



Prospects of yeast based feed additives in poultry nutrition: Potential effects and applications

R M BILAL, F HASSAN*, M SAEED, TUGAY AYASAN, N RASHED, M U AKHTAR and ALIREZA SEIDAVI

Islamia University of Bahawalpur, Pakistan 63100

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ABSTRACT

Yeast and its derivatives are extensively utilized as feed additives in poultry industry owing to their desirable health and growth promoting effects. Exhaustive number of studies had reported positive effects of yeast based additives on growth, meat quality, immunity, antioxidant status, and gastrointestinal functions in poultry birds. Owing to their prebiotic/probiotic properties, they also play significant role in gut development and modulation of gut microbiome by favouring beneficial microbes while reducing colonization of pathogenic microbes by competitive exclusion. They also possess effective potential for binding of dietary toxins in addition to improving digestion and utilization of nutrients. Moreover, yeast based additives have exhibited desirable effects on humoral immunity by increasing serum immunoglobulin (Ig) A levels. These additives have been also used as immune adjuvants to boost innate immune response under any pathogenic challenges in birds. Due to their diverse biological activities, yeast products are potentially capable for immune hemostasis by mediating balance between pro- and anti-inflammatory activities. These unique properties of yeast based products make them promising feed additive to promote health and productivity leading to efficient poultry production. Yeast can be supplemented in poultry diets @ 5.0–10.0 g/kg of feed. Numerous studies had reported significant improvement in body weight gain (3 to 8%) and FCR (1.6 to 12%) in broilers in response to supplementation of yeast based additives. Moreover, yeast supplementation also improved hemoglobin (Hb g/dl) levels up to 2.59 to 6.62%, total protein (>0.69%) while reducing serum cholesterol (mg/dl) up to 3.68 to 13.38%. Despite the potential properties and beneficial effects, use of yeast and its derivatives as feed additives in poultry industry is not matching its inherent potential due to many reasons. This review aims to highlight the importance and potential role of yeast and its products as natural growth promoter to replace in feed antibiotics to address the issues of antibiotic residues and microbial resistance. This article provides insights on functional role of yeast based additives in poultry diets and their importance as commercially viable alternatives of antibiotic growth promoters in poultry feed industry.

Keywords: Additive, Nutrition, Poultry, Yeast

Antibiotic growth promoters (AGPs) are usually added in poultry diets to enhance productivity and resolve health issues (Salaheen *et al.* 2017). Recently increasing concerns regarding microbial resistance and antibiotic therapy failure in human and animal have compelled scientific community to search for alternative approaches to replace AGPs (Yang *et al.* 2009). Since 2006, the European Union (EU) has restricted utilization of antibiotics in animal feed industry as growth promoting feed additive (Alloui *et al.* 2013). After this ban on use of antibiotics, several products with robust mechanisms and growth promoting effects to replace AGPs have been recommended. These include; *mannan oligosaccharides* (MOS), live and dry yeast, distillery yeast sludge (DYS), prebiotics, probiotics and phytobiotics etc. (Choudhari *et al.* 2008, Yang *et al.* 2009).

Yeasts are ubiquitous unicellular fungi, and an ideal eukaryotic model micro-organism for biological experiments. They live as saprophytes on organic matter and can catabolize sugars contents for production of ethanol

*Corresponding author email: faizabg@gmail.com

(Kandasamy *et al.* 2012). Modern life sciences experiments on yeast are highly turning to the evolution of many modern scientific fields and its industrial biotechnology research is well known globally (Barnett and Barnett 2011). The cells of yeast have a somewhat smooth ellipsoidal shape and their size vary greatly depending on environment and species, normally measuring 3–4 μm diameters but some can reach above 40 μm (Adebisi *et al.* 2012).

Yeast like *Saccharomyces cerevisiae* (SC) also known as baker's yeast, is a facultative anaerobic fungi and is ubiquitously recognized for its industrial endeavour (Mortimer 2000, Piskur and Langkjaer 2004). Furthermore, the EU has declared SC as safe organism for supplementation in animal feeds. Additionally, United States Food and Drug Administration (FDA) have declared it 'generally recognized as safe' (GRAS) (Nitta and Kobayashi 1999). On dry weight matter (DM) SC, involve 95 to 98% DM, 42–46% CP, 30–37% carbohydrate, 7–8% minerals, 6–8% nucleic acid and 4–7% lipids (Lamoolphak *et al.* 2006). Supplementation of yeast in poultry has exhibited

beneficial effects by improving immune response, intestinal health, nutrient digestion and absorption capacity leading to overall improvement in performance (Sims *et al.* 2004, Msadeq *et al.* 2015). Numerous yeast derivatives and yeast containing feed ingredients such as yeast culture, yeast extracts and yeast-fermented products are frequently being used as growth promoter (Zhang *et al.* 2005). Yeast and its products have also been used successfully in large animals like buffaloes to modulate their performance (Azzaz *et al.* 2015, Hansen *et al.* 2017).

