

## Could probiotics be the panacea alternative to the use of antimicrobials in livestock diets?

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### Supplementary references S1. Selected probiotic animal trials reporting FCR values

- Agazzi, A., Tirloni, E., Stella, S., Marocolo, S., Ripamonti, B., Bersani, C., Caputo, J.M., Dell'Orto, V., Rota, N. and Savoini, G., 2014. Effects of species-specific probiotic addition to milk replacer on calf health and performance during the first month of life. *Annals of Animal Science* 14: 101-115.
- Ahmed, S.T., Islam, M.M., Mun, H.-S., Sim, H.-J., Kim, Y.-J. and Yang, C.-J., 2014. Effects of *Bacillus amyloliquefaciens* as a probiotic strain on growth performance, cecal microflora, and fecal noxious gas emissions of broiler chickens. *Poultry Science* 93: 1963-1971.
- Alhidary, I., Abdelrahman, M. and Khan, R., 2016. Comparative effects of direct-fed microbials alone or with a trace minerals supplements on the productive performance, blood metabolites, and antioxidant status in grazing Awassi lambs. *Environmental Science and Pollution Research* 23: 25218-25223.
- Amerah, A., Quiles, A., Medel, P., Sánchez, J., Lehtinen, M. and Gracia, M., 2013. Effect of pelleting temperature and probiotic supplementation on growth performance and immune function of broilers fed maize/soy-based diets. *Animal Feed Science and Technology* 180: 55-63.
- Bai, K., Huang, Q., Zhang, J., He, J., Zhang, L. and Wang, T., 2016. Supplemental effects of probiotic *Bacillus subtilis* fmbJ on growth performance, antioxidant capacity, and meat quality of broiler chickens. *Poultry Science* 96: 74-82.
- Bai, S., Wu, A., Ding, X., Lei, Y., Bai, J., Zhang, K. and Chio, J., 2013. Effects of probiotic-supplemented diets on growth performance and intestinal immune characteristics of broiler chickens. *Poultry Science* 92: 663-670.
- Balasubramanian, B., Li, T. and Kim, I.H., 2016. Effects of supplementing growing-finishing pig diets with *Bacillus* spp. probiotic on growth performance and meat-carcass grade quality traits. *Revista Brasileira de Zootecnia* 45: 93-100.
- Bhatt, R. and Sahoo, A., 2018. Effect of feeding milk replacer alone or in combination with probiotic on pre-weaning performance, nutrient utilization and rumen fermentation in malpura lambs. *Animal Nutrition and Feed Technology* 18: 1-12.
- Bhatt, R., Sahoo, A., Karim, S. and Gadekar, Y., 2018. Effects of *Saccharomyces cerevisiae* and rumen bypass-fat supplementation on growth, nutrient utilisation, rumen fermentation and carcass traits of lambs. *Animal Production Science* 58: 530-538.
- Cai, L., Indrakumar, S., Kiarie, E. and Kim, I., 2015. Effects of a multi-strain *Bacillus* species-based direct-fed microbial on growth performance, nutrient digestibility, blood profile, and gut health in nursery pigs fed corn-soybean meal-based diets. *Journal of Animal Science* 93: 4336-4342.
- Dash, G., Raman, R.P., Prasad, K.P., Makesh, M., Pradeep, M. and Sen, S., 2014. Evaluation of *Lactobacillus plantarum* as feed supplement on host associated microflora, growth, feed efficiency, carcass biochemical composition and immune response of giant freshwater prawn, *Macrobrachium rosenbergii* (de Man, 1879). *Aquaculture* 432: 225-236.
- Dersjant-Li, Y., Awati, A., Kromm, C. and Evans, C., 2013. A direct fed microbial containing a combination of three-strain *Bacillus* sp. can be used as an alternative to feed antibiotic growth promoters in broiler production. *Journal of Applied Animal Nutrition* 2: e11.
