.; Hosseindoust, A. R.; Lee, S. H. and Chae, B. J. 2017. Effects of mannan level and β-mannanase supplementation on growth performance, apparent total tract digestibility and blood metabolites of growing pigs. Animal 11:202-208. https://doi.org/10.1017/S1751731116001385

Kim, J. S.; Ingale, S. L.; Lee, S. H.; Kim, H. M.; Kim, J. S.; Lee, J. H and Chae, B. J. 2013. Effects of energy levels of diet and β-mannanase supplementation on growth performance, apparent total tract digestibility and blood metabolites in growing pigs. Animal Feed Science and Technology 186:64-70. https://doi.org/10.1016/j.anifeedsci.2013.08.008

Klein, J.; Williams, M.; Brown, B.; Rao, S. and Lee, J. T. 2015. Effects of dietary inclusion of a cocktail NSPase and β-mannanase separately and in combination in low energy diets on broiler performance and processing parameters. Journal of Applied Poultry Research 24:489-501. https://doi.org/10.3382/japr/pfv055

Kong, C.; Lee, J. H. and Adeola, O. 2011. Supplementation of β-mannanase to starter and grower diets for broilers. Canadian Journal of Animal Science 91:389-397. https://doi.org/10.4141/CJAS10066

Kwon, W. B.; Park, S. K.; Kong, C. and Kim, B. G. 2015. The effect of various inclusion levels of β-mannanase on nutrient digestibility in diets consisting of corn, soybean meal and palm kernel expellers fed to growing pigs. American Journal of Animal and Veterinary Sciences 10:9-13.

Kwon, W. B. and Kim, B. G. 2015. Effects of supplemental beta-mannanase on digestible energy and metabolizable energy contents of copra expellers and palm kernel expellers fed to pigs. Asian-Australasian Journal of Animal Sciences 28:1014-1019. https://doi.org/10.5713/ajas.15.0275

Latham, R. E.; Williams, M.; Smith, K.; Stringfellow, K.; Clemente, S.; Brister, R. and Lee, J. T. 2016. Effect of β-mannanase inclusion on growth performance, ileal digestible energy, and intestinal viscosity of male broilers fed a reduced-energy diet. Journal of Applied Poultry Research 25:40-47. https://doi.org/10.3382/japr/pfv059

Lee, J. T.; Bailey, C. A. and Cartwright, A. L. 2003. β-Mannanase ameliorates viscosity-associated depression of growth in broiler chickens fed guar germ and hull fractions. Poultry Science 82:1925-1931. https://doi.org/10.1093/ps/82.12.1925

Lee, J. T.; Connor-Appleton, S.; Bailey, C. A. and Cartwright, A. L. 2005. Effects of guar meal by-product with and without beta-mannanase hemicell on broiler performance. Poultry Science 84:1261-1267. https://doi.org/10.1093/ps/84.8.1261

Li, Y.; Chen, X.; Chen, Y.; Li, Z. and Cao, Y. 2010. Effects of β-mannnase expressed by *Pichia pastoris* in corn-soybean meal diets on broiler performance, nutrient digestibility, energy utilization and immunoglobulin levels. Animal Feed Science and Techonology 159:59-67. https://doi.org/10.1016/j.anifeedsci.2010.05.001

Lovatto, P. A.; Lehnen, C. R.; Andretta, I.; Carvalho, A. D. and Hauschild, L. 2007. Meta-análise em pesquisas científicas: enfoque em metodologias. Revista Brasileira de Zootecnia 36:285-294. https://doi.org/10.1590/S1516-35982007001000026

Lv, J. N.; Chen, Y. Q.; Guo, X. J.; Piao, X. S.; Cao, Y. H. and Dong, B. 2013. Effects of supplementation of β-mannanase in corn-soybean meal diets on performance and nutrient digestibility in growing pigs. Asian-Australasian Journal of Animal Sciences 26:579-587. https://doi.org/10.5713/ajas.2012.12612

Mehri, M.; Adibmoradi, M.; Samie, A.; Shivazad, M. and Mehri, M. 2010. Effects of β-mannanase on broiler performance, gut morphology and immune system. African Journal of Biotechnology 9:6221-6228.

Mishra, A.; Sarkar, S. K.; Ray, S. and Haldar, S. 2013. Effects of partial replacement of soybean meal with roasted guar korma and supplementation of mannanase on performance and carcass traits of commercial broiler chickens. Veterinary World 6:693-697. https://doi.org/10.14202/vetworld.2013.693-697

Mohayayee, M. and Kazem, K. 2012. The effect of guar meal (germ fraction) and β-mannanase enzyme on growth performance and plasma lipids in broiler chickens. African Journal of Biotechnology 11:8767-8773.