Prebiotics are mostly described as non-digestible ingredients, which beneficially affect hosts health by selectively stimulating growth or competence of health promoting bacteria (Alloui *et al.* 2013). Fructo-oligosaccharides, MOS and gluco-oligosaccharides are principal prebiotics used in poultry feed industry (Yang *et al.* 2009, Msadeq *et al.* 2015). Probiotics are live microbial feed supplement, which beneficially affect the host by improving survival and mediating its intestinal microbial architecture (Yang *et al.* 2009). Many preferred bacterial species (like *Bacillus*, *Enterococcus*) and yeast (*Saccharomyces*) have already been used as probiotics in poultry feeding (Choudhari *et al.* 2008). These are substantially available in the form of dietary feed supplements possessing components of microbial cells, metabolites and cultures (Choudhari *et al.* 2008). The MOS are derived from cell walls of yeast, which constitutes glucomanno-protein complex (Yang *et al.* 2009). The β D-glucans are components of yeast cell walls (YCW) known as natural biological modifiers (Novak and Vetvica 2008). Distillery yeast sludge is a product derived from brewing industry, which mainly possesses SC as major protein contents (Ali 2004). Principally, it is a mixture of cell sediments of yeast and metabolites remaining after molasses fermentation and possess appreciable quantities of proteins, macro and micronutrients (Pradeep 2007). Since two decades aforementioned literature survey revealed that poultry industry and researchers are efficiently applying yeast and yeast based products as potential feed supplement (Fig. 1). This review aims to highlight some of the new potential uses of yeast and its derived products as natural

growth promoters to replace in feed antibiotics.

Yeast products

Yeast and its derived products, i.e. inactive dry yeast, yeast culture, yeast autolysate, yeast cell wall, and live yeast etc., are frequently used as natural growth promoters in poultry feed industry (Aydin and Aydin 2012, Mousa *et al.* 2014). Yeast culture is based on the yeast cells as well as metabolites, like peptides, organic acids, oligosaccharides, amino acids, flavour aroma substances and unidentified growth factor having positive effects on animals. Yeast culture possesses 1400 units/kg of phytase, which could also augment beneficial effects of yeast on feed digestion in the gut (Gao *et al.* 2008). Yeast autolysis is a degradation process accomplished by stimulating the yeast's own autolytic enzymes to solubilize cell units within the cell. Lysis of glucan and chitin degrades the cell wall. The hydrolytic enzymes (e.g. nucleases and proteases) found in the general matrix of the cell, are liable for breakdown of yeast proteins and nucleic acid. Proteases degrade yeast proteins into peptides and amino acid derivatives, whereas nucleases cleave nucleic acids (Sommer 1998). Yeast autolysate is a potential source of nutrients, such as proteins, nucleotides, vitamins, fiber, and micronutrients (Stone 1998).

Potential of yeast based products to replace in feed antibiotics

Search for non-antibiotic growth promoters is at peak these days worldwide to replace in feed antibiotics in poultry diets. In present scenario, yeast and its derivatives seem to be the most suitable and potential alternatives of antibiotic growth promoters (Onifade *et al.* 1999). Currently, yeast products have been used in poultry feed to exploit their beneficial effects on growth performance without any risk of developing microbial resistance (Kim *et al.* 2011). Moreover, yeast and its products do not have any residual effects on poultry and its products. Supplementation of yeast derivatives (MOS) in poultry diets has increased bird's survival as compared to the antibiotic growth promoters (Hooge 2003). Recently, comparison of yeast prebiotics with commercial antibiotics revealed that prebiotics increased growth rate and inhibited colonization of cecal microbial populations particularly *Campylobacter* (Park *et al.* 2017). Moreover, prebiotics also stimulated proliferation of beneficial microbes like *Lactobacillus* as compared to antibiotic treated group at 2nd week of age. The best feature of prebiotics is the capability of binding mannose-specific type-1 fimbriae of pathogen and inhibiting pathogen's colonization (Newman 1994).

