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The Potential of Tropical Agro-Industrial by-Products as a Functional Feed for Poultry

Review Article

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ABSTRACT

Following the ban of synthetic antibiotics as antimicrobial agents and growth promoters, poultry nutritionists are now trying to find antibiotic substitutes. Agro-industrial by-products are abundant in tropical countries and have been used as the alternatives to conventional feedstuffs in poultry rations. These by-products are also known to contain several bioactive compounds such as oligosaccharides, phenolic compounds, certain fatty acids, vitamins, etc. The compounds may serve as antimicrobial agents, antioxidants and immune-modulators for poultry. Owing to this, agro-industrial by-products have a potential to become functional feeds that can promote the health and well-being of poultry. The potentials of some tropical agro-industrial by-products (e.g., palm kernel meal, rice bran, cassava meal, copra meal, banana peel meal, orange peels and pulp) and their derivative products as functional feeds for poultry are elaborated in the present review, and the possible mechanisms through which agro-industrial by-products may improve the health status of poultry will also be discussed. Future studies are needed to confirm the efficacy of agro-industrial residues and their derivative products in substituting the use of synthetic antibiotics in poultry rations.

KEY WORDS agro-industrial residues, functional feed, health, poultry, tropical countries.

INTRODUCTION

Tropical countries are rich in plant resources that may be processed for food or other products. This processing activities (agro-industries) produce a large quantities of by-products that can ultimately lead to environmental problems. In response to the increased price of conventional feedstuffs (e.g., maize and soybean), there has been a rising interest to reutilize by-products from the agro-industries as feed ingredients in poultry rations. This may not only deal with environmental issues, but also reduce the cost of feed in poultry production (Kasapidou *et al.* 2015). Recently, there has been a global concern about antibiotic resistance both in poultry and human as consumers, leading to the ban

of sub-therapeutic use of synthetic antibiotics as antimicrobial agents and growth promoters in poultry production (Sugiharto, 2016). It has been known that agro-industrial by-products are rich in bioactive components (e.g., oligosaccharides, phenolic compounds, certain fatty acids, vitamins, etc.) with beneficial effects on the health and well-being of poultry. These compounds may act as antimicrobials, antioxidants and immune-modulators (Esa *et al.* 2013; Abbasi *et al.* 2015; Ebrahimi *et al.* 2015; Kang and Kim, 2016), which are antibiotic properties. For the sustainable global poultry production, therefore, agro-industrial by-products need to be used not only as the alternatives to conventional feedstuffs, but also as safe antibiotic substitutes for poultry.

Several tropical agro-industrial residues have been researched as functional feed ingredients for poultry, including palm kernel meal, rice bran, cassava meal, copra meal, banana peel meal, orange peels and pulp, etc. The detailed properties and nutraceutical effects of each by-product on poultry are elaborated in the present review. To suggest the potential of selected tropical agro-industrial by-products as functional feeds, some parameters on poultry have been taken into consideration when preparing this review, including immune competences, intestinal health (e.g., intestinal morphology and bacterial populations), physiological responses and production parameters.

To prepare the review, literature search with focus on the functional properties of tropical agro-industrial by-products has been conducted. During the search, peer-reviewed journal articles in English were included, while conference proceedings and Ph D. dissertation were selectively included. Studies on humans, pigs and rodents were selectively cited to support the existing data on poultry. A number of scientific portals have been used for literature search, including Elsevier Science-Direct, EBSCO E-Journal, Proquest Research Library, Cambridge University Press E-Journal, Springerlink E-Journal and Google Scholar.

Definition of functional feed

Functional feed ingredients have recently attracted much attention as additives, following the withdrawal of sub therapeutic antibiotics from poultry feeds. Currently, there is no exact definition for the functional feed in poultry nutrition. On the basis of human nutrition, however, functional feed can be regarded as the whole feed, fortified, enriched or enhanced feed that have potentially health effects in addition to the basic nutrition (Hasler, 2002; Martirosyan and Singh, 2015). Hence, functional feed has to be able to promote the health and growth of poultry. Compared to conventional feed, functional feed have a similar appearance, but functional feed provides components with health- and growth-promoting effects (Cencic and Chingwaru, 2010). In addition to carbohydrates, proteins, fats, vitamins and minerals, functional feed may contain some biologically-active components including flavonoids, capsaicinoids, lignin, terpenoids, carotenoids, chlorophylls, stilbene, phenolic acids, fibres, sterols, polysaccharides, etc. needed for healthy growth of animals (Martirosyan and Singh, 2015). These bioactive components may occur in either the natural or the processed feeds (Syngai *et al.* 2016). Palm kernel meal is one of the example of natural feeds that is rich in β -mannan, capable of improving the growth performance and health of chickens (Zulkifli *et al.* 2003; Sundu *et al.* 2006). With regard to the processed feed, rice bran oil (extracted

from rice bran, rich in essential fatty acids and unsaturated fatty acid) has been used as a functional feed ingredient to improve growth performance, total cholesterol in serum and the immune defense system of broiler chicks (Kang and Kim, 2016).