- Dick, K., Duff, G., Limesand, S.W., Cuneo, S.P., Knudson, D., McMurphy, C., Hall, L., Bernal-Rigoli, J. and Marchello, J.A., 2013. Effects of a direct-fed microbial on digestive-tract morphology of Holstein bull calves and performance and carcass characteristics of Holstein steers. *The Professional Animal Scientist* 29: 107-115.
- Dos Santos Monnerat, J.P.I., Paulino, P.V.R., Detmann, E., Valadares Filho, S.C., Valadares, R.D.F. and Duarte, M.S., 2013. Effects of *Saccharomyces cerevisiae* and monensin on digestion, ruminal parameters, and balance of nitrogenous compounds of beef cattle fed diets with different starch concentrations. *Tropical Animal Health and Production* 45: 1251-1257.
- Flores, C., Williams, M., Pieniasek, J., Dersjant-Li, Y., Awati, A. and Lee, J., 2016. Direct-fed microbial and its combination with xylanase, amylase, and protease enzymes in comparison with AGPs on broiler growth performance and foot-pad lesion

- development. *Journal of Applied Poultry Research* 25: 328-337.
- Fomenky, B.E., Chiquette, J., Bissonnette, N., Talbot, G., Chouinard, P.Y. and Ibeagha-Awemu, E.M., 2017. Impact of *Saccharomyces cerevisiae boulardii* CNCMI-1079 and *Lactobacillus acidophilus* BT1386 on total lactobacilli population in the gastrointestinal tract and colon histomorphology of Holstein dairy calves. *Animal Feed Science and Technology* 234: 151-161.
- Geiger, A., Ward, S., Williams, C., Rude, B., Cabrera, C., Kalestch, K. and Voelz, B., 2014. Effects of increasing protein and energy in the milk replacer with or without direct-fed microbial supplementation on growth and performance of preweaned Holstein calves. *Journal of Dairy Science* 97: 7212-7219.
- Giri, S.S., Sukumaran, V. and Oviya, M., 2013. Potential probiotic *Lactobacillus plantarum* VSG3 improves the growth, immunity, and disease resistance of tropical freshwater fish, *Labeo rohita*. *Fish and Shellfish Immunology* 34: 660-666.
- Gobi, N., Vaseeharan, B., Chen, J.-C., Rekha, R., Vijayakumar, S., Anjugam, M. and Iswarya, A., 2018. Dietary supplementation of probiotic *Bacillus licheniformis* Dahb1 improves growth performance, mucus and serum immune parameters, antioxidant enzyme activity as well as resistance against *Aeromonas hydrophila* in tilapia *Oreochromis mossambicus*. *Fish and Shellfish Immunology* 74: 501-508.
- González-Félix, M.L., Gatlin III, D.M., Urquidez-Bejarano, P., De la Reé-Rodríguez, C., Duarte-Rodríguez, L., Sánchez, F., Casas-Reyes, A., Yamamoto, F.Y., Ochoa-Leyva, A. and Perez-Velazquez, M., 2018. Effects of commercial dietary prebiotic and probiotic supplements on growth, innate immune responses, and intestinal microbiota and histology of *Totoaba macdonaldi*. *Aquaculture* 491: 239-251.
- He, Z., Ferlisi, B., Eckert, E., Brown, H., Aguilar, A. and Steele, M., 2017. Supplementing a yeast probiotic to pre-weaning Holstein calves: feed intake, growth and fecal biomarkers of gut health. *Animal Feed Science and Technology* 226: 81-87.
- Hossain, M., Begum, M. and Kim, I., 2015. Effect of *Bacillus subtilis*, *Clostridium butyricum* and *Lactobacillus acidophilus* endospores on growth performance, nutrient digestibility, meat quality, relative organ weight, microbial shedding and excreta noxious gas emission in broilers. *Veterinari Medicina* 60: 77-86.
- Hu, Y., Dun, Y., Li, S., Zhao, S., Peng, N. and Liang, Y., 2014. Effects of *Bacillus subtilis* KN-42 on growth performance, diarrhea and faecal bacterial flora of weaned piglets. *Asian-Australasian Journal of Animal Sciences* 27: 1131.