It has been reported that cell wall of yeast (SC) might successfully bind mycotoxin through esterified glucomannan. For example, addition of 0.1% esterified glucomannan ameliorated adverse effects of mycotoxins and showed better growth performance with higher antibody titer against NDV than AGPs group in broiler (Kamalzadeh *et al.* 2009). Furthermore, on a low protein and high fibre

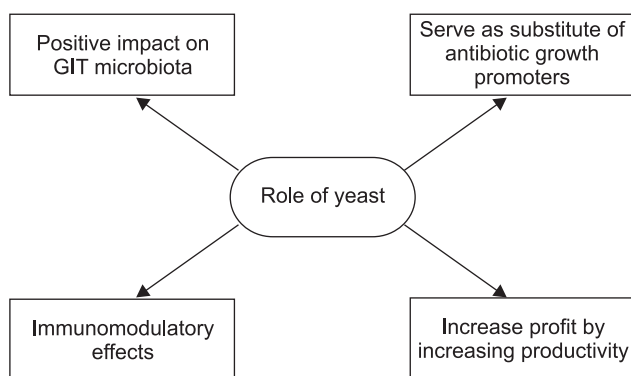


Fig. 1. Yeast and yeast based products as potential feed supplement.

diet, supplementation of SC promoted growth, carcass weight and lowered the abdominal fat contents compared to antibiotics fed groups (Onifade *et al.* 1999). Similarly, comparison of MOS with antibiotic growth promoter revealed increased number of *Lactobacilli* in broiler gut (Chee *et al.* 2010). Moreover, yeast has also shown to enhance epithelial maturation in ileal tissue just like bacitracin methylene disalicylate (BMD) in broiler (Fasina and Thanissery 2011). This shows that yeast and its derivatives possess effective potential to replace in feed antibiotics as they can influence bird performance by increasing digestion and absorption of nutrients. Moreover, they potentially enhance ileal activity and reduce pathogenic load in gut by favoring competitive exclusion by beneficial microbes like *lactobacillus*.

Effects on performance of broilers

Yeast and its derived products have potential to promote growth performance, reduce morbidity and mortality losses in broiler. Due to these potential properties, their application in poultry diets has numerically improved birds performance on industrial scale (Patterson and Burkholder 2003). Mechanism of action of beneficial effects of yeast includes; stimulation of brush border disaccharidases, anti-adhesive effect against pathogens, and activation of non-specific immunity, toxin binding and antagonistic effect against pathogenic organisms (Auclair 2001). Additionally, yeast supplementation also mitigates adverse effects in challenged state of alfatoxicosis and necrotic enteritis (Liu *et al.* 2017). This property of yeast really helps birds to survive through critical stages of infection along with maintaining their body weight and feed efficiency (Jazi *et al.* 2018). Furthermore, supplementation in normal rearing conditions is translated into effects higher gains and better feed conversion (Xue *et al.* 2107). Generally, two sources of dietary yeast, i.e. yeast-fermented additives (YFA) and non-yeast fermented additives (NYFA) have been used in poultry diets especially for broiler production. Inclusion of yeast fermented additives @ 5.0 to 10 g/kg of feed or non-yeast fermented additives @ 5.0 g/kg have shown optimum growth rate owing to presence of large number of active yeast cells (Yasar and Yegen 2017).

Many studies have indicated that broilers fed yeast fortified diet showed higher feed intake as compared to those fed un-supplemented diets (Koc *et al.* 2010, Lea *et al.* 2013). In the same context, broilers reared with DYS (6%) containing diet exhibited higher feed intake than control group (Khan 2001). Koc *et al.* (2010) reported that broilers exhibited significantly higher feed intake, body weight gain and better feed efficiency in response to supplementation of SC and MOS for 1–21 days of rearing. Similarly, Lea *et al.* (2013) observed that addition of YCW (200 g/tonne) exhibited higher feed intake compared to control. Different studies on broiler revealed that dietary inclusion of SC showed significant improvement in feed intake, weight gain and FCR (Santin *et al.* 2001, Shareef and Al-Dabbagh 2009, Fowler *et al.* 2015, Chen *et al.* 2017).

Yeast contains vitamin B complex, proteins and minerals which exhibit beneficial effects on feed intake of birds. Yeast help to maintain balanced intestinal microflora which helps to maintain healthy gut integrity that indirectly stimulates feed intake (Shareef and Al-Dabbagh 2009). Many recent studies have revealed involvement of gut microbiome in better immune response and host defense against pathogens (Saeed *et al.* 2018). Gut microbiome is not only important for gut integrity but also influences epithelial barriers to mediate nutrient absorption through gut. Modulation of gut microbiome mediated by yeast and its derived products is major driving force behind pronounced effects of yeast on feed intake and nutrient absorption. Gut microbes especially *Lactobacillus* sp promote chicken survival without affecting its weight gain and FCR (Brzoska *et al.* 2010). Many other studies revealed that manipulation of gut microbiome is most plausible reason for pronounced effects of prebiotics supplementation on feed intake and feed efficiency of birds (Bednarczyk *et al.* 2016). Studies have shown that birds fed diet supplemented with yeast have more balanced microbial population of gastrointestinal tract (Thongsong *et al.* 2008, Koc *et al.* 2010). Moreover, it is believed that better performance may be associated with the reduced energy partitioning toward tissue turnover in case of yeast supplementation (Al-Mansour *et al.* 2011) as revealed in many studied (Hosseini 2011, Aluwong *et al.* 2013). Yeast derived products like *mannan oligosaccharides* (MOS) also proved to be potential feed additive with beneficial effects on bird performance. Supplementation of MOS in poultry diets especially broiler rations at different concentrations have been studied extensively. Inclusion of MOS in poultry feed at the level of 0.01 to 0.3% have been used elucidate its potential benefits in terms of growth, immunity and feed efficiency (Benites *et al.* 2008, Zhang *et al.* 2012). Moreover, supplementation of MOS has also proven useful in broilers challenged with *Salmonella Typhimurium* to mitigate adverse effects of infection on performance and livability (Jazi *et al.* 2018). Such beneficial effects under immune-suppressive conditions make MOS a promising alternative of antibiotic growth promoters (Zhang *et al.* 2012).