The term of functional feed is often confusing with nutraceuticals, as both terms are usually used to describe health-promoting feed or its extracted components. Although the exact meaning of these terms has not been found, El Sohaimy (2012) inferred that nutraceuticals is healthful products that are isolated or purified from feeds, and formulated and taken in dosage form (capsules, tinctures or tablets). On the other hand, functional feeds are products that are provided and consumed as conventional feeds, not in dosage form.

Tropical agro-industrial waste as poultry feed ingredients

Agro-industrial waste refers to the by-product derived from the processing of agricultural products (Sindhu *et al.* 2002). Molasses, milk whey, wheat bran, cottonseed meal, cottonseed cake, groundnut cake, palm kernel meal, palm kernel cake, copra meal, banana peel meal, soybean hull, brewers grains (dried and bran), rice bran, rice husk, rice chaff, cassava pulp, cassava peeling, orange peels and pulp, maize bran, etc. are among the examples of agro-industrial by-products in general. Of the aforementioned agro-industrial by-products, molasses, palm kernel meal, copra meal, banana peel meal, rice bran, cassava pulp, orange peels and pulp are probably the most prominent examples of agro-industrial by-products in the tropical countries including Indonesia. Due to its abundant availability and low cost, nutritionists have now been encouraged to incorporate agro-industrial by-products in poultry nutrition, especially as an alternative to conventional feedstuffs (Abbasi *et al.* 2015; Kasapidou *et al.* 2015). Palm kernel meal (Zulkifli *et al.* 2003; Sundu *et al.* 2006), cassava pulp (Khempaka *et al.* 2009; Sugiharto *et al.* 2016) and fruit processing co-products such as orange peels and pulp (Abbasi *et al.* 2015; Kasapidou *et al.* 2015) are among the examples of agro-industrial waste being used as feed ingredients in poultry diets. However, there is a limitation in the use of agro-industrial waste as feed ingredients in poultry diets. For example, Khempaka *et al.* (2009) reported that cassava pulp may only be used as an energy source in poultry diet at maximum 8%. The inclusion level above 8% negatively impact the growth performance of broiler chicks. A high concentration of rice bran (above 20%) was also associated with a retarded growth rate in broiler chicks (Gallinger *et al.* 2004). In general, the high and low fibre and protein contents, respectively, as well as the presence of anti-nutritional factors and toxins, may limit the use of agro-

industrial by-products as poultry diets (Sindhu *et al.* 2002; Gallinger *et al.* 2004; Khempaka *et al.* 2009).

Of the methods available to improve the nutritional qualities, fermentation is a simple technique that can be exploited especially to lower fibre and increase protein contents of the agro-industrial waste, so that can be included in poultry diets at higher levels (Khempaka *et al.* 2014; Sugiharto *et al.* 2015; Sugiharto *et al.* 2016). For instance, fermentation can be a tool to produce functional feed ingredients for poultry. Recent studies revealed that fermentation of cassava pulp with the fungus *Acremonium charticola* decreased fibre (Sugiharto *et al.* 2015; Sugiharto *et al.* 2016) while the addition of urea as a nitrogen source increased protein content (Sugiharto *et al.* 2016) of cassava pulp. Consequently, the cassava pulp could be incorporated in broiler diets up to 24% without adversely affecting the nutritional and metabolic status of birds (Sugiharto *et al.* 2016). Apart from the nutritional improving effects, fermentation may produce health-beneficial properties for poultry. Indeed fermentation increased the content of lactic acid bacteria (LAB) (Sugiharto *et al.* 2015) and the antioxidant and antimicrobial properties in the pulp (Wen *et al.* 2013).

