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Postbiotics for Animal Health and Performance

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Abstract

The rise of drug resistance in microbial populations has led researches to find new natural alternatives that can be used safely in both humans and animals. Probiotics, prebiotics and synbiotics have been used for several years as growth promoters and as preventive measures against several pathogens with advantageous results in livestock. Of late, postbiotics which are derivatives of probiotic cultures, have been used in humans, animals and poultry. Postbiotics have been classified as promising alternatives to antimicrobials due to their multiple benefits on livestock health and performance. They are regarded as immune-stimulators, anti- inflammatory, anti-oxidants and ant-microbial, as well as growth promoters. Robust and long term studies are required in this area of research.

Keywords: Animal health; performance; polyphenol; postbiotic; probiotic

Introduction

Recently postbiotics have been classified as promising alternatives to antimicrobials due to their multiple benefits on livestock health and performance. The terms para-probiotics and postbiotics have emerged in some literature, where the first term denotes the dead or inactivated living cells of probiotics and the second term refers to healthful metabolic products that are produced by the living cells of probiotics (Barros *et al.,* 2020). In other words, the term post-biotic denotes the health benefits beyond the inherent viability of probiotics providing a wide dimension to the probiotic concept (Aguilar *et al.,* 2018). Postbiotics include any substance released by or produced through the metabolic activity of microorganism, which exerts a beneficial effect on the host, directly or indirectly (Tsilingri *et al.,* 2013). The conventional methods being in use to influence post-biotic synthesis are through manipulation of gut microbes with prebiotics, probiotics, synbiotics and macronutrients in food.

The term postbiotics comprises bioactive substances such as short-chain fatty acids (SCFAs), which are produced by probiotics and components of bacterial cell wall. The postbiotics are also known by other names such as metabiotics, biogenics or metabolite/cell-free supernatants (Reynés *et al.,* 2018). The soluble factors provided by probiotics, postbiotics alone are sufficient to elicit the desired response in host (Tsilingiri and Rescigno, 2012). An example of a postbiotic is butyrate, which exerts neuro-pharmacological effects and influences the brain indirectly *via* immune and vagal nerve regulation as well as possible epigenetic modulation (Stilling *et al.,* 2016). Initial studies suggest that postbiotics exert a positive impact on inflammatory markers (Tsilingiri and Rescigno, 2012).

Postbiotics are soluble non-viable metabolites produced by a bacterial or probiotic metabolic process (Tsilingiri *et al.,* 2012; Klemashevich *et al.,* 2014). So, postbiotics shared probiotics with the same mode of action but differed being non-living organisms (Thanh *et al.,* 2009). Moreover, postbiotics are fed products such as organic acids and bacteriocins that are produced by beneficial intestinal microbiota and are able to reduce the gut pH, prohibit opportunistic pathogens proliferation, and consequently have a positive influence on host health (Aguilar *et al.,* 2018). Bacteriocins, short chain fatty acids, peptides and proteins are considered as postbiotics inhibitory metabolites (Cicenia *et al.,* 2014).

Postbiotics Sources

The cell wall components and cytoplasmic extracts of various bacteria such as *Lactobacilli* species, including *L. acidophilus, L. casei, L. fermentum,*

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L. rhamnosus, L. paracasei, L. delbrueckil subsp. Bulgaricus, L. gasseri, L. helveticus, L. reuteri and *L. johnsonni,* have been reported to be highly effective postbiotics (Vidal *et al.,* 2002; Matsuguchi *et al.,* 2003; Choi *et al.,* 2006; Kim *et al.,* 2011; Cicenia *et al.,* 2016; TiptiriKourpeti *et al.,* 2016; Johnson *et al.,* 2019). Further, *Bifidobacterium* species (Tejada-Simon and Pestka, 1999), *Faecalibacterium prausnitzii* (Sokol *et al.,* 2008) and *Bacillus coagulans* (Jensen *et al.,* 2010) showed postbiotics properties. Strains of *L. plantarum,* either alone or in combination are the most common postbiotics producers (Thanh *et al.,* 2009; Thu *et al.,* 2011). The strains of *L. plantarum* revealed efficiency in rats (Loh *et al.,* 2009), pigs (Loh *et al.,* 2013), broiler chickens (Thanh *et al.,* 2009; Loh *et al.,* 2010; Rosyidah *et al.,* 2011; Jahromi *et al.,* 2016; Kareem *et al.,* 2016, 2017), layer chickens (Loh *et al.,* 2014), and ruminants (Izuddin *et al.,* 2019), as well as humans (Kim *et al.,* 2011). *Saccharomyces cerevisiae*, a yeast has been used for the production of metabolites after anaerobic fermentation in a proprietary medium and drying of the liquid (Jensen *et al.,* 2007).