Dietary yeast sludge (DYS) is most abundant fraction among yeast fermentation byproducts. Efforts have been made to use DYS on a larger scale to partially replace protein sources in poultry diets. For example, replacement of soybean meal with dietary yeast single cell protein in meat birds at inclusion rate of yeast (10.5 g/kg) significantly increased birds weight while reducing FCR (Chand *et al.* 2014). Broilers challenged with 500 ppb Ochratoxin showed best feed efficiency when supplemented with 2% yeast sludge (Mujahid *et al.* 2012). Santin *et al.* (2001) and Chee *et al.* (2010) were of view that growth promoting effects of feeding yeast might be associated with the increased villus growth especially during early stages of life. Similarly, Azeem (2002) and Chand *et al.* (2014) reported that yeast supplementation may promote villus height by accelerating anaerobic and cellulytic bacterial population which

enhances lactate utilization and sustains a favourable intestinal pH, thereby leading to a better nutrients retention, digestibility and growth (Liu *et al.* 2002, Fasina and Thanissery 2011).

No doubt that dietary yeast sludge is promising feed additive but higher inclusion levels can pose adverse effects on bird health. Because higher inclusion levels of DYS (30, 50 and 70%) have resulted in decrease in feed intake, decline in body weight along with poor FCR (Rameshwari and Khethyan 2005). Even a linear decrease in BWG and FCR was observed with addition of more than 15% DYS in poultry diets (Ozorio *et al.* 2012). The ultimate reason behind this depression in bird's performance with higher inclusion levels of DYS is abundance of nucleic acids and non-starch polysaccharides, which pose anti-nutritional effects. Moreover, it may be due to reduced dietary energy and poor nitrogen utilization at higher levels of DYS as higher intake of dietary nucleic acids might reduce uric acid excretion, leading to metabolic disorder and anorexia (Schulz and Oslage 1976, Tuse 1984, Rodrigiez *et al.* 2014).

Effects on performance of layers

It is well reported that yeast derivatives positively influence performance of layers. Supplementation of (0.15 and 0.20%) baker's yeast significantly increased egg production rate of layers compared to control group during a 10-week trial period (Hameed *et al.* 2019). Inclusion of yeast (SC) culture (0.05, 0.1, 0.2%) in diets of laying hens (of 18–19 weeks) showed desirable effects on body weight gain, FCR and egg production. Yeast numerically (0.1, 0.2%) increased egg production and final body weight with a better FCR (Ozsoy *et al.* 2018). Similarly, supplementation of much higher levels of yeast culture (0.4, 0.8, 1.2 and 1.6%) in laying hens exhibited significantly more number of eggs compared to control diet (Hassanein and Soliman 2010). Furthermore, beneficial effects of yeast on layer production performance have been observed in many studies conducted worldwide (Yalcin *et al.* 2012, Gul *et al.* 2013, Yalcin *et al.* 2015). Supplementation of yeast cell wall components (225, 450 and 900 ppm) for 46 weeks in laying hens showed significant improvement in production performance. Hens fed with 450 ppm of YCW exhibited a 4.9% significantly higher egg production with a 3.68% better FCR/dozen eggs relative to control and other YCW levels (Koiyama *et al.* 2017). Dietary dried DYS have also shown beneficial effects on overall health and performance of layers (Bilal *et al.* 2016, Bilal *et al.* 2018 a, b). Beneficial effects of yeasts and its derivatives are based on mediation of digestion and absorption of nutrients while maintaining better immune response through gut integrity, so it is equally applicable and effective in all species of meat type and laying type birds.