Tropical agro-industrial by-product as functional feed ingredients for poultry

In response to the global concern about antibiotic resistance both in human and farm animals, the use of functional feeds as the substitute for synthetic antibiotics in poultry diets has been encouraged. Apart from its use as the substitute for conventional feed ingredients, agro-industrial by-products have been reported to benefit the health of poultry, and therefore can serve as functional feed ingredients. For instance, Zulkifli *et al.* (2003) and Sundu *et al.* (2006) reported that palm kernel meal was able to improve the immune system, intestinal microbial ecosystem and thus chicken health. The beneficial impacts of either the cassava pulp on intestinal health (Khempaka *et al.* 2009) or the dried sweet orange (*Citrus sinensis*) pulp on humoral immunity and caecum microbial population (Abbasi *et al.* 2015) have also been reported. The detailed discussion about the use of each agro-industrial waste as functional feed ingredients will be elaborated in the following section.

2 Palm kernel meal

Palm kernel meal, also called palm kernel cake or palm kernel expeller, is an agro-industrial waste derived from the palm oil industry. This agro-industrial by-product has been used as feed ingredients to reduce the proportion of maize in poultry rations (Sundu *et al.* 2006; Alshelmani *et al.* 2016). Note that palm kernel meal contains 16.58% crude protein and 20.4 MJ/kg gross energy (Zulkifli *et al.* 2003).

Due to its high content of β -mannan (a good source of prebiotics), feeding palm kernel meal has also been expected to improve the health of chickens (Sundu *et al.* 2006). Zulkifli *et al.* (2003) reported that feeding palm kernel meal reduced mortality rate and maintained the antibody titre for Newcastle disease (ND) in broiler chicks during a week period of heat stress. Concomitant with this, Soltan (2009) showed that feeding palm kernel cake increased antibody titre to ND vaccine and relative weights of immune organs of broilers such as spleen, bursa of fabricius and thymus. Moreover, Ugwu *et al.* (2008) reported an improvement in haematological indices (e.g., red blood cells, haemoglobin, packed cell volume and eosinophils) in broiler chicks fed palm kernel cake. With regard to gut health, Sundu *et al.* (2006) revealed that feeding palm kernel meal was able to reduce the load of pathogenic bacteria (*Salmonella* and *Escherichia coli*) and increase the population of non-pathogenic bacteria (*Bifidobacterium* sp.) in the intestine of broiler chickens. In laying hens, feeding palm kernel meal increased the population of *Lactobacilli* and decreased growth of coliform/*E. coli* (Yusrizal *et al.* 2013). In these regard, palm kernel meal may serve as functional feed ingredients for poultry. In contrast to the above studies, Shakila and Sudhakar (2012) reported that feeding palm kernel meal had no significant effect on the humoral immune system (antibody titre to ND) of laying hens, although the treatment improved hen-day egg production and feed efficiency. Moreover, Navidshad *et al.* (2015) revealed that feeding palm kernel meal had no substantial effect on the intestinal bacteria population (*Lactobacilli*, *E. coli*, *Enterococcus* genus and *Enterobacteriaceae* family) of chicks.

These divergent results might be due to the different types of chickens, nature of palm kernel meal and conditions of experiment (e.g., diets, environment, stage of production, etc.). So far, there is no exact recommendation on the proportion of palm kernel meal in poultry rations. Considering that palm kernel meal contains no anti-nutritional factors, Sundu *et al.* (2006) suggested that palm kernel meal can be included up to 40% in the poultry rations provided that the diet is balanced in amino acids and metabolisable energy. In some tropical countries, such as Indonesia and Malaysia, palm oil industries produce a huge amount of palm kernel meal throughout the entire year. Considering their abundant availability, good nutritional values and health-promoting properties, palm kernel meal may therefore be encouraged (especially for the palm oil producing countries) to be included in poultry rations to reduce feed cost and substitute the role of synthetic antibiotics.

As mentioned above, fermentation may not only improve the nutrient values (so that increase the inclusion level of palm kernel meal in poultry rations), but also increase the functionality of feed or feed ingredients. In the study of

Alshelmani *et al.* (2016), it was apparent that feeding palm kernel cake fermented by *Paenibacillus polymyxa* ATCC 842 decreased the number of *Enterobacteriaceae* and increased LAB in the intestine of broiler chickens. In respect to immune system, Chinajariyawong and Muangkeow (2011) reported that feeding *Aspergillus wentii* TISTR 3075 fermented palm kernel meal increased the relative weight of spleen of broiler chickens. However, the latter report was in contrast to Khin (2004) who reported that feeding palm kernel cake fermented with *Aspergillus niger* had an adverse effect on the weight of bursa of fabricius in broiler chicks. The different microorganisms used as a starter, the level of incorporation of fermented palm kernel meal and the study conditions might be responsible for these differences.