Some postbiotics are also obtained from plant polyphenols. Polyphenols are diverse class of plant metabolites, associated with color, taste and defense mechanisms of fruits and vegetables. Plants synthesize them as a protection against UV light and pathogens. They can be found in skin, flesh and fiber of many fruits and vegetables. Polyphenols are molecules with reported antioxidant, anti-inflammatory, anti-microbial and disease modulating properties and they possess their bioactive roles after ingestion, either in their native form or as metabolites (Rowland *et al.,* 2018). A number of studies have been conducted in authors laboratory with regard to beneficial effects of polyphenols in goat and poultry rations (Jan *et al.,* 2015, Singh *et al.,* 2013, Zargar *et al.,* 2016, Daing *et al.,* 2020, Zargar *et al.,* 2020). All polyphenols are absorbed with equal efficacy and they are often transformed before absorption. Many polyphenols are extensively metabolized by intestinal and hepatic enzymes as well as by intestinal microflora. This transformation modulates their biological activity. Some polyphenol metabolites produced by gut microbiota are even more biologically active than their precursors. The gut microbiota plays a unique role in liberating fiber-bound polyphenols from fruit and vegetable fiber sources and transforming dietary polyphenols into biologically active species that can act locally within the colon or systemically when absorbed. Many colonic metabolites of plant polyphenols have been found in urine confirming that some colonic absorption occurs in animals (Hollman and Katan, 1997).

Moreover ***s***ome postbiotics are also obtained from protein putrefaction**.** A large variety of protein substrates such as dietary proteins that escape small intestinal digestion, sloughed epithelial cells, hydrolytic enzymes secreted by pancreas or mucin glycoproteins are available for microbial action in colon. Anaerobic degradation of undigested protein in colon is referred to as putrefaction. Bacterial proteases and peptidases break the protein to peptides and amino acids, which in turn causes release of ammonia (NH_3) through deamination. Other metabolites of proteolysis include branched chain fatty acids (BCFA) from fermentation of branched amino acids, phenolic and indolic compounds from aromatic amino acids and hydrogen sulfide (H_2S) from sulfur containing amino acids*.* Finally, decarboxylation of amino acids results in appearance of amines in gut. In human beings, it is accepted that carbohydrate fermentation results in beneficial effects for the host because of generation of short chain fatty acids, whereas excessive protein fermentation is considered detrimental for host's health. The recent research findings reveal that similar trends may be applied to canines and felines. The excessive protein putrefaction has been reported to cause undesirable effects in animal model studies (Windey *et al.,* 2012). However to prevent such action, dietary fiber can be supplemented in ration and probable mechanism of action by which carbohydrates inhibit putrefaction is that active carbohydrate fermentation stimulates the bacterial requirement for nitrogen to support increased growth of bacterial biomass, there by lowering nitrogen availability for putrefaction. The positive effects of carbohydrate fermentation are also attributable to the fact that SCFA lower the colon pH, which inhibits bacterial proteases and peptidases which are more active at neutral to alkaline pH. Thus, promoting the production of SCFA from carbohydrates and maintenance of an acidic colonic pH will help to lower putrefaction (Jackson and Jewell 2018, Windey *et al.,* 2012).

Types of Postbiotics

The postbiotics include short chain fatty acids, short chain bile acids, cell free supernatants and others (vitamins, amino acids etc.).

Short-chain fatty acids (SFCAs): The short chain fatty acids are produced by fermentation of non-digestible dietary carbohydrate by gut bacteria and the most abundant SCFAs are acetate, propionate and butyrate (Koh *et al.,* 2016, Reynes *et al.,* 2018, Zolkiewicz *et al.,* 2020, Brial *et al.,* 2018). Provision of carbohydrates to the gut microbiota results in a saccharolytic type of fermentation. The amount of dietary carbohydrate that reaches the colon is affected by many factors such as meal size, food processing techniques (cooking, extrusion), food form (*e.g.* whole grain versus refined starch) and rate of enzymatic digestion by the host and gut transit. In colon, the bacterial breakdown of carbohydrates such as resistant starch, oligosaccharides or fiber which are not digested in small intestine takes place. The major postbiotics generated by microbes in intestine of canine and feline are acetate, propionate, and butyrate. These short chain fatty acids so produced have important physiological functions such as they provide a powerful driving force for movement of sodium and water out of the large bowel lumen, which allows prevention from diarrhea.