Effects on immunity of birds

Poultry nutritionists generally aim to make quality feed with balanced nutrients to meet all dietary requirements necessary for normal growth, health and survival. It is well

established that birds with a better immune activity have ability to defend pathogenic attacks and can withstand different environmental stresses. Therefore, better immune response is vital for successful poultry enterprise worldwide. Yeast and its derived products have shown potential immunomodulation in birds especially under stress caused by environmental factors or diseases. This ability of yeast base products make them versatile feed additive that enhances bird survival along with improving performance in challenged conditions. Stimulation of immune cells is one of the most significant biological activities of yeast (Swiatkiewicz *et al.* 2014). Supplementation of yeast based products (DYS, yeast autolyse, yeast protein concentrate and MOS) in poultry diets have shown beneficial effects on immune functions as reported in many studies (Hashmi *et al.* 2006, Yalcin *et al.* 2010, Haldar *et al.* 2011).

Recently, β -glucans from yeast are being frequently used in animal production as an effective immunomodulators (Griggs and Jacob 2005, Chae *et al.* 2006, Rosen 2007). Addition of 0.02% and 0.1% dietary β -glucans in broiler diets resulted in reduction of lesions in coccidiosis challenged state (Cox *et al.* 2010). Similarly, feeding of β -glucans (0.05%) exhibited better immune response against New Castle disease virus (NDV) and Infectious bursal disease virus (IBV) in broiler chicks than control group (An *et al.* 2008). Modulation of macrophage chemotaxis activity has been observed during cellular immune responses mediated by inclusion of β -glucan in broilers (Cheng *et al.* 2004). Moreover, it has also shown to enhance innate immune system in *Salmonella* challenged broilers (Lowry *et al.* 2005). Supplementation of β -glucan have also shown increased serum cytokine, IgG, IgA, plasma globulins and lymphoid organ weight relative to control group in broiler (Zhang *et al.* 2008).

Environmental factors especially heat stress negatively affects bird's performance and survival by lowering immunity. Therefore, it is imperative to mitigate adverse effects of heat stress in summer especially in tropical and sub-tropical countries to avoid poultry production losses. Yeast have also shown its promise in mediating heat stress in epithelial barrier by reducing the translocation of bacterial products, and production of pro-inflammatory cytokines like IL-6 which may activate HPA-axis as shown in Fig. 2 (Ruth 2018).

Additionally, studies have reported that supplementation of yeast and its derivatives like MOS improved antibody titers in case of cellular, humoral and mucosal immunity in broiler (Gomez-Verduzco *et al.* 2009, Ozpinar *et al.* 2010, Zakeri and Kashefi 2011) resulting in better response to vaccination. A variety of macrophages reside, as the part of so-called gut associated lymphoid tissues (GALT) in bird's intestinal tract. These protective cells recognize pathogens by different particular nature of molecules that are only the component of microbes. These exclusive molecules are called pathogens associated molecular patterns (PAMP). The component of yeast cell wall such as