Apart from the provision as a whole meal, palm kernel meal may be extracted to produce mannose and mannan-oligosaccharides that can serve as prebiotics for broiler chickens (Chen *et al.* 2015). The prebiotics extracted from palm kernel meal have been reported to reduce the number of potential pathogenic bacteria (*Enterococcus*, *Enterobacter* and *E. coli*) and promote the growth of beneficial bacteria (*Lactobacillus* and *Bifidobacterium*) and thus the health of the bird (Chen *et al.* 2015). Accordingly, Rezaei *et al.* (2015) reported that feeding oligosaccharides extracted from palm kernel expeller tended to increase *Bifidobacterium* and decrease *Salmonella* colonization in the intestine of broilers. This study also showed a positive treatment effect on the immune and health status of broiler, as indicated by the increased plasma immunoglobulin (Ig) A level and decreased heterophil and basophil counts.

Rice bran

Rice bran, a by-product of rice milling industry, has commonly been used as an energy source in poultry rations (Mu *et al.* 2011). This by-product contains 12.10% crude protein and 3165 kcal/kg gross energy (Supriyati *et al.* 2015). Due to its content in prebiotics and other phytochemicals/nutraceutical compounds (e.g., α , β , γ , δ -tocopherol, tocotrienols/vitamin E and γ -oryzanol; Esa *et al.* 2013), rice bran has also been reported to improve host' health status through modulating intestinal homeostasis and mucosal immune system (Komiya *et al.* 2011; Henderson *et al.* 2012; Kumar *et al.* 2012). However, its high content in phytate, an enzyme inhibitor (trypsin inhibitor), and fibre may limit the use of this feedstuff in poultry diets (Gallinger *et al.* 2004).

To overcome these constraints, nutritionists employed fermentation. Not only improving the nutritional qualities and thus increasing the inclusion level of rice bran in the poultry rations (Supriyati *et al.* 2015), fermentation may also improve the functionality of rice bran for poultry.

Fermentation increased phenolic compounds and antioxidant activity of rice bran (Oliveira *et al.* 2008). Indeed, report regarding the use of fermented rice bran to improve the health status of poultry is scarce, but in human, rice bran fermented with *Lentinus edodes* increased interferon (IFN)- γ production, which may be beneficial to healthy individuals (Choi *et al.* 2014). Concomitantly, in animal models it has been shown an anti-stress effect of fermented rice bran on spleen, thyroid and thymus gland, beneficial for enhanced immunity (Koh *et al.* 2002).

Extraction of rice bran has been carried out to isolate the active compounds such as vitamin E and oryzanol responsible for the health of host. Inclusion of rice bran extract in poultry rations is believed to be more effective in improving poultry health than feeding rice bran as a whole stuff.

Indeed, Kang *et al.* (2015) reported that dietary supplementation with rice bran extract increased the concentration of IgG and consequently the immune responses in broiler chickens. In weanling piglets, the extracted rice bran was able to increase the populations of *Lactobacillus* and reduce *Salmonella* counts in faeces (Hossain *et al.* 2016). Different from the previous studies, Zheng *et al.* (2017) revealed that the dietary supplementation with fermented (using *Lactobacillus plantarum*, *Bacillus subtilis* and *Saccharomyces cerevisiae*) rice bran extract failed to affect on the concentrations of IgA, IgG, and tumor necrosis factor (TNF)- α in the ileal mucosa of broiler chickens, even though it was beneficial for the growth performance of birds.

The rice bran oil is another product from the rice bran extraction, which is rich in γ -oryzanol. Kang and Kim (2016) reported that dietary supplementation of rice bran oil improved both the production performance and the health status and immune response of broilers, as indicated by the increase in heterophils, lymphocytes and monocytes as well as the concentration of IgG. In laying hens, feeding rice bran oil tended to decrease heterophil to lymphocyte ratio (H/L ratio) which may indicate a better stress response in birds (Kim *et al.* 2016). Although it has widely been used in most tropical countries, no exact rule can be inferred with regard to the optimum inclusion level of rice bran in poultry rations. However, the inclusion level of 10% to 15% may not produce adverse effect on the performance of poultry especially broiler chickens (Mu *et al.* 2011; Supriyati *et al.* 2015). With regard to rice bran oil and rice bran extract, the use of both functional ingredients could be up to 20 g/kg in the poultry rations (Kang *et al.* 2015; Kang and Kim, 2016). Recently, rice bran has increasingly been used as functional foods for human consumption. The latter condition may consequently increase the demand and, thus price of rice bran. This increase in price, must therefore be considered by nutritionists when formulating poultry rations with rice bran.