Secondary Bile Acids (BAs): These are produced during metabolism of bile acids synthesized by host (Reynes *et al.,* 2018).

Cell-free Supernatants

This is the medium used to culture bacteria and yeast which contains the metabolic products secreted by them. (Klemashevich *et al.,* 2020).

Others

This include vitamins, aromatic amino acids, exopolysaccharides (biopolymers released from bacterial cell walls), cell wall fragments such as bacterial lipotheichoic acid, enzymes such as glutathione peroxidase, peroxide dismutase, catalase and NADH-oxidase, bacterial lysates obtained by chemical or mechanical degradation of environmental bacteria, vanillic acid produced by metabolisation of anthocyanins (Klemashevich *et al.,* 2020) and 10-oxo-12 (*Z*)-octadecenoic acid (KetoA) produced by metabolisation of linoleic acid by lactic acid bacteria (Reynes *et al.,* 2018).

Role of Postbiotics in Animal Health and Performance

Postbiotics mainly consist of antimicrobial metabolites such as organic acids and bacteriocins that are capable of reducing the gut pH and in turn, inhibiting the proliferation of opportunistic pathogens in feed and gut of animals (Humam *et al.,* 2019). The postbiotics that are most commonly adopted as antibiotic alternatives in monogastric animals are represented by metabolites from *Lactobacillus* and in minority of cases, *Pediococcus*, *Enterococcus, Leuconostoc*, *Rhodotorula* and *Cetobacterium (*with the latter three being exclusively used in fish).

Poultry

The administration of postbiotics obtained from *L. plantarum* has been reported to exert beneficial effects on the gut environment and immune system of healthy laying hens (Loh *et al.,* 2014) and broilers (Kareem *et al.,* 2017) in terms of reduced pH (Loh, *et al.,* 2014), increased abundance of lactic acid bacteria (Loh *et al.,* 2014, Kareem *et al.,* 2016). Further provision of *Bifidobacteria*, decreased abundance of *Enterobacteriaceae* (Loh *et al.,* 2014, Kareem *et al.,* 2016) and *E. coli* (Kareem *et al.,* 2017), increased production of propionic (Humam *et al.,* 2019) and acetic acids (Loh *et al.,* 2014, Kareem *et al.,* 2016) and down regulation of pro-inflammatory cytokines (Kareem *et al.,* 2017). Improvement in intestinal morphology and microbiota as well as the immune system in broilers under heat stress has also been reported (Humam *et al.,* 2019). The administration of postbiotics in broiler chickens obtained from *Pediococcus acidilactici, L. reuteri, Enterococcus faecium* and *L. acidophilus* has been reported to improve the lesion scores, *C. perfringens* counts and mortality rates as well as stimulation of the innate immune response and to reduce the pro-inflammatory responses in favour of a homeostatic like response in a broiler C. *perfringens* challenge model (Johnson *et al.,* 2019).

Evaluation of postbiotic as feed additive has been examined in quails field in Qushtapa for six weeks. Two hundred and forty one week old quails were distributed into four treatment groups, basal diet (control groups), T_1 = basal diet + 0.2% postbiotic, T_2 = basal diet + 0.4% postbiotic, T_3 = basal diet + 0.6% postbiotic and feeding trial lasted for five weeks. It was concluded that postbiotic as a new feed additive is a potential replacement for antibiotic growth promoters in quails feed (Kareem, 2020). Cakir *et al.* (2008) revealed that there were no differences for BW and BWG by supplementation of probiotics in comparison with control birds. Improved performances were observed in birds nourished with diet supplemented with postbiotic which may be due to the organic acids, bacteriocins, and vitamins present in metabolites (Loh *et al.,* 2006).