Mok, C. H.; Kong, C. and Kim, B. G. 2015. Combination of phytase and β-mannanase supplementation on energy and nutrient digestibility in pig diets containing palm kernel expellers. Animal Feed Science and Technology 205:116-121. https://doi.org/10.1016/j.anifeedsci.2015.04.012

Mok, C. H.; Lee, J. H. and Kim, B. G. 2013. Effects of exogenous phytase and β-mannanase on ileal and total tract digestibility of energy and nutrient in palm kernel expeller-containing diets fed to growing pigs. Animal Feed Science and Technology 186:209-213. https://doi.org/10.1016/j.anifeedsci.2013.10.008

Montanhini Neto, R.; Ceccantini, M. L. and Fernandes, J. I. M. 2013. Immune response of broilers fed conventional and alternative diets containing multi-enzyme complex. Brazilian Journal of Poultry Science 15:223-231. https://doi.org/10.1590/S1516-635X2013000300009

Mussini, F. J.; Coto, C. A.; Goodgame, S. D.; Lu, C.; Karimi, A. J.; Lee, J. H. and Waldroup, P. W. 2011. Effect of ß-mannanase on broiler performance and dry matter output using corn-soybean meal based diets. International Journal of Poultry Science 10:778-781. https://doi.org/10.3923/ijps.2011.778.781

Nunes, C. S.; Galibois, I.; Rérat, A.; Savoie, L. and Vaugelade, P. 1991. Hepatic and portal-drained viscera balances of amino acids, insulin, glucagon and gastrin in the pig after ingestion of casein or rapeseed proteins. Reproduction Nutrition Development 31:217-231. https://doi.org/10.1051/rnd:19910303

Oliveira, M. C. and Moraes, V. M. B. 2007. Mananoligossacarídeos e enzimas em dietas à base de milho e farelo de soja para aves. Ciência Animal Brasileira 8:339-357.

Oluwafemi, R. A. and Akpodiete, O. J. 2011. Comparison of the performance, haematology and serum chemistry of weaner pigs fed palm kernel cake with and without enzyme supplementation. Eletronic Journal of Environmental, Agricultural and Food Chemistry 10:2940-2944.

Oluwafemi, R. A.; Akpodiete, O. J. and Bratte, L. 2012. Effect of palm kernel cake replacement and enzyme supplementation on the performance and blood chemistry of finisher pigs. International Journal of Applied Agricultural and Apicultural Research 8:59-67.

Ouhida, I.; Pérez, J. F.; Anguita, M. and Gasa, J. 2002. Influence of β-mannase on broiler performance, digestibility, and intestinal fermentation. Journal of Applied Poultry Research 11:244-249. https://doi.org/10.1093/japr/11.3.244

Pettey, L. A.; Carter, S. D.; Senne, B. W. and Shriver, J. A. 2002. Effects of β-mannanase addition to corn-soybean meal diets on growth performance, carcass traits, and nutrient digestibility of weanling and growing-finishing pigs. Journal of Animal Science 80:1012-1019.

Rostagno, H. S.; Albino, L. F. T.; Donzele, J. L.; Gomes, P. C.; Oliveira, R. F.; Lopes, D. C.; Ferreira, A. S.; Barreto, S. L. T. and Euclides, R. F. 2011. Tabelas brasileiras para aves e suínos: Composição de alimentos e exigências nutricionais. UFV, Viçosa, MG.

Saki, A. A.; Mazugi, M. T. and Kamyab, A. 2005. Effect of mannanase on broiler performance, ileal and in-vitro protein digestibility, uric acid and litter moisture in broiler feeding. International Journal of Poultry Science 4:21-26. https://doi.org/10.3923/ijps.2005.21.26

Sato, S.; St-Pierre, C.; Bhaumik, P. and Nieminen, J. 2009. Galectins in innate immunity: dual functions of host soluble β-galactoside-binding lectins as damage-associated molecular patterns (DAMPs) and as receptors for pathogen-associated molecular patterns (PAMPs). Immunological Reviews 230:172-187. https://doi.org/10.1111/j.1600-065X.2009.00790.x

Sauvant, D.; Schmidely, P.; Daudin, J. J. and St-Pierre, N. R. 2008. Meta-analyses of experimental data in animal nutrition. Animal 2:1203-1214. https://doi.org/10.1017/S1751731108002280