Copra meal

Copra meal is a residue of the oil extraction from the endosperm of coconut. This tropical agro-industrial by-product contains 4247-5872 kcal/kg gross energy and high level of protein (15-25%) and carbohydrate (60%), and therefore the potential to be used as poultry feed ingredients. However, the low level of amino acid, particularly lysine and methionine, and its high level of fibre (major proportion of carbohydrate in copra meal) may limit its utilization in poultry diets (Sundu *et al.* 2009). To date, there is no exact recommendation upon the use of copra meal in poultry rations, however, Sundu *et al.* (2009) suggested that copra meal may be used up to 30% provided a balanced diet (in particularly amino acids and energy) is formulated. Fermentation has been conducted to improve the nutritional qualities of copra meal. Hatta and Sundu (2009) fermented copra meal with either *Aspergillus niger* or *Trichoderma* spp. and supplemented to broiler chickens fed a copra meal diet. They found that fermentation of copra meal with *Trichoderma* spp. could improve the performance of bird in a diet containing 30% copra meal. To date, report regarding the effect of raw and fermented copra meal on the health of poultry is scarce.

Attempt has been conducted to produce or isolate bioactive components (prebiotics) that may be beneficial for the health of poultry by degrading the crude fibre content of copra meal (Sundu *et al.* 2009). Manno-oligosaccharides (MOS) have been produced by using endo- β -1,4-mannanase (produced by *Aspergillus niger* BK01) on copra meal (Crong *et al.* 2010) or on pretreated and defatted copra meal (Ghosh *et al.* 2015). In an *in vitro* study, this isolated MOS had prebiotic potentials as it more supported the growth of *L. acidophilus* and *B. infantis* than with standard inulin (Ghosh *et al.* 2015). In an *in vivo* study, Sundu *et al.* (2012) showed that mannan derived from copra was able to counteract the negative impact of *E. coli* infection and aflatoxin B1 contamination in terms of growth performance and health status of broiler chickens. In accordance with those findings, Ibuki *et al.* (2013) reported that mannanase-hydrolysed copra meal improved intestinal histology (hence the intestinal absorptive function) and positively affect the immune system of broiler chicks. Further, β -1,4-mannobiose derived from the copra meal was able to prevent *Salmonella enteritidis* infection in broilers by improving *Salmonella enteritidis* clearance and increasing IgA production (Ibuki *et al.* 2010). However, those authors did not observe any impact of treatment on the immune organ development of broilers. In pigs, the mannanase-hydrolyzed copra meal exerted an anti-inflammatory activity (i.e., decreased the mRNA levels of ileal interleukin [IL]-1 β , IL-6, IL-17 and TNF- α) in the intestine, showing a beneficial effect alleviating the intestinal inflammation (Ibuki *et al.*

2014). As prebiotics, MOS isolated from copra meal may be administrated to broilers in combination with probiotics to obtain a symbiotic effect. Duarte *et al.* (2014) showed that the application of mannanase-hydrolyzed copra meal together with *Bacillus cereus* var. *toyoi* could improve the performance and duodenum and jejunum mucous morphology of broilers, when compared to control group.

Cassava pulp

Cassava pulp is a by-product of tapioca industry that is abundant in most of tropical countries. Due to its high energy content (2484 kcal/kg), this by-product has been used as feed ingredient to partially replace the role of maize in poultry rations (Khempaka *et al.* 2009). However, the high fibre (14.6%) and low protein contents (2.02%) may limit the use of cassava pulp in poultry diets. Fermentation has been used to improve the nutritional values of cassava pulp and thereby to increase its incorporation level in poultry rations. Khempaka *et al.* (2014) fermented cassava pulp using *Aspergillus oryzae* and subsequently included the fermented cassava pulp up to 16% in broiler diet without any adverse effects on the performance and well-being of broiler chickens. This proportion was apparently higher when compared with the level of inclusion of dried (raw) cassava pulp in broiler rations (8%) (Khempaka *et al.* 2009). Also Sugiharto *et al.* (2016); Sugiharto *et al.* (2017a) and Sugiharto *et al.* (2017b) included 16% of cassava pulp fermented with the fungus *Acremonium charticola* in broiler ration without any negative effects.