Postbiotics maintain the gut health, improve intestinal mucosal barriers integrity and enhance the inflammatory mediator secretion. Dietary addition of postbiotics to broiler rations improved the intestinal villi, increased production of lactic acid bacteria and reduced *Enterobacteriaceae* and fecal pH, resulting in increased growth performance and enhanced immune response and gut health (Thanh *et al.,* 2009, Loh *et al.,* 2010; Rosyidah *et al.,* 2011; Kareem *et al.,* 2017; Rowland *et al.,* 2018). Similarly, in layers, these metabolites contributed towards improvement of egg quality and reduction in plasma and yolk cholesterol (Loh *et al.,* 2014). Kareem *et al. (*2016) demonstrated that addition of combination of postbiotics and prebiotic containing inulin in the ration of broiler chickens improved the total body weight and feed efficiency and maintained the intestinal mucosal structure, growth factor 1 and growth hormone receptor mRNA expressions. Feeding of broiler chickens with postbiotics produced by *L. plantarum* indicated improvement of growth performance, intestinal morphology and maintained gut microbiota, even under heat stress conditions (Humam *et al.,* 2019) indicating antioxidative activity of postbiotic.

Swine

Little information is available on the use of postbiotics in swines. The administration of postbiotics obtained from *L. plantarum* has been reported to improve the gut health of postweaning piglets in terms of reduced incidence of diarrhoea, increased abundance of lactic acid bacteria, decreased abundance of *Enterobacteriaceae*, increased production of SCFAs, reduced pH and enhanced villus morphology (Thu *et al.,* 2011). It is proven that *S. cerevisiae* fermentation metabolites reduced the colonization of both *S. typhimurium and Campylobacter coli* in pigs (Price *et al.,* 2010; Hofacre *et al.,* 2015; Feye *et al.,* 2016; Rubinelli *et al.,* 2016). In piglets, liquid metabolite combinations produced by *L. plantarum* helped in improving the growth performance parameters, including birth weight, overall weight gain and average weight gain per day, as well as reduction in diarrhea production (Loh *et al.,* 2013).

Fish

Only few studies have been conducted with regard to evaluation of effect of postbiotics in fishes. In fish, utilization of postbiotics derived from *Lactobacillus* has been evaluated (Pérez-Sanchez *et al.,* 2020; Mora-Sanchez *et al.,* 2020), *Leuconostoc* (Perez-Sanchez *et al.,* 2020) with positive effects on gut health. Wu *et al.* (2020) observed a positive modulation of the gut microbiota in a hybrid sturgeon fed postbiotic-based diets. The administration of postbiotics has also been reported to improve the intestinal microbiota along with increased protection against *Lactococcus garvieae* infection in rainbow trout (Perez-Sanchez *et al.,* 2020; Mora-Sanchez *et al.,* 2020).

Ruminants

No systematic study is available with regard to the use of postbiotics in adult ruminants. It has been reported (Wan Ibrahim, Izuddin *et al.,* 2019) that the inclusion of 0.9% postbiotics from *L. plantarum* RG14 improved growth performance, nutrient intake and nutrient digestibility in diet of post-weaning lambs (Wan Ibrahim, Izuddin *et al.,* 2019). The improvement of growth and feed utilization in lambs fed with postbiotics were reflected by rumen fermentation characteristics, ruminal cellulolytic bacteria population and blood metabolites. The higher expression of hepatic IGF-1 and ruminal MCT-1 mRNA resulted in higher production of IGF-1 in liver and greater uptake of VFA through the ruminal epithelium respectively.

In future, postbiotics may emerge as the potential feed additive to be used to promote rumen fermentation and growth of post-weaning ruminant animals.

Pets

The large bowel of pets contain a range of different bacteria species which have enzymes to digest and utilize various substrates. These include saccharolytic species that break down and ferment carbohydrates, proteolytic bacteria that degrade proteins, peptides and amino acids, methanogens, and other bacteria that grow on intermediate products of fermentation, such as hydrogen, lactate, succinate and ethanol (Wernimont *et al.,* 2020).

When it comes to utilization of substrates, some anaerobes are specialists focusing on a single substrate for fermentation while others are generalists, capable of fermenting a variety of substrates. For example, acetate is produced by many bacteria, but propionate and butyrate tend to be produced by specific bacteria. In future, postbiotics may find a great usage as strong non-antibiotic growth promoters in ration of pets.

Conclusion

In view of the occurrence of drug resistance, much stress is being laid to find new alternatives to antibiotics for safe use in animals for better health and enhanced efficiency of utilization of feed nutrients. In continuation to the usage of probiotics and prebiotics, recently research is being carried out on use of postbiotics in animals for better health and performance. Postbiotics include any substance released by or produced through the metabolic activity of microorganism, which exerts a beneficial effect on the host. The research in this area is still in infancy and few studies have been conducted with regard to use of probiotics for improving the health, immune status and performance of host animals.