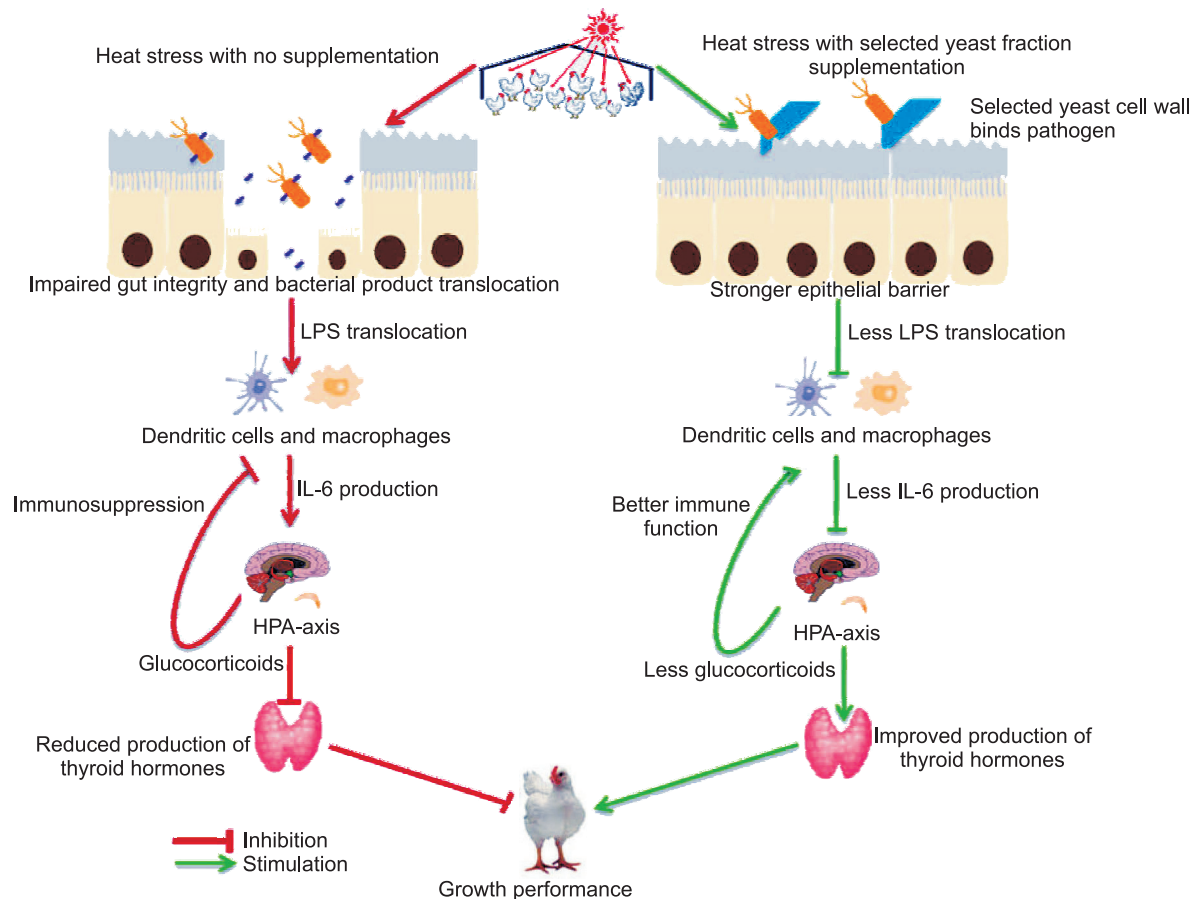


Fig. 2. Modulation of immune response and gut integrity by yeast supplementation under heat stress in poultry (Adapted from Raspoet 2018).

beta-glucan and mannan sugar polymers and other microbial molecules like peptidoglycan and lipopolysaccharide also contain PAMP. Mannans bind with the PAMP receptors found on defense cells of GALT leading to stimulation of bird's immune response (Shashidhara and Devegowda 2003). Supplementation of MOS have exhibited immune-modulatory effects in birds by significantly increasing antibody titers against New Castle disease (ND) and infectious bursal disease (IBD) under normal and heat stress situations (Kocher and Tucker 2005, Gao *et al.* 2008, Sohail *et al.* 2010).

Studies have indicated that supplementation of MOS and YCW in broiler diets showed better immunogenic response against NDV (Hashmi *et al.* 2006, Oliveira *et al.* 2009, Muthusamy *et al.* 2011) and avian influenza virus (AIV) (Tohid *et al.* 2010). Moreover, inclusion of yeast cell wall fractions (@ 2 g/kg of feed) ameliorated lethal effects of *fusarium* mycotoxin on the immune response. Many studies involving supplementation of prebiotics and synbiotics in poultry showed positive effects on birds' immune response and modulated gut microarchitecture while lowering *coliform* associated population in broilers (Yang *et al.* 2009; S³awinska *et al.* 2014, Madej *et al.* 2015, Roto 2015). Prebiotics can also improve immunogenic response of vaccines and serve as adjuvants to boost efficacy of vaccines (Alloui *et al.* 2013). The potential immunogenic activity

has also been proven by *in vitro* studies as YC activated B-lymphocytes and natural killer cells in addition with anti-inflammatory effects (Mehdi and Hasan 2012).

After vaccination, birds exhibited better humoral response in terms of higher antibody titers against NDV as revealed by hemagglutination inhibition test (Oliveira *et al.* 2009; Halder *et al.* 2011, Zakeri and Kashefi 2011). Higher IgA, IgM level and serum lysozyme antibody titers against viral diseases have been observed with inclusion of yeast culture (YC). The higher lysozyme production mediated by yeast culture supplementation has the capability of breaking polysaccharide wall of various types of bacteria, which protects the birds from diseases (Gao *et al.* 2008). Similarly, many other studies revealed better response of adding yeast based products in poultry diets on serum antibodies against viral diseases owing to complementary effects of mannans, glucans and nucleotides contents of yeast (Shashidhara and Devegowda 2003, Gheisari and Kholeghipour 2006, Gao *et al.* 2008, Tohid *et al.* 2010, Ghosh *et al.* 2012).

Contrarily, some studies have also reported that supplementation of yeast did not improve immunological status of bird against viral diseases like NDV and IBD (Silva *et al.* 2009, Lensing *et al.* 2012) which might be due to adverse effects of housing, environment, and management conditions of experiment. Moreover, number of live cells

of yeast in final supplemented feed is very crucial factor to have significant immunogenic response in birds.