The cassava pulp is a good source of oligosaccharide (mannose) that may act as prebiotics. Kurdi and Hansawasdi (2015) showed that the oligosaccharide isolated from cassava pulp was capable of promoting the growth of *Lactobacillus* and *Bifidobacterium in vitro*. An *in vivo* study showed that the fibre isolated from cassava pulp reduced the population of *E. coli* in the faeces of rats (Osundahunsi *et al.* 2012). However, the role of cassava pulp and its isolated active components as functional feed for poultry has not adequately been studied. Feeding dried cassava pulp improved the intestinal health (Khempaka *et al.* 2009) and also increased the relative weight of immune organs (thymus and bursa of fabricius) of broiler chicks (Sugiharto *et al.* 2016). Concomitant with this, feeding cassava pulp fermented with *A. charticola* or *Rhizopus oryzae* increased the relative weight of thymus and bursa of fabricius, and lowered both the heterophil to lymphocyte (H/L) and albumin to globulin (A/G) ratios (Sugiharto *et al.* 2016). In another study, it was also reported the increased of the relative weight of spleen, ileum and cecum as well as a reduced oxidative stress, as indicated by a lower 2,2-diphenylpicrylhydrazyl (DPPH) % inhibition, in broilers fed cassava pulp fermented with *A. charticola* (Sugiharto *et al.*

al. 2017a). It was also showed that cassava pulp fermented with *A. charticola* decreased the number of total coliform bacteria in the ileum and increased the concentration of butyric acid in the caeca of broilers (Sugiharto *et al.* 2017b). Owing to the aforementioned data, it may be suggested that it is safe to include up to 8% of raw cassava pulp and 16% of fermented cassava pulp as alternative to conventional feedstuffs and functional feed ingredients in the poultry rations.

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Banana peel

Banana peel or banana skin is the outer covering of banana fruit. Besides banana-processing industries, banana peel is produced by the fritter vendors and household consumption. A number of studies have reported the use of banana peels in poultry rations to partially replace maize as a source of energy (Duwa *et al.* 2014; Abel *et al.* 2015; Blandon *et al.* 2015). Banana peel contains 10% crude protein and 2932 kcal/kg metabolizable energy (ME) (Blandon *et al.* 2015). So far, no specific recommendation for the optimum proportion of banana peel in the poultry rations can be found in the literatures, however, Blandon *et al.* (2015) reported that dietary inclusion of banana peel up to 25% did not have adverse effects on the performance of broiler chickens. The use of banana peel meal as a functional feed ingredient to improve the health status for poultry has not been adequately researched. In the literature search, only one study was found referring that the feeding banana peel meal increased the weight of spleen of 35-days old broiler chicks (Siyal *et al.* 2016). According to recent studies (Pereira and Maraschin, 2015; Hernández-Alcántara *et al.* 2016) the banana peel is a good source of prebiotics, antioxidants and pro-vitamin A due to its contents of carotenoids, phenolics and amine compounds. Moreover, banana peel extract presented antimicrobial activity against *Porphyromonas gingivalis*, *Aggregatibacter actinomycetemcomitans* (Kapadia *et al.* 2015) and *Staphylococcus aureus* (Guil-Guerrero *et al.* 2016). These properties in the banana peel may therefore be beneficial for the health and well-being of poultry. Zhang *et al.* (2004) had previously reported that arabinoxylans derived from banana peels induced a positive oxidative burst in macrophages (activate a macrophage cell line as an immune stimulator), and can thus promote the health of broiler chicks. However, data regarding the application of banana peel extract on the health of poultry is scarce.

Orange peel and pulp

Orange peel is a by-product of sweet orange processing industry that are abundant especially during the harvesting period. Oluremi *et al.* (2008) revealed that the peels of sweet oranges contain 2440-2890 kcal/kg gross energy and

7.44-10% crude protein and may therefore be used to substitute the role of maize in poultry diets. The latter authors further showed that sweet orange peels can be included in broiler rations up to 15% without any detrimental impacts on final weight. In addition to vitamin C and dietary fibre, orange peels possess high contents of carotenoids (Erawita *et al.* 2017), phenols and hesperidin (Kasapidou *et al.* 2015), which are essential for stimulating the immune system. Orange peels also contains essential oils (terpens and aliphatic sesquiterpene) displaying antimicrobial activities against *E. coli* 0157:H7 and *Salmonella typhimurium* (Callaway *et al.* 2008). These latter properties may be beneficial for maintaining the poultry intestinal health. Ebrahimi *et al.* (2015) further reported that dried orange peels increased the mean value for the hemagglutination inhibition test in broiler chicks on day 42. Indeed, the treatment also reduced the population of *E. coli* in the caecum of broilers. Conversely, Alefzadeh *et al.* (2016) reported no effect of dried orange peel powder on the immune organ weights and the population of *E. coli* and *Lactobacillus* in the intestine of broiler chickens. The different nature of orange peels and the condition of the studies might explain these divergent results.