References

Aguilar-Toala, J., Garcia-Varela, R., Garcia, H., Mata-Haro, V., Gonzalez-Córdova, A., Vallejo-Cordoba, B. and Hernandez-Mendoza, A. **(2018)**. Postbiotics - An evolving term within the functional foods field. *Trends Food Sci. Technol.* **75**: 105-14.

Barros, C.P., Guimarães, J.T., Esmerino, E.A., Duarte, M.C.KH., Silva, M.C., Silva, R., Ferreira, B.M., Sant'Ana, A.S., Freitas, M.Q. and Cruz, A.G. **(2020)**. Paraprobiotics and postbiotics: concepts and potential applications in dairy products. *Current Opin. Food Sci.* **32**: 1-8.

Brial, F., Le Lay, A., Dumas, M. E. and Gauguier, D. **(2018)**. Implication of gut microbiota metabolites in cardiovascular and metabolic diseases. *Cellular and Molecular Life Sciences* (*CMLS)* **75**: 3977-90.

Cakir, S., Midilli, M., Erol, H., Simsek, N., Cinar, M., Altintas, A. and Antalyali, A. **(2008)**. Use of combined probiotic-prebiotic, organic acid and avilamycin in diets of Japanese quails. *Rev. Med. Vet.* **11**: 565-69.

Choe, D.W., Foo, H.L., Loh, T.C., Hair-Bejo, M. and Awis, Q.S. **(2013)**. Inhibitory property of metabolite combinations produced from *Lactobacillus plantarum* Strains. *J Trop. Agric. Sci.* **36**: 79-88.

Choi, S.S., Kim, Y., Han, K.S., You, S. and Oh, S. and Kim S.H. **(2006)**. Effects of *Lactobacillus* strainson cancer cell proliferation and oxidative stress *in vitro*. *Lett. Appl. Microbiol.* **42**: 452-58.

Cicenia, A., Santangelo, F., Gambardella, L., Pallotta, L., Iebba, V., Scirocco, A., Marignani, M.,Tellan, G., Carabott,i M., Corazziari, E.S., Schippa, S. and Severi, C. **(2014)**. Protective role of postbiotic mediators secreted by *Lactobacillus Rhamnosus* GG versus lipopolysaccharide-induced damage in human colonic smooth muscle cells. *J. Clin. Gastroent.* **50**: 140-44.

Cicenia, A., Scirocco, A., Carabotti, M., Pallotta, L., Marignani, M. and Severi, C. **(2016)**. Postbiotic activities of *Lactobacilli* derived factors. *J. Clin. Gastroent.* **48**: 18.

Daing, M.I., Pathak, A.K., Sharma, R.K. and Zargar, M.A. **(2020)**. Effect of feeding graded levels of guava leaf meal on performance and economics of broiler chicks. *Indian J. Anim. Nutrit.* **37**: 143-51.

Feye K.M., Anderson, K.L., Scott, M.F., Mcintyre, D.R. and Carlson, S.A. **(2016)**. Inhibition of the virulence, antibiotic resistance and fecal shedding of multiple antibiotic-resistant *Salmonella Typhimurium*in broilers fed original XPCTM. *Poult. Sci.* **95**: 2902-10.

Jan, O.Q., Kamili, N., Ashraf, A., Iqbal, A., Sharma, R.K. and Rastogi, A. **(2013)**. Hematobiochemical parameters of goats fed tannin rich *Psidium guajava* and *Carissa spinarum* against *Hemonchus contortus* infection in India. *J. Paras. Dis. DOI*:10.1007/s12639-013-0278-5.

Hofacre, C.L., Mathis, G.F., Mcintyre, D.R. and Broomhead, J.P. **(2015)**. Effects of original XPC on cecal colonization by *Campylobacter coli* in broiler chickens - *Preliminary Report.* p. 1-8. PO225.

Humam, A.M., Loh, T.C., Foo, H.L., Samsudin, A.A., Mustapha, N.M., Zulkifli, I. and Izuddin, W.I. **(2019)**. Effects of Feeding Different Postbiotics Produced by *Lactobacillus plantarum* on Growth Performance, Carcass Yield, Intestinal Morphology, Gut Microbiota Composition, Immune Status and Growth Gene Expression in Broilers under Heat Stress. *Animals* **9**: 644.