Effects on gut health

Modulation of gut health in animals is most attractive physiological function of yeast which makes it promising feed additive in present scenario of antibiotic free animal production. Inclusion of yeast based products in animal feeds is not a new concept but application of yeast in avian diet has no long history. Few decades back mostly yeast was tested in ruminant's diet whilst poultry and other monogastric animals attained less attention. Birds showed higher growth and better health when fed diets fortified with viable and non-viable yeast cells (Roto *et al.* 2015). Many studies reported that application of yeast revealed fruitful results in terms of gut health of birds (Halder *et al.* 2011, Ghosh *et al.* 2012)

Birds gut health plays vital role in growth performance and immune response especially under challenged conditions. Modulation of gut health by inclusion of yeast is mediated by increasing intestinal microbial diversity by favouring beneficial microbes while inhibiting growth of pathogenic microbial species. A well balanced microflora within the digestive system is vital for optimum performance and it is believed that MOS can effectively manage this balance by restricting the pathogenic load and increasing growth of beneficial and essential bacteria through different mechanism (Adebisi *et al.* 2012). Many studies revealed that yeast cell wall product (MOS) have the ability to reduce *Salmonella* infection in birds (Fernandez *et al.* 2002; Kumar *et al.* 2002). A recent study revealed promotion of cytokine mRNA expression and reduction of intestinal *C. perfringens* and *E. coli* population in broiler fed prebiotic supplemented diets (Liz-Wang *et al.* 2017). Inclusion of 0.25% FOS and 0.25% MOS in feed promoted the growth of *Lactobacilli* and depressed *Clostridium perfringens* and *Escherichia coli* propagation leading to increased intestinal microbial diversity with positive effects on gut and overall host health (Baurhoo *et al.* 2007, Yang *et al.* 2009, Koc *et al.* 2010, Halder *et al.* 2011). Similar findings have been reported by Mountzouris *et al.* (2007) who observed that bacterial species like *Lactobacillus* and *Saccharomyces* may beneficially modulate birds' intestinal microflora. Yeast along with other prebiotics proved itself as a promising candidate to maintain gut health in poultry by modulation of epithelial microarchitecture and enhancing colonization of LAB in intestinal tract of birds (Pourabedin *et al.* 2014, Roto *et al.* 2015).

Supplementation of live yeast in poultry diets has also revealed modulation of gut morphology as increased ileal villus width and villus surface area was observed in supplemented birds (Wang *et al.* 2016). This change in gut tissue was mediated by less cell renewal and turn over leading to reduced energy expenditure for intestinal epithelial maintenance. Moreover, yeast and MOS supplemented birds exhibited increased villi height with a

better crypt depth ratio (Iji *et al.* 2001, Sims *et al.* 2004, Luquetti *et al.* 2012, Swiatkiewicz *et al.* 2014). Increased villi height and crypt depth is directly associated with enhanced nutrient absorption owing to increased surface area available for microbial activity and diffusion pathway (Gao *et al.* 2008, Matur and Eraslan 2012). Further advocating yeast effect on gut maturation of chicken, it has been found that birds fed with basal diet having yeast protein concentrate-pellets developed villi more efficiently (Halder *et al.* 2011). Various studies have endorsed significantly better effects of yeast inclusion in term of gut maturation and health (Santin *et al.* 2001, Zhang *et al.* 2005, Baurhoo *et al.* 2009a). At low cecal pH, prebiotics tends to limit growth of pathogenic organisms and promote beneficial bacterial population like *Bifidobacterium* and lactic acid producing bacteria. This beneficial function has been observed with increased frequency in the cecum of birds (Cummings *et al.* 2001).

Supplementation of dietary yeast (@1.5 g/kg of feed) increased villus height, cryptal depth, mucosal height and area of cryptal gland of broilers (Adebisi *et al.* 2012). It is reported that tip of longer villi secrete more enzyme which accelerates the digestion and absorption of nutrients (Kiela and Ghishan 2016). Studies have demonstrated that MOS exhibit its beneficial effects on bird health in three different ways, viz. (i) inhibits the growth of pathogens, (ii) enhances immunity of host and (iii) beneficially modulates birds intestinal structure (Ferket 2003). The addition of MOS not only reduces pathogenic load but also helps to eliminate it from broilers gut. It has been observed that beneficial bacteria yield lactic acid by fermentation of feed leading to acidic intestinal pH, which reduces population of putrefactive and potentially pathogenic bacteria (Servin 2004, Yang *et al.* 2009, Li *et al.* 2014).