For some agro-industrial by-products, fermentation is one of the method not only to improve the nutritional qualities, but also to enhance the functionality of the products. With regard to the fermentation of orange peels, reports available in the literatures shows differently. For example, Oluremi *et al.* (2010) revealed that fermentation did not change the nutritive values of the sweet orange peels, and that its use in feeding during the starter period depressed the growth performance of broiler chicks. In a previous study, Oluremi *et al.* (2008) also reported that feeding fermented sweet orange peels to replace maize had depressed the feed intake and growth rate of broilers. The spontaneous (without fermentation starter) fermentation failed to decrease the fibre content in orange peels and therefore reduced the digestibility of broiler chicks (Oluremi *et al.* 2008; Oluremi *et al.* 2010).

The benefits of orange peel extract has been shown, not only in the production parameters (Ebrahimi *et al.* 2014), but also to the health and well-being of poultry. Pourhossein *et al.* (2015) reported that feeding orange peel extract increased antibody titer response to sheep red blood cells, antibody titer responses to ND virus, avian Influenza (AI), infectious Bursal disease (IBD) and infectious Bronchitis virus (IBV) vaccines. The treatment also increased the concentrations of IgA and IgG, but did not affect the relative weights of spleen and bursa of Fabricius. An earlier study by Akbarian *et al.* (2013) showed that the orange peel extract (400 mg/kg) increased the weight of bursa of fabricius and reduced the number of coliform bacteria in the

ileum and caecum of broiler chickens. Also, Pourhossein *et al.* (2012) reported that the orange peel extract was able to reduce *E. coli* and coliform counts and increase the population of *Lactobacilli* in the ileum of broilers. These studies were in accordance with an *in vitro* study showing the antibacterial activities of orange peel extract against *E. coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *S. typhi*, *S. paratyphi A*, *S. paratyphi B*, *Shigella flexneri* and *Vibrio cholerae* (Nisha *et al.* 2013). A recent study in Japanese quails further showed the usefulness of orange peels in improving the stress response of birds to unfavorable conditions, as indicated by the level of malondialdehyde, glutathione peroxidase activity and glutathione production in liver (Ciftci *et al.* 2016).

Orange pulp is the other by-product of sweet orange processing industry especially from juice extraction. It contains 8.1% crude protein and 18.13 MJ gross energy/kg DM. It is also rich in carotenoids, phenolic acids, flavonoids, terpenoids and vitamin C (Emawita *et al.* 2017). Several studies have reported the application of orange pulp in poultry rations. For instance, inclusion of up to 2% of dried sweet orange pulp in broiler diets improved feed intake and body weight gain, decreased liver and abdominal fat as well as serum triglyceride level in broilers, while also improving the immune responses (antibody titres against ND virus, IB virus and IBD virus) in treated vs. control groups (Abbasi *et al.* 2015). Moreover, the treatment was able to reduce the total aerobic bacteria counts and increase the numbers of *E. coli* and *Lactobacillus*. Similarly, feeding pigs with 150 g/kg of ensiled citrus pulp reduced the enterobacteria counts after two weeks of treatment (Moset *et al.* 2015).

Pascoal *et al.* (2015) further reported that the use of citrus pulp together with soybean hulls was capable of increasing the number of goblet cells and the density of villi in the jejunum as well as reducing the number of *E. coli* in the intestine of piglets slaughtered at day 35. Different from the aforementioned data, a different result was reported by Mourão *et al.* (2008), in which the dietary inclusion of citrus pulp (10%) lowered the growth rate and reduced the carcass yield of broiler chickens. The different natures and levels of orange pulp inclusion as well as the different of experiment conditions may explain the divergent results among the above reported studies. Interestingly, incorporating of citrus pulp in broiler diets resulted in higher content of polyunsaturated fatty acid (good fatty acids) in the meat of broilers as compared to control (Mourão *et al.* 2008).