Hollman, P.C.H. and Katan, M.B. **(1997)**. Absorption, metabolism and health effects of dietary flavonoids in man. *Biomed. Pharmacotherapy* **51**: 305-10.

Izuddin, W.I., Loh, T.C., Foo, H.L., Samsudin, A.A. and Humam, A.M. **(2019)**. Postbiotic *Lactobacillus plantarum* RG14 improves ruminal epithelium growth, immune status and upregulates the intestinal barrier function in post-weaning lambs. *Sci. Rep.* **19**: 9938.

Jackson M.I. and Jewell, D.E. **(2018)**. Balance of saccharolysis and proteolysis underpins improvements in stool quality induced by adding a fiber bundle containing bound polyphenols to either hydrolyzed meat or grain-rich foods. *Gut Microbes.* **8**: 1-23.

Jahromi, M.F., Altaher, Y.W., Shokryazdan, P., Ebrahimi, R., Ebrahimi, M., Idrus, Z., Tufarelli, V. and Liang, J.B. **(2016)**. Dietary supplementation of a mixture of *Lactobacillus* strains enhances performance of broiler chickens raised under heat stress conditions. *Int. J. Biometeorol.* **60**: 1099-10.

Jensen, G.S., Benson, K.F., Carter, S.G., Endres, J.R. and Ganden, B.C. **(2010)**. Cell wall and metabolites: anti-inflammatory and immune modulating effects *in vitro*. *BMC Immunol.* **1**: 1-15.

Jensen, G.S., Hart, A.N. and Schauss, A.G. **(2007)**. An anti-inflammatory immunogen from yeast culture induces activation and alters chemokine receptor expression on human natural killer cells and B lymphocytes *in vitro*. *Nutr. Res.* **27**: 327-35.

Johnson, C.N., Kogut, M.H., Genovese, K., He, H., Kazemi, S. and Arsenault, R.J. **(2019)**. Administration of a Postbiotic Causes Immunomodulatory Responses in Broiler Gut and Reduces Disease Pathogenesis Following Challenge. *Microorganisms* **7**: 268.

Kareem, K.Y., Loh, T.C., Foo, H.L., Akit, H. and Samsudin, A.A. **(2016)**. Effects of dietary postbiotic and inulin on growth performance, IGF1 and GHR mRNA expression, fecal microbiota and volatile fatty acids in broilers. *BMC Vet. Res.* **12**: 163.

Kareem, K.Y., Loh, T.C., Foo, H.L., Asmara, S.A. and Akit, H. **(2017)**. Influence of postbiotic RG14 and inulin combination on cecal microbiota, organic acid concentration and cytokine expression in broiler chickens. *Poult. Sci.* **96**: 966-75.

Kim, H.G., Lee, S.Y., Kim, N.R., Lee, H.Y., Ko, M.Y., Jung, B.J., Kim, C.M., Lee, J.M., Park, J.H., Han, S.H. and Chung, D.K. **(2011)**. *Lactobacillus plantarum* lipoteichoic acid down-regulated *Shigella Flexneri* peptidoglycan induced inflammation. *Mol. Immunol.* **48**: 382-91.

Koh, A., De Vadder, F., Kovatcheva-Datchary, P. and Backhed, F. **(2016)**. From Dietary Fiber to Host Physiology-Short-Chain Fatty Acids as Key Bacterial Metabolites. *Cell* **165**: 1332-45.

Klemashevich, C., Wu, C., Howsmon, D., Alaniz, R.C., Lee, K. and Jayaraman, A. **(2014)**. Rational identification of diet-derived postbiotics for improving intestinal microbiota function. *Curr. Opin. Biotech.* **26**: 85-90.

Klemashevich, J., Marzecm A., Ruszczynski, M. and Feleszko, W. **(2020)**. Postbiotics - A Step Beyond Pre- and Probiotics. *Nutrients* **12** (8).

Loh, T.C., Choe, D.W., Foo, H.L., Sazili, A.Q. and Bejo, M.H. **(2014)**. Effects of feeding different postbiotic metabolite combinations produced by *Lactobacillus plantarum* strains on egg quality and production performance, faecal parameters and plasma cholesterol in laying hens. *BMC Vet. Res.* **10**: 149.

Loh, T.C., Law, F.L., Foo, H.L., Goh, Y.M. and Zulkifli, I. **(2009)**. Effects of feeding fermented fish on egg cholesterol content in hens. *Anim. Sci. J.* **80**: 27-33.