Modulation of gut health by yeast and its derivatives

Modulation of gut health by yeast and its derivatives is accompanied by series of physiological changes that inhibit colonization of pathogens in gastrointestinal tract. Pathogens require attachment and further colonization in intestinal mucosa to exhibit their deleterious effects. For example, attachment of gram-negative bacteria including *Salmonella* and *E. coli* is mediated by type-1 fimbriae which possess mannose specific lectins called FimH. These lectins have great affinity for mannose residues present in intestinal mucosa. The MOS limit attachment of gram-negative bacteria with intestinal mucosa by binding itself with FimH of type-1 fimbriae. This results in passing of bacteria through intestine without being colonized (Fernandez *et al.* 2002, Hooge 2003, Baurhoo *et al.* 2009b). Moreover, MOS mediate accretion of goblet cells in the villi membrane of intestinal epithelium (Baurhoo *et al.* 2009a, 2009b). These goblet cells are very specialized for synthesizing secretory mucin glycoprotein particularly mucin which block the pathogens at entry portal (Kim and Ho 2010). Mucins have specific mannosyl-containing receptor which competitively bind to the type-1 fimbriae of gram-negative

bacteria and thus helps to eliminate pathogens from host intestine. MOS stimulate the growth of *Lactobacillus* species and *Bifidobacteria* in intestine of broilers. The depression in the growth of pathogens through above mentioned pathways results in an environment conducive for the propagation of beneficial microbes especially the *Lactobacillus* (Baurhoo *et al.* 2009a, 2009b).

In addition to *Lactobacillus*, yeast derivatives like MOS also enhance population of *Bifidobacteria* by increasing mucin synthesis from epithelial goblet cells. *Bifidobacteria* rely on mucin glycoprotein secreted from goblet cells by secreting the particular enzymes 1,2- α -L-fucosidase and endo- α -N-acetyl galactosaminidase (Katayama *et al.* 2005, Madiedo *et al.* 2008). These beneficial bacteria continuously compete against pathogenic ones for space and resources and decrease pathogenic load by competitive exclusion (Rolfe 2000). Among all other LAB bacteria, *Lactobacilli* produce bacteriocins (Joerger 2003) whereas, *Bifidobacteria* secrete some organic acids and bactericidal substances to kill pathogenic bacteria (Gibson and Wang 1994). *Lactobacilli* also ferment carbohydrates to produce lactic acid and acetic acid within the digestive tract (Audisio *et al.* 2000). These are alternate pathways which target all kinds of pathogenic bacteria even if they do not have type-1 fimbriae like *Clostridium* and *Campylobacter* species.

A feature of avian digestive tract is larger and longer healthy villi having shallow crypts and their low renewal rate (Ferket *et al.* 2002). Long villi and shallow crypts provide a larger gut surface area for the optimal absorption of nutrients and low epithelial cell renewal rate allows effective enzyme production and gut maturation (Yang *et al.* 2009). Improvement in gut morphology is mainly associated with change in the diet and drastic modification in intestinal microflora. These bacteria reduce pathogen load by competitive exclusion and other mechanism leading to the development of healthy intestinal environment resulting in an increase in villi length (Baurhoo *et al.* 2009b). Stable gut has low renewal rate which displays increased crypt depth (Shane 2006). Increased cell renewal rate results in higher crypt depth showing colonization of the enteropathogenic bacteria in the intestinal tract. Additionally, it is believed that villi length increases due to low enterocyte cell migration or renewal from the crypt to the villus height in all sections of intestinal tract (Markovic *et al.* 2009).

The short chain fatty acids (SCFAs) are fermented products which include acetate, propionate and butyrate. These have the capability of changing bacterial ecosystem by reducing the pH, which is intolerant to pathogenic bacteria like *Salmonella* and *Campylobacter*. Moreover, they provide energy to the gut and may replace antibiotics effectively. Diets supplemented with prebiotic increase SCFA production (Macfarlane *et al.* 2008). Many studies on broiler inoculated with necrotic enteritis reported that addition of YCW exhibited anti-inflammatory responses, enhanced immunoglobulins and SCFA production (Xue *et al.* 2017). The SCFA are also involved in regulation of cell proliferation in the gastrointestinal mucosa (Lan 2004,

Oliveria *et al.* 2009). They reduce the pH of the brush border micro-environment and block adhesion of pathogenic bacteria (Ferket 2003).

Conclusion

Yeast and its derivatives are promising feed additives with beneficial effects on performance and health of birds. Literature survey showed conclusive evidences that feeding yeast based feed additive possess various noticeable properties like modulation of growth performance, gut microbiome, gut development and integrity, immune system, antioxidant status and nutrient absorption/utilization. These diverse and potent biological activities make yeast a promising feed additive to replace frequently used chemical antimicrobial growth promoters. This article provides insights on functional role of yeast and its products in the poultry diets and highlights its importance as commercially viable alternative of in feed antibiotics in poultry feed industry.

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