Shastak, Y.; Ader, P.; Feurstein, D.; Ruehle, R. and Matuschek, M. 2015. ß-Mannan and mannanase in poultry nutrition. World's Poultry Science Journal 71:161-174. https://doi.org/10.1017/S0043933915000136

Singh, S.; Singh, G. and Arya, S. K. 2018. Mannans: An overview of properties and application in food products. International Journal of Biological Macromolecules 119:79-95. https://doi.org/10.1016/j.ijbiomac.2018.07.130

Sornlake, W.; Matetaviparee, P.; Rattanaphan, N.; Tanapongpipat, S. and Eurwilaichitr, L. 2013. B-mannanase production by *Aspergillus niger* BCC4525 and its efficacy on broiler performance. Journal Science of Food Agriculture 93:3345-3351. https://doi.org/10.1002/jsfa.6183

Sundu, B.; Kumar, A. and Dingle, J. 2006. Response of broiler chicks fed increasing levels of copra meal and enzymes. International Journal of Poultry Science 5:13-18. https://doi.org/10.3923/ijps.2006.13.18

Teirlynck, E.; Bjerrum, L.; Eeckhaut, V.; Huygebaert, G.; Pasmans, F.; Haesebrouck, F.; Dewulf, J.; Ducatelle, R. and Van Immerseel, F. 2009. The cereal type in feed influences gut wall morphology and intestinal immune cell infiltration in broiler chickens. British Journal of Nutrition 102:1453-1461. https://doi.org/10.1017/S0007114509990407

Torki, M. 2011. Evaluation of growth performance of broiler chicks fed with diet containing chickpea seeds supplemented with exogenous commercial enzymes. Advances in Environmental Biology 5:595-604.

Upadhaya, S. D.; Park, J. W.; Lee, J. H. and Kim, I. H. 2016. Efficacy of β-mannanase supplementation to corn-soya bean meal-based diets on growth performance, nutrient digestibility, blood urea nitrogen, faecal coliform and lactic acid bacteria and faecal noxious gas emission in growing pigs. Archives of Animal Nutrition 70:33-43. https://doi.org/10.1080/1745039X.2015.1117697

Wang, J. P.; Hong, S. M.; Yan, L.; Yoo, J. S.; Lee, J. H.; Jang, H. D.; Kim, H. J. and Kim, I. H. 2009. Effects of single or carbohydrases cocktail in low-nutrient-density diets on growth performance, nutrient digestibility, blood characteristics, and carcass traits in growing–finishing pigs. Livestock Science 126:215-220. https://doi.org/10.1016/j.livsci.2009.07.003

Williams, M. P.; Brown, B.; Rao, S. and Lee, J. T. 2014. Evaluation of β-mannanase and nonstarch polysaccharide-degrading enzyme inclusion separately or intermittently in reduced energy diets fed to male broilers on performance parameters and carcass yield. Journal of Applied Poultry Research 23:715-723. https://doi.org/10.3382/japr.2014-01008

Yoon, S. Y.; Yang, Y. X.; Shinde, P. L.; Choi, J. Y.; Kim, J. S.; Kim, Y. W.; Yun, K.; Jo, J. K.; Lee, J. H.; Ohh, S. J.; Kwon, I. K. and Chae, B. J. 2010. Effects of mannanase and distillers dried grain with solubles on growth performance, nutrient digestibility, and carcass characteristics of grower-finisher pigs. Journal of Animal Science 88:181-191. https://doi.org/10.2527/jas.2008-1741

Zakaria, H. A. H.; Jalal, M. A. R. and Jabarin, A. S. 2008. Effect of exogenous enzymes on the growing performance of broiler chickens fed regular corn/soybean-based diets and the economics of enzyme supplementation. Pakistan Journal of Nutrition 7:534-539. https://doi.org/10.3923/pjn.2008.534.539

Zangiabadi, H. and Torki, H. 2010. The effect of a *β*-mannanase-based enzyme on growth performance and humoral immune response of broiler chickens fed diets containing graded levels of whole dates. Tropical Animal Health and Production 42:1209-1217. https://doi.org/10.1007/s11250-010-9550-1

Zou, J.; Zheng, P.; Zhang, K.; Ding, X. and Bai, S. 2013. Effects of exogenous enzymes and dietary energy on performance and digestive physiology of broilers. Journal of Animal Science and Biotechnology 4:14. https://doi.org/10.1186/2049-1891-4-14

Zou, X. T.; Qiao, X. J. and Xu, Z. R. 2006. Effect of β-mannanase (Hemicell) on growth performance and immunity of broilers. Poultry Science 85:2176-2179. https://doi.org/10.1093/ps/85.12.2176