Loh, T.C., Thanh, N.T., Foo, H.L., Bejo, M.H. and Kasim, A. **(2010)**. Feeding of different levels of metabolite combinations produced by Lactobacillus plantarum on growth performance, faecal lactic acid bacteria and Enterobacteriaceae count, volatile fatty acids and villi height in broilers. *Anim. Sci. J.* **81**: 205-14.

Loh, T.C., Thu, T.V., Foo, H.L. and Bejo, M.H. **(2013)**. Effects of different levels of metabolite combination produced by *Lactobacillus plantarum* on growth performance, diarrhoea, gut environment and digestibility of post-weaning piglets. *J. Appl. Anim. Res.* **41**: 200-07.

Matsuguchi, T., Takagi, A., Matsuzaki, T., Nagaoka, M., Ishikawa, K., Yokokura, T. and Yasunobu, Y. **(2003)**. Lipoteichoic acids from *Lactobacillus* strains elicit strong tumor necrosis factor Alpha-inducing activities in macrophages through toll-like receptor 2. *Clin. Diagn. Lab. Immunol.* **10**: 259-66.

Mora-Sanchez, B., Balcazar, J.L. and Perez-Sanchez, T. **(2020)**. Effect of a novel postbiotic containing lactic acid bacteria on the intestinal microbiota and disease resistance of rainbow trout (*Oncorhynchus mykiss*). *Biotechnol. Lett.* **42**: 1957-62.

Perez-Sanchez, T., Mora-Sanchez, B., Vargas, A. and Balcazar, J.L. **(2020)**. Changes in intestinal microbiota and disease resistance following dietary postbiotic supplementation in rainbow trout (*Oncorhynchus mykiss*). *Microb. Pathog.* **142**: 1040-60.

Price, K.L., Totty, H.R., Lee, H.B., Utt, M.D., Fitzner, G.E., Yoon, I., Ponder, M.A. and Escobar, J. **(2010)**. Use of *Saccharomyces cerevisiae* fermentation product on growth performance and microbiota of weaned pigs during *Salmonella* infection. *J. Anim. Sci.* **88**: 3896-3908.

Reynes, B., Palou, M., Rodriguez, A.M. and Palou, A. **(2018)**. Regulation of Adaptive thermogenesis and Browning by Prebiotics and Postbiotics. *Frontiers in Physiol.* **9**: 1908.

Rosyidah, M., Loh, T., Foo, H., Cheng, X. and Bejo, M. **(2011)**. Effect of feeding metabolites and acidifier on growth performance, faecal characteristics and microflora in broiler chickens. *J. Anim. Vet. Adv.* **10**: 2758-64.

Rubinelli, P., Roto, S., Kim, S.A., Park, S.H., Pavlidis, H.O., Mcintyre, D. and Ricke, S.C. **(2016)**. Reduction of *Salmonella Typhimurium* by fermentation metabolites of Diamond V Original XPC in an *in vitro* anaerobic mixed chicken cecal culture. *Front. Vet. Sci.* **3**: 1-7.

Rowland, I., Gibson, G. and Heinken, A. **(2018)**. Gut microbiota functions: metabolism of nutrients and other food components. *Eur. J. Nutr.* **57**:1-24.

Singh, S., Pathak, A.K., Khan, Muzaffar and Sharma, R.K. **(2015)**. Effect of tanniferous leaf meal mixture based multi nutrient blocks on nutrient utilization and biochemical profile of *Haemonchus contortus* infected goats. *Indian J. Anim. Res.* DOI:10.18805/ijar.5716.

Sokol, H., Pigneur, B., Watterlot, L., Lakehdari, O., Bermudez-Humaran, L.G., Gratadoux, J.J. and Langella, P. **(2008)**. *Faecalibacterium prausnitzil* is an anti-inflammatory commensal bacterium identified by gut microbiota analysis of Crohn disease patients. *Proc. Natl. Acad. Sci. U.S.A.* **105**:16731-736.

Tejada-Simon, M.V. and Pestka, J.J. **(1999)**. Pro-inflammatory cytokine and nitric oxide induction in murine macrophages by cell wall and cytoplasmic extracts of lactic acid bacteria. *J. Food Prot.* **62**:1435-44.