- Jaworski, N., Owusu-Asiedu, A., Walsh, M., McCann, J., Loor, J. and Stein, H., 2017. Effects of a 3 strain *Bacillus*-based direct-fed microbial and dietary fiber concentration on growth performance and expression of genes related to absorption and metabolism of volatile fatty acids in weanling pigs. *Journal of Animal Science* 95: 308-319.
- Jeong, J. and Kim, I., 2014. Effect of *Bacillus subtilis* C-3102 spores as a probiotic feed supplement on growth performance, noxious gas emission, and intestinal microflora in broilers. *Poultry Science* 93: 3097-3103.
- Jia, P., Cui, K., Ma, T., Wan, F., Wang, W., Yang, D., Wang, Y., Guo, B., Zhao, L. and Diao, Q., 2018. Influence of dietary supplementation with *Bacillus licheniformis* and *Saccharomyces cerevisiae* as alternatives to monensin on growth performance, antioxidant, immunity, ruminal fermentation and microbial diversity of fattening lambs. *Scientific Reports* 8: 16712.
- Kenney, N., Vanzant, E., Harmon, D. and McLeod, K., 2015. Direct-fed microbials containing lactate-producing bacteria influence ruminal fermentation but not lactate utilization in steers fed a high-concentrate diet. *Journal of Animal Science* 93: 2336-2348.
- Kerr, B., Weber, T. and Shurson, G., 2013. Evaluation of commercially available enzymes, probiotics, or yeast on apparent total-tract nutrient digestion and growth in nursery and finishing pigs fed diets containing corn dried distillers grains with solubles. *Professional Animal Scientist* 29: 508-517.
- Kocyigit, R., Aydin, R., Yanar, M., Diler, A., Avci, M. and Ozyurek, S., 2016. The effect of direct-fed microbials plus exogenous feed enzyme supplements on the growth, feed efficiency ratio and some behavioural traits of brown swiss x eastern Anatolian red F1 calves. *Pakistan Journal of Zoology* 48: 1389-1393.
- Kongnum, K. and Hongpattarakere, T., 2012. Effect of *Lactobacillus plantarum* isolated from digestive tract of wild shrimp on growth and survival of white shrimp (*Litopenaeus vannamei*) challenged with *Vibrio harveyi*. *Fish and Shellfish Immunology* 32: 170-177.
- Latorre, J., Hernandez-Velasco, X., Bielke, L., Vicente, J., Wolfenden, R., Menconi, A., Hargis, B. and Tellez, G., 2015. Evaluation of a *Bacillus* direct-fed microbial candidate on digesta viscosity, bacterial translocation, microbiota composition and bone mineralisation in broiler chickens fed on a rye-based diet. *British Poultry Science* 56: 723-732.
- Lei, K., Li, Y., Yu, D., Rajput, I. and Li, W., 2013. Influence of dietary inclusion of *Bacillus*

- licheniformis* on laying performance, egg quality, antioxidant enzyme activities, and intestinal barrier function of laying hens. *Poultry Science* 92: 2389-2395.
- Lei, X., Piao, X., Ru, Y., Zhang, H., Péron, A. and Zhang, H., 2015. Effect of *Bacillus amyloliquefaciens*-based direct-fed microbial on performance, nutrient utilization, intestinal morphology and cecal microflora in broiler chickens. *Asian-Australasian Journal of Animal Sciences* 28: 239.
- Lei, X., Ru, Y. and Zhang, H., 2014. Effect of *Bacillus amyloliquefaciens*-based direct-fed microbials and antibiotic on performance, nutrient digestibility, cecal microflora, and intestinal morphology in broiler chickens. *Journal of Applied Poultry Research* 23: 486-493.
- Liu, H., Ji, H., Zhang, D., Wang, S., Wang, J., Shan, D. and Wang, Y., 2015. Effects of *Lactobacillus brevis* preparation on growth performance, fecal microflora and serum profile in weaned pigs. *Livestock Science* 178: 251-254.