General mechanism of tropical agro-industrial by-product in improving the health status of poultry

It is generally believed that functional feed ingredients may alleviate the risk factors responsible for a number of diseases in poultry. The exact mechanism by which the tropi-

cal agro-industrial by-products acting as functional feeds protect the poultry from diseases remains unclear, but multiple reports describe an improvement of the immune defense system (Sundu *et al.* 2006; Soltan, 2009), the modulation of intestinal microbial populations (Sundu *et al.* 2006) and other physiological functions of poultry (Abbasi *et al.* 2015; Ebrahimi *et al.* 2015). It has been mentioned earlier that agro-industrial residues are good sources for oligosaccharides such as mannose, mannan, arabinosylans, etc. (Chen *et al.* 2015; Kurdi and Hansawasdi, 2015; Rezaei *et al.* 2015), which can serve as prebiotics for poultry. These oligosaccharides may stimulate the growth of endogenous beneficial bacteria (e.g., bifid bacteria and lactobacilli) ensuring the intestinal microbial balance and enhanced immune defense of chicks. The detailed mechanisms through which prebiotics, which include the oligosaccharides, improve the gut microbial ecosystem and immune competence of poultry have intensively been reviewed elsewhere (Sugiharto, 2016). With regard to the role of prebiotics derived from agro-industrial residues on the physiological functions of poultry, data available in the literature are still limited. However, prebiotics may in general improve the morphology (perimeter and height of villi) and development of the intestine, and therefore improve digestion and absorption of nutrients (Oliveira *et al.* 2008; Ao and Choct, 2013). Prebiotics may also improve the hormonal regulation in poultry, as previously reported by Sohail *et al.* (2012) who found prebiotics (MOS) were able to alleviate the dramatic increased level of stress-related corticosterone in poultry (e.g., heat stress). Note that increased corticosterone compromises the physiological imbalance in poultry.

It has been known that agro-industrial by-products contain several bioactive components (Esa *et al.* 2013) that may provide nutraceutical effects on poultry. Among the active components derived from the agro-industrial residues, γ -oryzanol derived from the rice bran oil has immunostimulatory properties that may modulate the immune response of poultry against pathogenic microorganisms (Kang *et al.* 2015). Ghatak and Panchal (2012) reported that γ -oryzanol was able to improve immune competences of host through cellular and humoral mediated mechanisms. Further, γ -oryzanol may also promote the development of immune organs, such as thymus and spleen (Szczesniak *et al.* 2016). The latter workers further reported that γ -oryzanol has antioxidant potential and can therefore ameliorate the oxidative stress in poultry. To deal with the oxidative stress, γ -oryzanol may improve the body redox capacity of host (Zolali *et al.* 2015).

The antibacterial and antioxidant capacities of agro-industrial by-products may in some extent be determined by the presence of phenolic compounds in the by-products (Hemández-Alcántara *et al.* 2016; Emawita *et al.* 2017).

The definite mechanism by which phenolic compounds exert their antimicrobial activities are largely unknown, but one possible mechanism may be that they disrupt the cytoplasmic membrane of bacteria resulting in loss of membrane integrity and morphological changes, resulting in bacterial cell lysis and death (Wu *et al.* 2016). Apart from the amelioration of oxidative stress, the antioxidant properties of phenolic compounds may improve the immune response of poultry. In mice, the phenolic compounds were capable of improving the immune system as indicated by the increased antibody titres and the percentage of protected animals after swine herpesvirus type I (SuHV-1) challenge (Fischer *et al.* 2010).

Several mechanisms on how the phenolic compounds may be able to improve immune system of poultry have been suggested. One possible mechanism could be that phenolic compounds modulate the process of differentiation and activation of immune cells (Cuevas *et al.* 2013). Moreover, antioxidant properties of phenols may also prevent the destructive effect of free radicals on the immune functions of host (Brambilla *et al.* 2008).

CONCLUSION

Tropical agro-industrial by-products contain several bioactive compounds that may act as antimicrobial agents, antioxidants and immune-modulator. These properties may contribute to the role of agro-industrial by-products as functional feed ingredients in promoting the health and well-being of poultry. Future research is needed to confirm the potential of agro-industrial residues and their derivative products in substituting the use of synthetic antibiotics in poultry rations. Overall, given that the availability and price of the agro-industrial by-products may vary greatly across the regions, the use of such by-products as functional feed ingredients in poultry rations should therefore be adjusted according to the availability and cost of each by-product.

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