Thu, T.V., Loh, T.C., Foo, H.L., Yaakub, H. and Bejo, M.H. **(2011)**. Effects of liquid metabolite combinations produced by Lactobacillus plantarum on growth performance, faeces haracteristics, testinal morphology and diarrhoea incidence in postweaning piglets. *Trop. Anim. Health Prod.* **43**: 69-75.

Tiptiri-Kourpeti, A., Spyridopoulou, K., Santarmaki, V., Aindelis, G., Tompoulidou, E., Lamprianidou, E.E., Saxami, G., Ypsilantis, P., Lampri, E.S., Simopoulos, C., Kotsianidis, I., Galanis, A., Kourkoutas, Y., Dimitrellou, D. and Chlichlia, K. **(2016)**. *Lactobacillus casei* exerts anti-proliferative effects accompanied by apoptotic cell death and up-regulation of trail in colon carcinoma cells. *PLoS One.* **11:** 0147960.

Tsilingiri, K. and Rescigno, M. **(2013)**. Postbiotics: What else. *Benef. Microbes* **4**: 101-07.

Tang, W.H., Wang, Z. and Levison, B.S. **(2013)**. Intestinal microbial metabolism of phosphatidylcholine and cardiovascular risk. *N. Engl. J. Med.* **368**: 1575-84.

Thanh, N.T., Loh, T.C., Foo, H.L., Bejo, M.H. and Azhar, K. **(2010)**. Inhibitory activity of metabolites produced by strains of *Lactobacillus plantarum* isolated form Malaysian fermented food. *International J. Probiot. Prebiot.* **5**: 37-44.

Thu, T.V., Loh, T.C., Foo, H.L., Halimantun, Y. and Bejo, M.H. **(2011)**. Effects of liquid metabolites combinations by *Lactobacillus plantarum* on growth performance, faeces characteristics, intestinal morphology and diarrhea incidence in post weaning piglets. *Trop. Anim. Health Prod.* **43**: 69-75.

Tsilingiri, K., Barbosa, T., Penna, G., Caprioli, F., Sonzogni, A., Viale, G. and Rescigno, M. **(2012)**. Probiotic and postbiotic activity in health and disease: comparison on a novel polarised ex-vivo organ culture model. *Gut.* **61**: 1007-15.

Vidal, K., Donnet-Hughes, A. and Granato, D. **(2002)**. Lipoteichoic acids from *Lactobacillus johnsonii* strainLa1 and *Lactobacillus acidophilus* strain La10 antagonize the responsiveness of human intestinal epithelial HT29 cells to lipopolysaccharide and Gram-negative bacteria. *Infect. Immun.* **70**: 2057-64.

Wan Ibrahim, Izuddin., Loh, Teck Chwen, Asmara Samsudin, Anjas., Ling Foo, H., Ali, M.H. and Nurhazirah, Shazali **(2019)**. *BMC Vet. Res.* **15**: 315.

Wernimont, S.M., Radosevich, J., Jackson, M.I., Ephraim, E., Badri, D.V., MacLeay, J.M. and Sucholdoski, J.S. **(2020)**. The effects of nutrition on the gastrointestinal microbiome of cats and dogs - Impact on health and disease. *Front. Microbiol.* **11**: 1266.

Windey, K., De Preter, V. and Verbeke, K. **(2012)**. Relevance of protein fermentation to gut health. *Mol. Nutr. Food Res.* **56**:184-96.

Wu, X., Teame, T., Hao, Q., Ding, Q., Liu, H., Ran, C.. Yang, Y., Zhang, Y., Zhou, Z. and Duan, M. **(2020)**. Use of a paraprobiotic and postbiotic feed supplement (HWF) improves the growth performance, composition and function of gut microbiota in hybrid sturgeon (Acipenser baerii x Acipenser schrenckii). *Fish Shellfish Immunol.* **104**: 36-45.

Zargar, Mohd. Aqib, Pathak, A.K., Sharma, R.K. and Daing, Mohd. Iqbal **(2020)**. Antioxidants and Anticoccidial potential of aqueous extract from various tree leaves containing condensed tannins. *J. Anim. Res.* **6**: 563-70**.**

Zargar, Mohd. Aqib, Pathak, A.K., Rahman, S., Sharma, R.K. and Daing, Mohd. Iqbal **(2020)**. Effect of Eugenia jambolana and Psidium guajava leaf meal mixture supplementation on performance, biochemical profile and histopathological changes of broiler chicks. *J. Anim. Res.* **10***:* 221-30**.**

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