- Miandare, H.K., Yarahmadi, P. and Abbasian, M., 2016. Immune related transcriptional responses and performance of *Litopenaeus vannamei* post-larvae fed on dietary probiotic PrimaLac®. *Fish and Shellfish Immunology* 55: 671-678.
- Mirghaed, A.T., Yarahmadi, P., Hosseinifar, S.H., Tahmasebi, D., Gheisvandi, N. and Ghaedi, A., 2018. The effects singular or combined administration of fermentable fiber and probiotic on mucosal immune parameters, digestive enzyme activity, gut microbiota and growth performance of Caspian white fish (*Rutilus frisii kutum*) fingerlings. *Fish and Shellfish Immunology* 77: 194-199.
- Mookiah, S., Sieo, C.C., Ramasamy, K., Abdullah, N. and Ho, Y.W., 2014. Effects of dietary prebiotics, probiotic and synbiotics on performance, caecal bacterial populations and caecal fermentation concentrations of broiler chickens. *Journal of the Science of Food and Agriculture* 94: 341-348.
- Munir, M.B., Hashim, R., Chai, Y.H., Marsh, T.L. and Nor, S.A.M., 2016. Dietary prebiotics and probiotics influence growth performance, nutrient digestibility and the expression of immune regulatory genes in snakehead (*Channa striata*) fingerlings. *Aquaculture* 460: 59-68.
- Murugesan, G., Gabler, N. and Persia, M., 2014. Effects of direct-fed microbial supplementation on broiler performance, intestinal nutrient transport and integrity under experimental conditions with increased microbial challenge. *British Poultry Science* 55: 89-97.
- Park, J. and Kim, I., 2014. Supplemental effect of probiotic *Bacillus subtilis* B2A on productivity, organ weight, intestinal *Salmonella* microflora, and breast meat quality of growing broiler chicks. *Poultry Science* 93: 2054-2059.
- Peng, Q., Zeng, X., Zhu, J., Wang, S., Liu, X., Hou, C., Thacker, P. and Qiao, S., 2016. Effects of dietary *Lactobacillus plantarum* B1 on growth performance, intestinal microbiota, and short chain fatty acid profiles in broiler chickens. *Poultry Science* 95: 893-900.
- Rabelo, C.H., Valente, A.L., Barbero, R.P., Basso, F.C. and Reis, R., 2019. Performance of finishing beef cattle fed diets containing maize silages inoculated with lactic-acid bacteria and *Bacillus subtilis*. *Animal Production Science* 59: 266-276.
- Ramos, M., Gonçalves, J., Batista, S., Costas, B., Pires, M., Rema, P. and Ozório, R., 2015. Growth, immune responses and intestinal morphology of rainbow trout (*Oncorhynchus mykiss*) supplemented with commercial probiotics. *Fish and Shellfish Immunology* 45: 19-26.
- Saleem, A., Zanouny, A. and Singer, A., 2017. Growth performance, nutrients digestibility, and blood metabolites of lambs fed diets supplemented with probiotics during pre-and post-weaning period. *Asian-Australasian Journal of Animal Sciences* 30: 523.
- Seifzadeh, S., Mirzaei Aghjehgheshlagh, F., Abdibenemar, H., Seifdavati, J. and Navidshad, B., 2017. The effects of a medical plant mix and probiotic on performance and health status of suckling Holstein calves. *Italian Journal of Animal Science* 16: 44-51.
- Sharifuzzaman, S., Al-Harbi, A. and Austin, B., 2014. Characteristics of growth, digestive system functionality, and stress factors of rainbow trout fed probiotics *Kocuria* SM1 and *Rhodococcus* SM2. *Aquaculture* 418: 55-61.
- Soto, L.P., Zbrun, M.V., Frizzo, L.S., Signorini, M.L., Sequeira, G.J. and Rosmini, M.R., 2014. Effects of bacterial inoculants in milk on the performance of intensively reared calves. *Animal Feed Science and Technology* 189: 117-122.
- Thy, H.T.T., Tri, N.N., Quy, O.M., Fotedar, R., Kannika, K., Unajak, S. and Areechon, N., 2017. Effects of the dietary supplementation of mixed probiotic spores of *Bacillus amyloliquefaciens* 54A, and *Bacillus pumilus* 47B on growth, innate immunity and stress responses of striped catfish (*Pangasianodon hypophthalmus*). *Fish and Shellfish Immunology* 60: 391-399.
- Waititu, S., Yitbarek, A., Matini, E., Echeverry, H., Kiarie, E., Rodriguez-Lecompte, J. and Nyachoti, C., 2014. Effect of supplementing direct-fed microbials on broiler performance, nutrient digestibilities, and immune responses. *Poultry Science* 93: 625-635.
- Wilson, B., Holland, B., Step, D., Jacob, M., VanOverbeke, D., Richards, C., Nagaraja, T.G. and

- Krehbiel, C., 2016. Feeding wet distillers grains plus solubles with and without a direct-fed microbial to determine performance, carcass characteristics, and fecal shedding of *Escherichia coli* O157: H7 in feedlot heifers. *Journal of Animal Science* 94: 297-305.
- Ye, D. and Eastridge, M., 2018. Oral administration of *Megasphaera elsdenii* to Jersey cows during early lactation. *Professional Animal Scientist* 34: 67-74.
- Zhang, R., Zhou, M., Tu, Y., Zhang, N.F., Deng, K.D., Ma, T. and Diao, Q.Y., 2016. Effect of oral administration of probiotics on growth performance, apparent nutrient digestibility and stress-related indicators in Holstein calves. *Journal of Animal Physiology and Animal Nutrition* 100: 33-38.
- Zhang, Z., Cho, J. and Kim, I., 2013. Effects of *Bacillus subtilis* UBT-MO2 on growth performance, relative immune organ weight, gas concentration in excreta, and intestinal microbial shedding in broiler chickens. *Livestock Science* 155: 343-347.
- Zhang, Z. and Kim, I., 2014. Effects of multistrain probiotics on growth performance, apparent ileal nutrient digestibility, blood characteristics, cecal microbial shedding, and excreta odor contents in broilers. *Poultry Science* 93: 364-370.
- Zhao, P. and Kim, I., 2015. Effect of direct-fed microbial on growth performance, nutrient digestibility, fecal noxious gas emission, fecal microbial flora and diarrhea score in weanling pigs. *Animal Feed Science and Technology* 200: 86-92.
- Zokaeifar, H., Babaei, N., Saad, C.R., Kamarudin, M.S., Sijam, K. and Balcazar, J.L., 2014. Administration of *Bacillus subtilis* strains in the rearing water enhances the water quality, growth performance, immune response, and resistance against *Vibrio harveyi* infection in juvenile white shrimp, *Litopenaeus vannamei*. *Fish and Shellfish Immunology* 36: 68-74.

## Supplementary references S2. Selected probiotic trials for rumen pH modulation in ruminants

- Carrasco, C., Medel, P., Fuentetaja, A., Ranilla, M. and Carro, M., 2016. Effect of disodium/calcium malate or *Saccharomyces cerevisiae* supplementation on growth performance, carcass quality, ruminal fermentation products, and blood metabolites of heifers. *Journal of Animal Science* 94: 4315-4325.
- Chiquette, J., Lagrost, J., Girard, C., Talbot, G., Li, S., Plaizier, J. and Hindrichsen, I., 2015. Efficacy of the direct-fed microbial *Enterococcus faecium* alone or in combination with *Saccharomyces cerevisiae* or *Lactococcus lactis* during induced subacute ruminal acidosis. *Journal of Dairy Science* 98: 190-203.
- De Raphélis-Soissan, V., Li, L., Godwin, I., Barnett, M., Perdok, H. and Hegarty, R., 2014. Use of nitrate and *Propionibacterium acidipropionici* to reduce methane emissions and increase wool growth of Merino sheep. *Animal Production Science* 54: 1860-1866.
- Diaz, T.G., Branco, A.F., Jacovaci, F.A., Jobim, C.C., Bolson, D.C. and Daniel, J.L.P., 2018a. Inclusion of live yeast and mannan-oligosaccharides in high grain-based diets for sheep: ruminal parameters, inflammatory response and rumen morphology. *PLoS ONE* 13: e0193313.
- Diaz, T.G., Branco, A.F., Jacovaci, F.A., Jobim, C.C., Daniel, J.L.P., Bueno, A.V.I. and Ribeiro, M.G., 2018b. Use of live yeast and mannan-oligosaccharides in grain-based diets for cattle: ruminal parameters, nutrient digestibility, and inflammatory response. *PLoS ONE* 13: e0207127.
- Jiao, P., Wei, L., Walker, N., Liu, F., Chen, L., Beauchemin, K. and Yang, W., 2017. Comparison of non-encapsulated and encapsulated active dried yeast on ruminal pH and fermentation, and site and extent of feed digestion in beef heifers fed high-grain diets. *Animal Feed Science and Technology* 228: 13-22.
- Kenney, N., Vanzant, E., Harmon, D. and McLeod, K., 2015. Direct-fed microbials containing lactate-producing bacteria influence ruminal fermentation but not lactate utilization in steers fed a high-concentrate diet. *Journal of Animal Science* 93: 2336-2348.
- Le, O.T., Schofield, B., Dart, P.J., Callaghan, M.J., Lisle, A.T., Ouwerkerk, D., Klieve, A.V. and McNeill, D.M., 2017. Production responses of reproducing ewes to a by-product-based diet inoculated with the probiotic *Bacillus amyloliquefaciens* strain H57. *Animal Production Science* 57: 1097-1105.
- Narvaez, N., Alazzeah, A., Wang, Y. and McAllister, T., 2014. Effect of *Propionibacterium acidipropionici* P169 on growth performance and rumen metabolism of beef cattle fed a corn-and corn dried distillers' grains with solubles-based finishing diet. *Canadian Journal of Animal Science* 94: 363-369.
- Obeidat, B.S., Mahmoud, K.Z., Obeidat, M.D., Ata, M., Kridli, R.T., Haddad, S.G., Titi, H.H., Jawasreh, K.I., Altamimi, H.J. and Subih, H.S., 2018. The effects of *Saccharomyces cerevisiae* supplementation on intake, nutrient digestibility, and rumen fluid pH in Awassi female lambs. *Veterinary World* 11: 1015.
- Philippeau, C., Lettat, A., Martin, C., Silberberg, M., Morgavi, D., Ferlay, A., Berger, C. and Noziere, P., 2017. Effects of bacterial direct-fed microbials on ruminal characteristics, methane emission, and milk fatty acid composition in cows fed high-or low-starch diets. *Journal of Dairy Science* 100: 2637-2650.
- Sun, P., Wang, J. and Deng, L., 2013. Effects of *Bacillus subtilis natto* on milk production, rumen fermentation and ruminal microbiome of dairy cows. *Animal* 7: 216-222.
- Vyas, D., McGeough, E., McGinn, S., McAllister, T. and Beauchemin, K., 2014a. Effect of *Propionibacterium* spp. on ruminal fermentation, nutrient digestibility, and methane emissions in beef heifers fed a high-forage diet. *Journal of Animal Science* 92: 2192-2201.
- Vyas, D., Uwizeye, A., Mohammed, R., Yang, W., Walker, N. and Beauchemin, K., 2014b. The effects of active dried and killed dried yeast on subacute ruminal acidosis, ruminal fermentation, and nutrient digestibility in beef heifers. *Journal of Animal Science* 92: 724-732.
- Zhang, R., Dong, X., Zhou, M., Tu, Y., Zhang, N., Deng, K. and Diao, Q., 2017. Oral administration of *Lactobacillus plantarum* and *Bacillus subtilis* on rumen fermentation and the bacterial community in calves. *Animal Science Journal* 88: 755-762.